



LABORATORY
MANUAL OF
BOTANY

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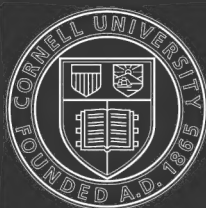
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TWENTIETH CENTURY TEXT-BOOKS

EDITED BY

A. F. NIGHTINGALE, PH. D., LL. D.

FORMERLY SUPERINTENDENT OF HIGH SCHOOLS, CHICAGO

TWENTIETH CENTURY TEXT-BOOKS

A
LABORATORY MANUAL
OF BOTANY

OUTLINES AND DIRECTIONS FOR LABORATORY AND
FIELD-WORK IN BOTANY IN SECONDARY SCHOOLS

BY

OTIS W. CALDWELL, Ph. D.

PROFESSOR OF BOTANY IN THE EASTERN ILLINOIS
STATE NORMAL SCHOOL



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P R E F A C E

THE newer points of view and the advanced methods in the study of botany during the past few years have greatly increased its desirability and efficiency as a disciplinary as well as an informational subject for study in secondary schools. It is believed that suggestions as to the laboratory and field work to be done by the students, based upon the more recent conception of the subject, will prove helpful. The diversity in age, maturity, and environment of the pupils who may pursue the subject, and the variations in the materials and equipment at their disposal, make it impossible to formulate outlines that shall meet equally well the needs of all classes of students. Fairly definite suggestions are presented, however, and it is understood that each teacher will make additions or eliminations wherever such become advisable for his purposes.

In the author's opinion much laboratory work has led to confusion or incoherent knowledge through an attempt to compel the student to discover things for himself which can not be so discovered. The so-called "development" method of teaching too often results in an ineffectual attempt of the teacher to lead the student to make a discovery. The student will certainly gain power and knowledge by such work in the laboratory, and he should be encouraged to do it within proper limitations. But those facts which he can not discover, and many even which he can,

should be stated by the teacher or in the text in a clear and definite way, leaving the student to work out things that are within the range of his maturity, and that will accrue most to his interest and profit.

This manual has been prepared in harmony with these convictions. In all his directions the author has aimed to make the study of botany full of meaning, of pleasure, and of profit to the young people who are to study the subject; to lead them to observe constantly and accurately; to form well-founded judgments from their observations; to inspire them with an intelligent and abiding love for nature; and to have them see and appreciate the ways in which the lives of plants are allied to their own lives.

The manual is divided into two parts: Part I considers plants from the view-point of their physiology and ecology, while Part II considers their structure and evolution as they have developed with reference to the problems of nutrition and reproduction. Either part may be used as the basis of a course in botany. When both parts are used, covering a year's course, the second may precede the first, if this order seems preferable. In either case Chapter I is essential as an introduction.

The lessons are outlined for a laboratory period of from ninety to a hundred minutes, though in some cases the work can not be completed in that time. In schools where a laboratory period is not more than thirty or forty minutes it will be necessary to shorten the lessons or to use two periods to each outline. In most cases each outline may be divided easily into two or more lessons as needed. Assignments from the text used should accompany the laboratory lessons as closely as possible.

The questions at the close of the lessons are not intended to be exhaustive, and thoughts and inquiries along similar lines will occur to both teacher and pupils.

The materials for study suggested at the beginning of

each lesson include more than are intended to be used, and those only will be selected which are in the best condition and most convenient. Some attempt has been made also to suggest materials adapted to schools that are somewhat dependent upon greenhouse specimens.

It is the opinion of the author that in a high-school course in botany little or no time should be given to preparation of permanent mounts for the microscope. In making good temporary preparations the student will develop an appreciation for permanent mounts or lantern slides that may be purchased for the laboratory. Those purchased will usually be better than the student can make, and when permanent mounts are desired it will be better to buy them. At times, however, unusually good materials or field illustrations may be found, and it may be advisable for the students to preserve these in permanent mounts or in pictures.

At the close of the book is (1) a list of addresses of firms furnishing equipment and supplies; (2) a list of prepared mounts for the microscope, some of which will be serviceable in both parts of the manual; and (3) a list of books that will be found helpful as texts or reference works. In addition to the book used as text, it is desirable to have at the student's disposal a number of approved works for collateral reading.

In presenting this manual it is a pleasure to acknowledge the author's obligation to Professor John M. Coulter, who by his suggestions and criticism has made possible the publication of the book.

OTIS W. CALDWELL.

EASTERN ILLINOIS STATE NORMAL SCHOOL,
CHARLESTON, ILL.

CONTENTS

PART I.—PLANTS AT WORK

CHAPTER	PAGE
I.—INTRODUCTORY WORK: THE PURPOSE, ADJUSTMENT, APPARATUS, AND USE OF THE LABORATORY	3
II.—THE PARTS OF A PLANT AND THEIR WORK	14
III.—PLANTS AND THE LIGHT	20
IV.—RELATION OF PLANTS TO WATER	26
V.—PROTECTION AGAINST HEAT, COLD, AND ANIMALS	29
VI.—STORAGE OF FOOD MATERIALS	35
VII.—DEPENDENT PLANTS	40
VIII.—REPRODUCTION	46
IX.—THE ORGANIZATION OF PLANTS INTO SOCIETIES	56

PART II.—THE STRUCTURES OF PLANTS AS THEY HAVE DEVELOPED IN RELATION TO THE PROBLEMS OF NUTRITION AND REPRODUCTION

X.—THE ALGÆ	65
XI.—FUNGI	77
XII.—BRYOPHYTES	82
XIII.—PTERIDOPHYTES	87
XIV.—THE GYMNOSPERMS.	92
XV.—THE ANGIOSPERMS	96
REFERENCE LISTS	103

PART I
PLANTS AT WORK

CHAPTER I

INTRODUCTORY WORK: THE PURPOSE, ADJUSTMENT, APPARATUS, AND USE OF THE LABORATORY

1. **Purpose.**—If it were possible always to study all the features of plants in the field where they grow it would be very desirable; as this is impossible, we must provide a laboratory, a work place, where we may handle them better even than we can outside. It is often important and helpful to grow plants where all the conditions influencing them may be fairly well controlled. A given temperature or a given moisture may be better maintained in the laboratory than out of doors. It is also the place where we should conduct experiments concerning the effect of certain kinds of light upon plants.

Many important phases of plant life can not be seen with the unaided eye, and must be observed, if at all, through magnifying-glasses. Sometimes even with magnifiers they can not be observed until very thin sections have been made and the tissues colored by some special staining fluids. Obviously, all this handling of plants, as well as the manipulation of apparatus for it, can be accomplished better in a room specially set apart for such work.

Furthermore, we have ceased to think that botany can be studied in the springtime only, although some parts of the year are not as favorable as others. For these less favorable seasons a laboratory is indispensable. Much, however, may be learned about plants by outdoor study even when the weather conditions are unfavorable for growth.

From the considerations mentioned, it should be evident that the laboratory and its apparatus are merely devices that assist us in the practical and profitable study of plants. The microscope enables us to see things which otherwise we could not examine. The protection of the laboratory allows us to work at all times and to grow plants under conditions that can be regulated. Other advantages as important as these are obtained, but it must be understood clearly that the essential use of a laboratory is to study the development and behavior of plants living under natural conditions, and the student should be put in possession of this fact on the very threshold of his investigations.

2. **Adjustments.**—Almost any well-lighted room may be made into a laboratory. It should be so situated that abundance of light may be admitted from the north and west sides, as direct sunlight is troublesome as well as injurious to the eyes. A long, narrow room, with one side facing the north, is the most desirable. Some south light, however, is better for growing certain kinds of material. The room should be large enough to make it convenient for students to pass about without disturbing others at the tables.

3. **Apparatus.**—The amount and quality of apparatus used must be regulated by the needs and resources of different schools. An expensive equipment is not absolutely essential for good work, but a complete outfit greatly facilitates operations, and it should be provided whenever practicable. Better results are often obtained from some improvised apparatus constructed by the pupils and teacher than from more expensive apparatus. Interest is heightened, and a better knowledge of the truth to be demonstrated often results from this method of securing apparatus. Ingenuity on the part of the teacher and students will do much toward enlivening and illuminating the laboratory work.

There are, however, certain desirable pieces of apparatus which can not be made in the laboratory, and which with others should be purchased if possible.

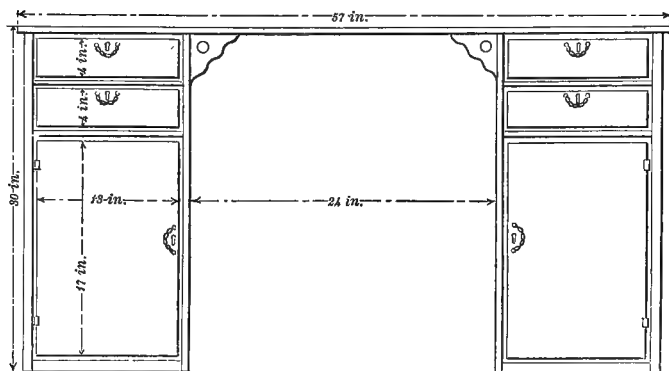


FIG. 1.—Plan for a laboratory table. The top is 57 in. long, 32 in. wide, and $1\frac{1}{2}$ in. thick. If desired, the back may be filled with a panel.

(a) *Tables.*—The tables should be made of good heavy material, not polished or varnished, so that they may be

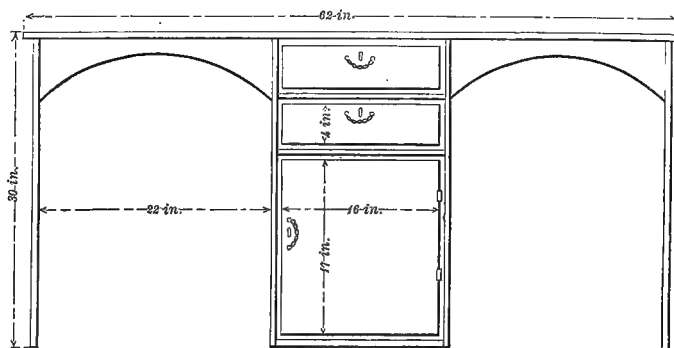


FIG. 2.—Plan for a laboratory table. The top is 62 in. long, 40 in. wide, and $1\frac{1}{2}$ in. thick. There are lockers on the opposite side of the table, duplicating those shown in the figure, the lockers being 19 in. deep.

washed without damage. They should contain drawers in which laboratory drawings and notes and the smaller pieces of apparatus may be kept. The accompanying figures illustrate two types of tables, either of which is good. The one shown in Fig. 1 is designed to stand with one side against the wall, so that the student may face the light. The one shown in Fig. 2 is designed for rather crowded laboratories, and with one end of the table placed toward the light it will seat four persons. The lockers on the rear side may be omitted, when it serves well for two students, both facing the light. These tables are good, not expensive, and can be built by any capable carpenter. Much cheaper tables, without lockers, can be obtained, and a few of these should always be kept in the room, serving as convenient places for keeping jars of growing specimens.

(b) *Cases and shelves.*—An ample supply of cases or shelves, where jars, bottles, and herbarium materials may be placed, helps very much to make the laboratory convenient and orderly.

(c) *Plant boxes and aquaria.*—There is little danger of having too many growing plants in any room where botany is studied. Boxes, pots, and glass jars should be supplied in abundance. Some of the jars should be large enough to make possible the growth of a few of the flowering water-plants, as well as the lower forms. Large cement tanks for this purpose can be constructed without much difficulty. It is necessary to supply all water-plants frequently with fresh water, as well as to see that they are properly aerated. This may be done by allowing water to drip into the vessel, or even better by placing in it some small animals.

(d) *Glassware.*—A few large bell jars will be found serviceable for covering small plants. Fruit jars and a number of small, wide-mouthed bottles are indispensable for collecting and preserving materials. Bottles containing 100 cubic centimeters and 200 cubic centimeters are

convenient sizes. A few small bottles with balsam-bottle stoppers for such stains as iodine, a cubic centimeter graduate, some water-flasks, some squares of glass for covering jars, glass slides and cover-slips for mounts for the microscope, also a few pieces of glass tubing of different sizes, will be needed.

(e) *Preserving fluids*.—Alcohol grading from 85 to 95 per cent may be obtained at drug-stores, and should be reduced to 70 per cent for preserving specimens. Formalin, a 40 per cent solution of formaldehyde, is cheap and very useful as a preservative. A $3\frac{1}{2}$ to 5 per cent solution of formalin is best. These preservatives should be kept ready for use at any time.

(f) *Microscopes*.—Small glasses magnifying 8 to 10 diameters can be had at very slight expense. A convenient form is one mounted upon a tripod, and such a glass should be at the disposal of each student. Every laboratory should have at least one good compound microscope, and, if practicable, one for each student. Two or three persons may work successfully with a single microscope, but if one only is supplied for all the students, it may be used in demonstration work for the benefit of the entire class. With but one instrument for all, little individual microscope work can be done; but gross structures may be studied, and with class demonstrations under the microscope quite creditable work may be accomplished.

The idea that botany can be studied with profit only by means of the microscope is erroneous, although its use greatly increases the interest and the value of the study.

If funds are limited, it will be better to purchase one good compound microscope than two or three poor ones. Poor instruments soon get out of order and must be repaired or replaced, while one good one should serve for many years. The stand of the instrument should be strong and sufficiently heavy to keep it from being easily over-

turned. It should be provided with the rack and pinion and fine adjustments, with 1-inch and 2-inch eyepieces, and with a $\frac{2}{3}$ -inch objective, together with either a $\frac{1}{6}$, $\frac{1}{7}$, or $\frac{1}{8}$ objective. Such an instrument is made by several reliable firms, and costs from \$30 to \$50. Fairly good instruments may be had at a lower price.

Student supplies.—Each student should be provided with the following articles: (1) a scalpel, a slender knife-blade set in a straight wooden handle; (2) a pair of needles, which the student may make by setting the eye end of medium-sized needles in holders of soft wood (these may be purchased at slight cost if they are not made in the laboratory); (3) a pair of forceps (small straight-pointed ones are best); (4) a pipette or “medicine dropper” is found convenient for putting drops of water upon the mounts; (5) a few glass slides and cover-slips for making mounts for the microscope; (6) a watch-glass or other small dish for keeping water at hand during laboratory work; (7) a sheet of blotting-paper; (8) drawing materials, consisting of heavy drawing-paper, a rather hard pencil, and a piece of sponge rubber; (9) a note-book for laboratory notes (this may be made together with the drawing-book). It will be found advisable for the school to own and lend to the student all these things except those directly connected with the drawings and notes. In the laboratory there should also be two or three good section razors, a good stone for sharpening them, and another for the scalpels; also a good balance with which careful weights of plants may be made.

The description, use, and care of the microscope.¹—In beginning to use the compound microscope each student should read the following description and at the same time

¹ Although the microscope may not be used for some time in any extended work, it will be best to get acquainted with its use at the outset.

identify the parts with an instrument at hand. Familiarity with the uses and names of parts greatly facilitates further work.

Description.—The horseshoe-like support is the *base*. Directly above the base is a horizontal expansion—the *stage*; running upward from near the stage is a cylindrical column—the *tube*; the tube and stage are fastened to the base by a hinge-joint. In the center of the stage is an opening, the size of which is regulated by a *diaphragm*. This may be an *iris diaphragm*, opening and closing as the iris of the eye; it may be a metal disk with openings of various sizes which may be used by revolving the disk; or the opening may be regulated by the insertion into the stage of pieces of metal having apertures of various sizes. Below this opening in the stage is the *mirror*. This must be adjusted so that good light is reflected through the stage, the object to be examined, the tube, and to the eye which is at the upper end of the tube. At the lower end of the tube are the *objectives*, metal holders containing the lenses. Both objectives may be fastened to a metal piece—the *nose-piece*—so arranged that either objective may be turned below the end of the tube; or it may be necessary to unscrew one objective and screw on the other to make the change. The shorter objective is the *low power*, as it magnifies less than the longer, the *high power*. Inserted in the upper end of the tube is the lens known as the *eyepiece*. Neither of the eyepieces magnifies nearly so much as the objectives, but the shorter one has the higher power of magnification. There are two devices for raising and lowering the tube. One known as the *rack and pinion*, or *coarse adjustment*, is designed to move the tube rather rapidly. On either side of the tube is a screw-head for its manipulation. The *fine adjustment* is managed by means of a screw-head placed immediately behind the tube.

Use.—First is the preparation of the object to be exam-

ined. The object must be very small, or if large small pieces must be used, since the light must pass through them. Place a drop of water on the glass slide somewhere near its center, and in this place the object. Take one of the cover-slips with the forceps and let it down upon the mount, one side going down first, and the other slowly following, in order that all air-bubbles may be excluded. Place the slide on the stage, with the object directly above the diaphragm opening. By looking into the eyepiece make sure the mirror is so placed as to reflect the best light. Then with the low-power objective in position for use, lower it until it almost touches the cover-slip, and while again looking into the eyepiece slowly raise the objective by using the rack and pinion until the object comes into view.¹ The object is then said to be in focus, and may now be studied. When the object is once in focus the fine adjustment should be brought into constant use in order that the various parts of the object may be observed. When higher magnification is desired the high-power eyepiece and objective may be used. The high-power objective when in focus is so near the cover-slip that great care must be used in adjusting it, else it may become injured. It will be necessary to turn about the nose-piece or lower the tube slowly and carefully, to prevent the glass from striking the cover-slip.

Care.—A soft cloth or chamois skin should be at hand for removing finger prints or dust from the metal part of the microscope, and for cleaning the mirror and eyepieces. Objectives needing attention should always be reported to the instructor in charge. No dirt or moisture should be

¹ While using the microscope both eyes should be kept open. Constantly closing one eye often results in serious injury to it, the one used being in much less danger. Preferably one should use the eyes alternately. If one has trouble in seeing through the microscope with both eyes open, the hand may be held over the eye not in use until such trouble is removed.

allowed to stand on any part of the instrument, and care should be taken never to place the fingers upon any of the glass parts.

When not in use the microscopes may be returned to their boxes and placed in the lockers, or may be set in dust-proof cases. When in frequent use they may be left upon the tables and covered with dust-proof cones made of heavy Manila paper. These may be constructed easily and cheaply, and in many respects afford the best protection for the instruments.

Laboratory drawings and notes.—The value of good laboratory drawings and notes is rarely overestimated. The best knowledge of an object is obtained by making an accurate sketch and writing a definite description of it. If the sketches are inaccurate and the notes merely mechanical answers to suggestions given in the laboratory outlines, no very valuable results follow. It should be distinctly understood that scientific accuracy in the drawings holds no necessary relation to artistic effect, and that artistic ability is often a doubtful gift in the laboratory. Any exact observer can make a good sketch, although it may be very imperfect from an artist's standpoint. Lines should always be neat and definite, and no line or mark that does not stand for something should be introduced. The specimen under consideration should be so well studied and the lines and shadings so carefully made that the drawing represents that particular specimen. The specimen in hand probably has as much individuality as those represented in the text-book. Drawings should never be made in the absence of the specimens. At first considerable time is needed for studying a single specimen and properly representing it, but it is quality and not quantity of work that is desirable, and that really gives a knowledge of the subject.

The notes should consist of a description of the subject in hand, its parts, and their significance. The outlines may

suggest the line of discussion in the notes, but the notes should not become mere answers to the outlines. Constant reference should be made to the drawings by means of numbers corresponding to those placed on the drawings. The laboratory work should be submitted frequently to the instructor for his criticism.

Some beginners in writing laboratory notes have found the following general outline helpful. It is assumed that the notes are to contain such a description of the form studied that they would make a clear though brief presentation of it to one who does not know that particular plant. The following topics may each serve as the subject for at least one paragraph:

1. Where the form lives.
2. General appearance in normal growing place.
3. The nutritive body—its form, structure, and adaptation to work done.
4. Reproduction.
5. Peculiarities not included in above.

LESSON I

Introductory exercise

To obtain an idea of the use of the microscope and of its magnification, and to study the cell as a unit of structure, is the purpose of the work outlined in this exercise.

Method of work.—On the glass slide place a drop of water, and in the water place a hair from the head, some fine fibers of paper, and small grains of sand. Over these place one of the cover-slips, letting it down in such a way as to force out all the air. Then place the mount thus made on the stage of the microscope and bring it into focus with the low power, as previously directed. By making slight changes in the focus through use of the fine adjustment better views of the objects may be had.

Study the objects carefully, noting size, form, and structure. Is the surface of the sand smooth? How do the hair and paper fibers differ in structure? Place a needle or pin point on the cover-slip and compare it with the ends of the hair and fibers. Sketch the hair as large as it seems to you to be both with and without magnification. See whether you can observe anything as to the form and structure of the sand and fibers without magnification. Remove the materials, and carefully clean and dry the slide and cover-slip.

Study of a plant-cell.—By use of the forceps or needles remove one or two leaves from a moss plant, and mount as previously directed. Study first with the low power, then with high power. Note the *cells* appearing as sections composing the leaf, their walls appearing almost colorless. Have adjacent cells a wall in common? Within the cells are bodies called *plastids*, and those in this cell, being green, are called *chloroplastids*. About how many plastids are there in a cell? What is their form? The very lightly granular material, the *cytoplasm*, can be seen just within the wall and among the plastids. Usually in fresh unstained material the *nucleus* can not be seen. Draw a group of two or three cells.

All plants are composed of cells, and in different plants or in different parts of a plant they may vary greatly in size and form. In numbers of cells plants range from those whose adult body is a single cell to those in which it is made up of millions of cells.¹

¹ Under a demonstration microscope there should be placed a prepared mount showing the cell structure, including the nucleus.

CHAPTER II

THE PARTS OF A PLANT AND THEIR WORK

LESSON II

General study of the parts of plants

Materials.—Any plot of ground where growing plants abound. A lot or a roadside with numerous weeds is a favorable place for study.

Observations and study.—In each of the plants most commonly seen there are three regions: roots, stem, and leaves. Though each region is definitely connected with and dependent upon the others, each has its own part to perform in enabling the whole plant to live and grow successfully. We shall see what constitutes each region and what each has to do in the work of the plant.

Carefully remove from the ground a plant of red clover, ragweed, or any other similar specimen. Make a general sketch showing the three regions.

The roots.—Are all other roots offshoots from one central or tap-root? Note the size and length of different roots. Where are the smallest roots? Were they near the surface or deep in the soil when the plant was growing? Do you find on the smallest rootlets the fine, white, furry growth of root-hairs? A small hand lens will help much in recognizing them. Draw in detail a part of the root system.

The stem.—Note how roots and stem join. Was any of the stem below ground? Is it of the same size throughout its length? Has the plant a single or a branching stem?

Are there any joints in it? If branches are present, do they arise from any definite regions?

Note thickness and strength of the stem. How much straight pull will it withstand? How much supporting strength has it? Is it easily bent sidewise? Is it brittle?

The leaves.—Are leaves many or few? Large or small? How attached to the stem? Does the flattened part join the stem, or is there a leafstalk (*petiole*) which joins it? Draw.

Note the color of the leaf. Compare the color on both surfaces. Observe the veins in the leaf and how they branch.

Examine a number of plants with reference to these points, and make notes and sketches showing any variations from the plant just studied.

LESSON III

The roots

Materials.—A week or more before this lesson is to be studied put a few grains of corn, wheat, and oats on wet blotting-paper, in damp sawdust, and in clean damp sand; cover carefully, and set in a warm place. Have at hand a few thrifty potted sunflower plants, and some rubber and glass tubing about the size of the plant stems in diameter.

Study of the root-hairs.—On the seedlings growing on paper observe the numerous root-hairs. Are they equally distributed over all parts of the roots? Examine some of the older roots and see whether root-hairs persist as the roots become older. What is their general form? Their length? Draw roots and root-hairs of a specimen of each kind of seedling. Remove carefully a specimen of each from the sawdust or sand, allowing the particles to adhere to the roots. Compare root-hairs in number, distribution, and form with the specimens already examined. How are the

particles of sawdust or sand held by the roots? What happens when the end of a root-hair grows against a solid body?

Remove from the soil one of the sunflower plants and note the distribution of its root-hairs. Pull the roots bearing root-hairs through the hand in such a way that all the root-hairs will be injured. The drying which occurs while the examination is being made will injure at once some of the root-hairs. Repot the plant.

Remove and repot another plant, taking care to keep the root-hairs moist and uninjured. Give both plants plenty of water. Note the plants after intervals of a few hours, and one and two days, and see if they wilt and regain their normal condition in the same way. Examine the first plant after a few days to see if it has developed new hair-roots. Have the notes contain a full comparison of the behavior of these two plants, the facts illustrated by their behavior, and some inferences from these facts.

Cut off the stem of a good thrifty plant; over the stump slip a short closely fitting piece of rubber tubing, and into the tubing place a piece of glass tubing; with string and paraffin, or beeswax, make the joints water-tight. Keep the roots well watered. After intervals note whether water rises in the glass tube. If so, note the amount of rise at different intervals.¹

The roots of plants serve at least two general purposes. They hold the plants in place and the root-hairs absorb water from the soil and help to force it up the stem into the leaves. Without the root-hairs plants which grow in the earth can not take up enough water to serve for their needs. The root-hairs are developed from surface cells of the smallest roots, are never at the root-tip or on old roots, and are very delicate, short-lived structures.

¹ If the classes are large, it may be advisable for the teacher and a few pupils to prepare these experiments, all observing and making drawings and notes on the preparations and the results.

LESSON IV

Stems and leaves

Materials.—Some stems or branches from plants such as those studied in the first lesson, and some from trees and shrubs. One specimen from each should be cut and put in a warm place for a day before the lesson, and one from each should be fresh. Leaves, when present, should be left upon all specimens. A young sunflower plant, a coleus, and a begonia, which have been allowed to dry until they are considerably wilted. A day before this lesson place in alcohol leaves from a number of plants—beech, maple, bean, corn, etc.; also have some fresh leaves in the laboratory.

If a considerable number of specimens are available, this lesson should be made into two.

The stem.—Compare the fresh and the wilted specimen of each kind of plant at hand as to the ease with which they bend or break; as to their ability to support their leaves in an upright position. How do the branches from the shrubs and trees differ from the others? To what is the difference due? Place a number of the wilted stems in water and see whether they regain their former position. Note and sketch the position of the stem and leaves of the wilted plants.

Pour water into the pots in which the plants are growing, and approximate the time required for the leaves and stem to assume a normal position. Can you see any of the leaves move as they regain their position?

The leaf.—Remove the leaves from the alcohol and note their color and that of the alcohol. The alcohol has removed the green coloring-matter—*chlorophyll*—from the leaves.

Select a compound leaf, such as that of the maple or bean, and study carefully its system of veining. Is the main axis of the system one midrib or several parallel veins?

Note the very fine veins running through all spaces between larger veins. The normally green tissue through which the veins run is called the *mesophyll*, the internal part of the leaf. Draw, showing the skeleton of the leaf.

From both surfaces of some of the leaves remove the epidermis by carefully peeling it away with the scalpel. Mount it with the outside up and examine with the low power of the microscope. Note the form of the epidermal cells. Note also pairs of crescent-shaped cells with an opening between them. The opening extends well into the mesophyll.

The pair of cells, called *guard-cells*, and the opening between are called a *stoma*, often spoken of as a "breathing-pore." Note the distribution of stomata throughout the epidermis. Does the epidermis from both leaf surfaces contain stomata? Draw stomata and some of the epidermal cells.

General suggestions.—The structures seen in these lessons are all concerned in enabling the plant to live. The root-hairs take up water from the soil and it passes through the roots into the stem, and from the stem most of it goes into the branches and leaves. In the roots, stem, branches, and leaves the water passes through woody tissue, which is especially arranged for this work. We see this tissue in the leaves as the veins, and in the stems and roots it makes up the strong woody cylinder. The plants that persist for a period of years (perennials) have much more of a woody cylinder than plants growing but a single season (annuals).

In the water taken up by the root-hairs are numerous substances that are essential to the proper sustenance of plants, and in order to obtain sufficient quantities of these substances more water is taken up than is really needed. Consequently the surplus water must be disposed of, and this is done mainly through the stomata. If stomata are examined when the plant has too much water they will be

found to have their guard-cells so arranged that the spaces between them permit water to evaporate readily; but if examined when the plant is too dry, they will be found closed, or nearly so, thus tending to prevent loss of the scanty supply of water.

While the root-hairs are taking in water and substances in solution, and while these are being transported to the leaves, a gas called carbon dioxide is taken from the air into the interior of the leaf. However, neither water and the substances it has in solution, nor the carbon dioxide can be used directly as nourishment, but must be made first into other substances.

The water and the carbon dioxide are made into starch or sugars or other things similar to these, which can be used as food for the plant. While they are being made a surplus of oxygen appears as a waste. Some of this may be used by the plant, but most of it escapes from the leaves, and is used by other plants and the animals.

The process of making starch, sugars, and similar substances requires a large amount of energy, and this is obtained by means of the chlorophyll as the sun's rays fall upon it. Chlorophyll is said to absorb energy from sunlight. Only those plants which have chlorophyll can obtain the needed energy in this way, therefore they only can manufacture these food materials and set free oxygen. All animals obtain their food directly or indirectly from plants, and since plants are themselves dependent for food upon the agency of chlorophyll and sunlight, it follows that all plants and animals are dependent upon chlorophyll and sunlight.¹

The substances from the soil that are carried up in solution in the water are not used in making starches, sugars, etc., but are afterward added to them in the formation of proteids and other foods.

¹ It has been found that an intense artificial light, as electric light, falling upon chlorophyll may also enable plants to manufacture food.

CHAPTER III

PLANTS AND THE LIGHT

As much as possible of the work outlined in this chapter should be done in the field. If field-work can not be done, abundance of material should be carried into the laboratory.

Although chlorophyll must be exposed to sunlight, it does not follow that all plants have similar structures bearing chlorophyll, nor that they expose it to the light in the same way. The most common plants have leaves, which are structures specialized for chlorophyll work. It is evident that if a given plant has a number of leaves, there must be some definite arrangement among them, otherwise some might interfere with the work of others. If one leaf lies directly upon another, the lower one will not have light enough to enable it to work well. Plants show various devices for securing a large extent of chlorophyll exposure and for preventing continuous shading of some of the leaves. It must be borne in mind, as will be seen in later lessons, that while leaves are arranged with reference to the light, the best conditions for proper air and temperature must also be secured, and what would fully meet one condition might not always be suitable for others.

LESSON V

Leaves and the light—on upright stems

Materials.—Such plants as geranium, milkweed, sunflower, horse-ragweed, and branches of horse-chestnut, oak, maple, elm, etc.

Observation and study.—Selecting the milkweed, sunflower, or branch of horse-chestnut, note and sketch the form and size of the leaves. If variation in form or size occurs, show this in the notes and sketches. Does the *petiole* (the leafstalk) vary in length? Are any leaves *sessile* (without petioles)? Is there any definite arrangement of leaves upon the stem—in pairs, fours, alternate, or opposite?

With the top of the plant directed toward the eye, see whether all the leaves are placed so that they would get sunlight at one time. Observe from a side view. Are all leaf-blades parallel to the surface of the earth? Are they the same on young and old parts of the stem? Compare the sunflower and the ragweed in these respects. What advantage is gained by the position in each case? Are the leaves which you have examined arranged for receiving the rays of light that strike the plant parallel with the stem, or at right angles to it?

With these points in mind, make comparisons with the other plants mentioned as to the form, size, and position of leaves and their consequent lighting. Of what advantage are partially divided leaves, as in those of the oaks, maples, and ragweeds? Is this a common device among plants?

LESSON VI

Leaves and the light—trees

Materials.—Such common trees as maple, elm, chestnut, cottonwood, oak, pine, spruce, etc.

Observation and study.—Examining a vigorous maple or oak, note the general outline of the stem and branches. Are branches mainly upright or horizontal? In this respect, does the tip of the branch differ from the rest of the axis? Are the leaves arranged around the branch, as in the milkweed and the sunflower? Is this arrangement the

same for the turned-up tip of a branch? Standing a short distance from the tree, see whether the leaves present an essentially solid surface of green to the sunlight. Then standing beside the main stem or climbing up among its branches, see whether the leaves grow abundantly on the inner part of the tree top. Explain the conditions found. What evidence from dead twigs and branches within the tree top that conditions were once different? With the maple or oak compare other trees, especially the elm and pine, showing by notes and sketches their outline of stem and branches and where the leaves are borne. Which have their branches mostly directed upwards?

Why do trees growing in a forest become taller than those growing in fields? In an open space find two trees which have grown quite close together, so that the branches from one crowd those from the other. Account for the conditions found among the branches.

LESSON VII

Plants and the light—rosette and prostrate plants

Materials.—Dandelion, wild lettuce, mullein, plantain, sour dock, trumpet-creeper, sweet potato, pumpkin, and any species of ivy.

Observation and study.—Use the plantain as a specimen of the rosette form. Study the leaves. Sketch, showing various forms and sizes, and indicate the relative height on the stem from which each leaf is taken. Note the different positions of the leaves. In notes describe how this arrangement permits abundant lighting. Compare with the other rosette plants. How do dandelion and wild lettuce differ from the plantain? What advantages have these two plants in the form of their leaves? What would be the result if in these rosette plants the large and small leaves should change places? What would be the result if the

dandelion should have its leaves as large as the leaves of the mullein? Can you prove your conclusion by conditions in any materials at hand? Study various vines to see where the leaves arise and how they are placed to insure proper lighting. Do vines growing on trees and houses differ from those growing on the ground? Can you find any vines with leaves of two sizes? If so, how are they arranged? Are there any procumbent plants that show the rosette habit?

From these observations do you find any relation necessarily existing between the size and the number of the leaves? Is there any relation between the width of the leaves and their number? Between the size of leaves and the length of the stem between successive leaves? When leaves stand one above another, is there any relation between the length of the petiole and the size of the succeeding leaf? Prove your answers by reference to the specimens that you have studied.

LESSON VIII

Plants and the light—a comparison of shade and sun plants

Materials.—If the work can be done out of doors, select a deeply wooded region, near which is one well exposed to light. Locate specimens of cottonwood, wild balsam (*Impatiens*), vines, and various herbaceous plants growing in shaded places, also plants of the same species growing in exposed places. If the work is to be done in the laboratory, specimens of plants from the two regions should be provided, or greenhouse material will afford illustrations of the two habits. Some distinctly sun-plants, and other distinctly shade-plants, may be used even if the same species are not represented in both habitats. When good illustrations are found, it is advisable to make herbarium mounts of the leaves for further comparison. In this way a laboratory may soon possess a valuable collection for illustration.

Color.—Group the leaves of plants of the same species from the different regions, having some leaves that show the lower and some the upper surface. Note and describe color variations.

Size, form, and number.—Observe whether plants of the same species from the two regions have leaves alike in size and form. Note the relative number of leaves in the two regions. Illustrate by sketches.

Structure.—Examine leaves from the two regions as to their thickness, strength, and prominence of veins. Do you find hairy outgrowths from the epidermis? Of what advantage could hairs be in protecting leaves against excessive lighting?

In the laboratory make sections of the leaves, and under the microscope compare (*a*) thickness of cuticle and epidermal walls, and (*b*) the amount and arrangement of chlorophyll-bearing tissue and nearness of plastids to the surface. Show differences by drawings. In notes show how each leaf structure is of peculiar advantage to plants in the region in which the structure is developed.

LESSON IX

Leaves and the light—leaf movements

Materials.—In the laboratory, such plants as geranium, begonia, coleus, some water-plants which are growing from the bottom of a dish of water, as water-milfoil and *Vaucheria*; out of doors, compass-plants, wild lettuce, locust, pea, clover, and oxalis. If a greenhouse is convenient, an examination of it will afford some good class work.

Observation and study.—Note the house plants to see whether they are making any attempt to get to the light. Do all the house plants observed behave in the same way? Change the position of a geranium, coleus, or begonia, and see how many hours or days are required for readjustment.

Change the position of the dish containing water-plants, and see whether they readjust themselves. Will these plants turn, as often as they are changed in their position, for light exposure?

Examine the locust, pea, or clover, the wild lettuce, and compass-plants in early morning, noon, and late afternoon, and see whether the leaves change position. At each examination note from what direction the light is striking the leaf. In the wild lettuce, compass-plant, and clover note especially the leaf positions at noon on a very hot day. Which leaves change their positions during the day? Try to find some of these plants growing in shaded places and see whether their leaves have colors and positions similar to those that are growing in open places. Is the arrangement of the leaves in the shaded and open regions more alike at night or in the day? Do the exposed plants have the same leaf positions on cloudy as on bright days? How do you account for the various positions found? Do the leaves of young and old plants behave in the same way in reference to these points?

At midday place some oxalis plants in a dark closet and see what leaf changes occur. To what cause do you attribute these changes? Place in the light again and observe.

Observe plants, such as corn and other grasses, which fold their leaves during very hot dry days. In what ways may this position be of advantage?

CHAPTER IV

RELATION OF PLANTS TO WATER

LESSON X

To approximate the amount of water in plants

Materials.—A good supply of several species of Algæ. Some higher forms of water-plants. Fresh leaves of land plants. Pieces of green wood, and dry oak or pine.

Observation and study.—From the water-plants allow the water to drip until the surplus has been removed, and lay them upon pieces of tin or glass of known weight, and weigh, tabulating the exact weight of the plants. Place the plants where the water from them may readily evaporate. Weigh after intervals of a few hours or a day until they cease to lose weight, and show from your results the percentage of water in the plants. Treat the green leaves and the pieces of green wood in the same way. Split the wood into small pieces in order that the water may evaporate more readily. Weigh the piece of dry wood, then place it in an oven or upon a furnace or radiator. Does it lose in weight? Can you prove that the decrease is due to loss of water? Test various kinds of wood to see which contain least water. Do you think there is any relation between the strength of the wood and the amount of water it contains?

LESSON XI

Relation of plants to water—transpiration

Materials.—Potted plants of sunflower, geranium, begonia, a fern, a cactus, and some succulent plants, such as live-forever (*Sedum*). Most potted plants will serve fairly well in this work.

In Lesson IV it was shown that in order to make foods plants must obtain some material from the soil, and others from the air, and that in connection with this process they dispose of surplus water from the surfaces of the leaves. When the water supply is insufficient there is danger of too great loss of water, and plants vary greatly in their ability to prevent injury from this source.

Observation and study.—By holding pieces of paper over representative leaves of each specimen, and by marking their size and calculating their area, calculate also the area of exposure of each plant. Tabulate the weight of one specimen of each kind of plant, and place it where it will have plenty of light and air. Weigh on successive days until all the plants are wilted.

Which plants lose most weight as they wilt? Which lose most per square inch of exposed surface? Is wilting in proportion to the amount of water lost? What other factors determine wilting? Why do shade-plants wilt more readily than exposed plants? Water all the plants and note the relative rate at which they regain their normal position. Do those that wilted first regain their position first?

Cut some water-plants, such as water-lily or pondweed, and some such land plant as branches of oak or ironweed. Note relative time in which each wilts. See if you can determine from the structure by means of sections why one should wilt before the others. Is it true that plants subjected to great exposure must reduce the amount of ex-

posure relative to their bulk in order to prevent excessive drying? What advantages in having such plants develop water-storage tissue? What plants illustrate these points?

LESSON XII

Relation of plants to water—transpiration

Materials.—Potted sunflower or geranium plants.

Observation and study.—1. Experiment to show the exact amount of water used in a day by a plant.

Select a thrifty plant. Over the top of the soil place a piece of sheet cork or sheet lead, cutting it so that it may be placed around the plant-stalk. Cut a small hole in this covering, and insert the lower end of a funnel-tube or thistle-tube; with sealing-wax completely seal over and around the covering so as to prevent all evaporation from the soil. Allow the plant to stand until it needs water, then pour water into the thistle-tube and tabulate the amount used each day. See if the same is used when the plant stands in bright light as when it stands in shade. Is as much used at night as in daytime? Explain why. Cover the plant with a paper cone and see whether it uses as much water. Explain.

2. Experiment to show whether leaves take up water as well as transpire it.

Select three plants which have been allowed to become well wilted. Around the stalk of one and over the earth in the pot place some sheet rubber, so that no water can reach the earth. Then sprinkle the leaves thoroughly. Invert the second, immerse the leaves in water, and secure the plant in this position for some time. Pour plenty of water upon the earth in the pot of the third plant. Note in each case whether the plants regain their normal condition, and state in the notes what is demonstrated by each plant.

CHAPTER V

PROTECTION AGAINST HEAT, COLD, AND ANIMALS

LESSON XIII

Plant hairs, spines, and secretions

Materials.—Specimens of mullein, geranium, begonia, verbena, catchfly (*Silene antirrhinum*), cactus, thorny locust, thistle, etc.

1. **Spines and thorns.**—Note and sketch the various kinds of spines and thorns. Test their sharpness and strength. Are they on all parts of the plant? Have they any definite arrangement? Are strongest spines in places exposed to greatest dangers? Show in the case of each plant just how the spines may be of advantage. Show how spines may be especially helpful in the regions to which cactuses are peculiar. Thorn-bushes frequent roadsides, fence-rows, etc. Do you think the success of the bushes in these places has any relation to the development of thorns?

2. **Hairs.**—Note the general appearance of the hair-bearing leaves. Peel off and mount some of the epidermis from each and study kinds of hairs, their abundance and arrangement. Sketch the form of each. Select some of the pointed ones and mount together with a pin or needle to see their relative sharpness. Sketch. Some of the hairs have bulbous tips, and these are usually secretory in function.

Which plants do you think have hairs that may serve as protection against injuries from animals, such as insect bites, and which ones may also be protected by the hairs

from extremes of temperature? How do you think hairs can protect a leaf against excessively strong rays of light? How do they protect against cold and excessive transpiration?

Examine all these leaves to see which seem best protected against attacks from insects. Is the absence of evidence of insect attacks a positive proof that the hairs have protected the leaf? Upon this point examine the milkweed both from surface view and by cutting the leaf, and report your conclusions.

Examine the catchfly. Note the rings of sticky secretion about the stem. Will it support the body of such an insect as a fly or ant? See whether you can discover how this protects the plant.

LESSON XIV

Plant hairs, spines, and secretions

A field lesson on points studied in the preceding exercise should be added whenever material for the purpose is available. Locate as many illustrations as you can of spines, hairs, and secretions, and explain the particular use in each case. In addition to further study of the preceding points try to locate some hawthorn bushes in various stages of growth and note stages in the evolution of the adult bush. The young bushes have tender leaves at the top, and these are eaten by animals, which procedure, when continued for some time, causes the entire clump of plants to become short, rough, and spreading. The plants continue to spread and to be eaten off until the central bushes are no longer within reach of the animals from the outside of the clump. This gives an opportunity for the central plants to elongate. Side branches that reach out too far are eaten off, while the central stalks become tall enough to have their terminal branches and leaves out of reach, and finally side branches

enjoy the same exemption. These then shade the shorter plants, which have been eaten off. They soon die, and gradually disappear.

Find hawthorn plants showing these stages in the development of the adult bush, and note the character and position of the thorns in each case.

A careful study of other thorn-bearing shrubs and trees will furnish excellent illustrations of the significance of thorns among plants.

LESSONS XV AND XVI

Evergreen and deciduous trees

Materials.—Some branches and leaves of pine, spruce, cedar, arbor vitæ, and of beech or elm or any deciduous plant.

Observation and study.—Compare the number, form, relative amount of exposure, and general solidity of leaves from each specimen. Draw a surface view of each leaf on a uniform scale. How many pine leaves are required to make as much chlorophyll exposure as has one elm or beech leaf? Do you think the number of pine leaves on a branch is enough greater to give it as much chlorophyll exposure as there is in a similar branch from an elm?

Make cross-sections of a pine leaf, mount and examine under low power of the microscope. Note the following points:

The general form of the cross-section.

The heavy epidermal layer, and just beneath it other heavy walled cells resembling the epidermis. These together serve as the protecting and strengthening tissue of the leaf. The chlorophyll-bearing cells. Note their arrangement.

The resin-ducts surrounded by the chlorophyll tissue. The wall of each duct is made up of light-colored sheath-cells. Is there any regularity in the number and position of the resin-ducts?

The stomata, having their openings passing through the epidermis and strengthening cells, and into the chlorophyll tissue. Where are the guard-cells? Are the stomata well protected?

Surrounded by the green tissue is the central conducting and pith region. Draw enough of the section to show the kinds of tissue and their arrangement.

About what percentage of the leaf is doing chlorophyll work? Make a cross-section of a deciduous leaf, and compare in this respect.

If leaves are to be retained during cold weather they must have special protection. What devices for protection do you see in this pine leaf? Has the size of the leaf any significance? The form? Could any other size or form be protected more easily?

Do you think the resinous substance has anything to do with the protection? What advantages have evergreen plants with reference to chlorophyll work? What disadvantages? Evergreens are slow-growing plants. Why?

Examine sections of the stems or branches of evergreen and of deciduous plants, and compare their protective structures.

More than two years are required for the pines to ripen their seeds, consequently partially mature ones must pass through the winter. Examine young and old pine-cones, locate the developing seeds, and see how they are protected.

LESSON XVII

Autumn protection of deciduous plants

Materials.—Plants with color beginning to change, some with leaves beginning to fall. The work is preferably done in the woods with trees and shrubs, such as oak, maple, hickory, elm, sumach, etc.

If the season or location is not favorable, some of the chief changes in preparation for discarding leaves can be illustrated in the laboratory by disturbing the roots and ceasing to water such potted plants as geraniums, begonias, and sunflowers.

If woods and the season are convenient, several weekly lessons should be given to this subject, and a much more detailed outline used; while if only one lesson is given, the outline below must be considerably changed.

Colors.—Observe differences in leaf color, and make notes upon the various colors appearing, the order in which they appear, and the time required in different plants for transition from one color to another. Do all the leaves of a given plant assume the same color at the same time? If not, what particular part of the plant precedes others? Does the color appear all over a single leaf at once? If not, is there any regular order of coloration on the different parts of the leaf? Do all plants of a given species show the same colors at one time? Does the slope of the ground upon which the trees stand seem to affect the color changes? Do the leaves of plants standing near water develop color in the same way and at the same time as those standing in drier places? Do exposed trees and those crowded together develop colors alike?

Formulate a statement showing the color changes in different trees and the dates on which they are observed. Do shrubs and herbs pass through essentially the same color changes as the trees?

Leaf fall.—Do leaves begin to fall when color changes begin?

See whether a leaf that has begun to change color is more easily removed than one that has not. Does it “bleed” at the point of separation? Compare with one that has passed through all its color changes.

Does the slope of the ground or the nearness to water

have anything to do with the relative time of leaf fall? Compare also isolated plants and those closely crowded.

Make a longitudinal section through the base of a leaf which is just ready to fall, and determine why the leaf separates from the twig at that point, and why green leaves are so much harder to pull off than these autumn leaves? Examine leaves of such plants as buckeye, locust, walnut, hickory, and sumach. Do their devices for leaf fall vary in any way from the types already studied?

Is frost the cause of the development of autumn colors in leaves and does it cause the leaves to fall?

As unfavorable weather approaches, the water-supply of plants decreases, and this is supposed to induce the plant to remove from the leaf the stored foods and living materials within it, at the same time to prepare to remove the leaf in order to reduce the amount of surface exposed to evaporation and cold. While these changes are going on, the variations in color appear. Doubtless some color changes are due merely to the removal or destruction of the chlorophyll. It is known that as chlorophyll appears and disappears a yellow coloring-matter is formed. But not all the colors can be explained in this way. A comparatively recent suggestion seems to account for the formation of some red colors. It is known that the presence of solutions of sugar sometimes induces formation of red colors, as has been proved by growing water-plants in sugar solutions. It is also known that starch is a storage form of food, that it is often stored in leaves, and that it must be changed to sugar before it can be removed from the leaf. These things would account for the presence of sugar solutions, and possibly for the development of red colors in the leaf. But there are many shades of color developed that apparently are not accounted for in this way, and no satisfactory explanation of their formation has as yet been offered.

CHAPTER VI

STORAGE OF FOOD MATERIALS

PLANTS often manufacture more food than they need during the actively growing season, and then use different parts of the body as storehouses. This stored-up food in plants has different kinds of protection, and different ways in which it serves both plants and animals.

LESSON XVIII

Laboratory study of stored foods

Materials.—Specimens of the root-stalk of Solomon's-seal, false Solomon's-seal, the rhizome of a fern, potato, onion, sweet potato, bulbs of crocus or gladiolus, tubers of Dutchman's-breeches, dog-tooth violet, bloodroot, bitter cress, pineapple, banana, orange, some twigs of a healthy tree (especially if the lesson is studied during the time deciduous trees are without leaves). Many other specimens will serve equally well.

Observation and study.—Note the part of the plant used as a storage region in the case of each specimen at hand.

In the white potato the tuber is an underground stem, as is shown by the presence of buds or "eyes" upon it. In the sweet potato the corresponding storage structure is a root. Compare with these the size, form, and arrangement of other underground storage structures.

Most plants store their food in the form of starch, though this is by no means universal. The presence of starch

may frequently be determined by observation of the unstained specimen, but may be demonstrated by the addition of a weak solution of iodine. This causes the starch grains to assume a bright-blue, deep-blue, or brownish-blue color.

Make thin sections of the storage tissues at hand, stain them with iodine, and examine them under low power of the microscope. Sketch all specimens studied, showing the following points:

How much of the structure is used as a storage organ? Has the storage tissue a protective covering? If present, against what do you think it protects? What is the form of the storage cells? Are all equally filled with stored food? Are all starch grains of similar size and form? What plants studied have most stored food relative to the amount of storage structures used? Which have actually the largest amount?

In your notes describe the form and position of each storage structure with reference to the plant observed. Describe also the form, arrangement, and storage capacity of the storage tissues in each.

LESSON XIX

Field study of storage of foods

Materials.—Those of the last lesson with others that may be located in the field. The most favorable time for this work is in early autumn or early spring, when such plants as bitter cress, violets, dog-tooth violet, bloodroot, hepatica, mullein, sour dock, spring-beauty, etc., and leaves of other deciduous plants are to be found.

Observation and study.—By means of a trowel or sharp stick carefully dig down to the storage region of such plants as the spring-beauty or Dutchman's-breeches. Note its depth from the surface of the soil. Is this about the same with different specimens of a given species? Is it the same

with different species? How do the aerial parts connect with the storage region—that is, do the leaves connect directly or by means of a stem?

What is the character of the soil? Of the covering of the soil? Do you consider this a wet or a dry soil? Will it be so most of the year? Are these plants found in equal abundance in both wet and dry places? What special significance in this?

Are these plants found in equal abundance on hill slopes and bottom-lands? On hill slopes are they equally abundant on north and south slopes?

Account for any differences in representation in bottom-lands and hillsides, and hillsides of different directions of exposure. Account for any differences in the time of appearance in spring of these plants growing in the different regions mentioned.

Locate some plants that have assumed the adult form, and compare the storage region with that of plants just beginning to grow. Account for changes. In case favorable specimens are not located in the field this last point is well illustrated by sectioning, staining with iodine, and examining a potato from which a plant has grown.

General questions.—What advantages have the early spring flowering plants in possessing an abundance of stored food? For example, will they be likely to mature from seed without excessive shading from other plants? Would this, if true, give the new plants formed from seed any advantage? To what dangers are the stored foods of these spring flowering plants exposed? Has the location of the plants and depth in the soil any relation to this? Does the soil-cover, as leaves, etc., bear any relation to this? Are these dangers common to all food-storage structures?

LESSON XX

The storage of food in seeds

Materials.—Seeds of corn, oats, beans, sunflowers, apple, hickory, cockle-bur, and of such others as may be conveniently obtained.

Observation and study.—Open the seeds and observe the amount of material stored within. Test for the presence of starch. The stored food may be starch, oil, or other substances, consequently the absence of starch does not prove that there is no food present. Do most of the seeds contain starch? What plants store most food in their seeds?

Make the following tests to determine the nourishing power of the food stored in various seeds: After soaking seeds from a number of plants in warm water for a few hours, plant some of each kind in clean sawdust, on blotting-paper, in a clean dish, and in rich earth. Water them with distilled water, keep them covered, and as nearly uniform as to moisture, light, and temperature as possible.

Tabulate accurately the following points, using three columns for each kind of seed, one column to represent what occurs in each place where seeds are planted:

When seeds are planted.

When plants begin to appear.

When roots and leaves are developed.

Size and number of leaves.

Relative length and size of stalks and roots developed.

When plants begin to decline in vigor.

When most of the plants die.

From these daily observations determine how long seeds may furnish nourishment to the young plants, and which of these studied can nourish their young plantlets longest without other nourishment.

Determine also which seeds can produce the largest and strongest plantlets from the enclosed nourishment.

Is there variation between those grown in different places? If so, how do you account for it? Do you think the sawdust and blotting-paper furnish any nourishment to the plants growing on them?

Do the plants appear equally vigorous in all regions?

CHAPTER VII

DEPENDENT PLANTS

THE plants that we have seen in the lessons already studied have possessed the green coloring-matter, chlorophyll; which means that they have the ability to construct their own nourishment from quite simple substances. There are many plants, however, which are devoid of chlorophyll, and which obtain their nourishment either directly or indirectly from plants that are able to manufacture their own food. These are classed as dependent plants, and the forms of dependency that they assume are quite varied. Some of these plants, known as *parasites*, attack living plants and animals, and take their food material from them; some, known as *saprophytes*, live upon dead and decaying organisms; and some live with other organisms, taking some foods from them, but giving in return advantages of some kind to compensate for food taken. The last are known as *mutualists*.

LESSON XXI

Plant parasites

Materials.—Lilac-mildew, grape-mildew, wheat-rust, water-mold (*Saprolegnia*), tree-destroying toadstools, corn-smut, dodder, mistletoe, and any other available plants that live upon other living things. If nearly all the materials suggested can be had it will be advisable to have two or more lessons upon this subject.

Observation and study.—With some good specimens of dodder growing upon its host plant study carefully the relations existing between the two. Is the dodder attached to the soil? How is it attached to its host plant? Make a section through one of the attaching roots and see how it is arranged for holding and for absorbing nourishment. Draw. Note the relative vigor of the two plants, and determine the effect of this relationship upon each one. A study of a region in which many dodder plants are growing will be instructive.

Some seeds of the dodder should be collected and planted in a box in which other plants are growing. This will enable you to see just how dodder plantlets get started upon their host plants.

If specimens of mistletoe upon pieces of its host can be had, note the following points:

Is mistletoe devoid of chlorophyll? What does this indicate? Cut into the host plant at the base of a mistletoe plant and see where the absorbing region is, and how it is arranged. Account for its position and form. How are the seeds of mistletoe distributed? Study the other parasites at hand, noting how they are arranged with reference to their hosts, and how they take their food material from the host. Make sketches and notes descriptive of each.

Do all the parasites grow thriftily? Do they ever cause the death of the host plant? Are there any cases in which they do not seem to injure the host plant? Observe in your walks whether the distribution of these plant parasites is general, and the various effects they produce upon their hosts.

LESSON XXII

Saprophytes

Materials.—Molds of various kinds growing upon fruit, exposed leather, etc., toadstools, mushrooms, and puffballs.

Observation and study.—With each kind of saprophyte present observe the following points:

Color.

Form and position with reference to the thing which furnishes nourishment.

Does the saprophyte penetrate the supporting structure?

Structure. Mount parts of each plant and determine their composition. How are cells arranged in building up the plant?

Also examine some of the substratum to see how food material is obtained.

Reproduction.—All these plants form at certain times small one-celled bodies, the *spores*, which under favorable conditions germinate, and thus form new plants. Mount some of the upright stalks of molds, some of the undersurface of the expanded part of a toadstool, and some of the body of a puffball, and locate the spores. How are spores usually discharged from puffballs?

Place some of the toadstools upon pieces of white paper, so that the spores will fall upon the paper as they ripen. After a day or so observe the number of spores, their color, and their arrangement.

Some toadstools become jelly-like as their spores ripen. Mount some of these jelly-like masses and see what proportion of the jelly mass is spores.

Why do molds appear so readily when favorable materials are exposed? To demonstrate this, expose a piece of bread to the air for a few minutes, then place under a glass cover for a few days, and see how soon and how abundantly molds develop upon it.

Note the effect these plants produce on their supporting structures.

Suggestions.—Sometimes these forms have all their bodies, except the reproductive regions, embedded in the nourishing substance. The thing which we call the toadstool

is but the reproductive part of it, and has little to do with the plant's nourishment.

Since the nutritive part of the plant is well distributed through the substratum and has abundance of nourishment at hand, the aerial structure can, at times, be produced with surprising rapidity.

The economic importance of these destructive plants is readily seen when we consider that it is necessary to break up organized bodies and to return the substances composing them to a condition again fit for use by green plants. If these processes of decay brought about by saprophytes and parasites in both the plant and animal kingdoms did not reduce materials in this way, we should eventually exhaust all the available food substances.

Furthermore, when these organisms attack things which we desire to preserve for our own uses, the economic significance is of another kind.

LESSON XXIII

Mutualists

Materials.—Specimens of several kinds of *lichens* illustrating as wide range in habitat as possible; some specimens of clover, sweet clover, or alfalfa, on the roots of which there are tubercles.

Lichens—habitat and general appearance.—Note where the lichens grow and the relation they bear to their support. Do they seem to be upon this support merely for benefit of position, or do they have parts penetrating the substance upon which they grow in order to obtain nourishment from them?

Form.—Note the form of the lichen body. Is there much variation in form between different kinds? How does the “reindeer-moss” lichen differ in form from those growing

upon stones and bark? Make sketches illustrating some of the forms.

Color.—Note the color. Is it uniform in all specimens present? Does the color change when specimens become wet? Compare the color with that of leaves and the molds.

Structure.—Place a small piece of lichen upon a slide and dissect as completely as you can. Mount and examine. Note the two elements which compose the lichen; the almost colorless filamentous part is a plant belonging to the fungi, the group of plants to which the molds belong; the green part is usually made up of unicellular organisms belonging to the algæ, or seaweed group of plants. These two plants live together in a combination called the lichen. This is not one plant, but a combination of plants of two kinds, that live together in a very intimate relationship. Each plant reproduces itself—the alga by having its body divide into two new cells and the fungus by forming spores. Consequently the lichen as such does not reproduce itself directly, although the plants that compose it may reproduce themselves and eventually form new lichens. On lichen bodies at certain times there will be seen cup-like outgrowths. It is in these that the fungus elements of the lichen form spores. These spores may be seen in the ends of some of the filaments by carefully dissecting a part of the cup and examining it under magnification.

What advantage does the fungus obtain by having the alga grow with it in this way?

What advantage does the alga obtain? For example, does it get food material it could not otherwise obtain? Is it less likely to suffer from drying? Does the position of the alga in the lichen body indicate that it is protected by the fungus? Does this position favor the use of the alga by the fungus? Does this combination assist the alga to grow in places where alone it would not grow? Can the lichen grow in places where neither element could grow alone?

Do the alga cells seem to be growing vigorously? This might indicate whether in the combination the fungus is obtaining the greater benefit.¹

Root-tubercles.—Examine the smaller roots of the plants provided, looking for the bulbous outgrowths upon them. In these there are large quantities of bacteria which assist the plant by obtaining certain foods which the plant needs but can not obtain directly. With good magnification these bacteria may be seen. The plant builds around them the wall of the tubercle, and from the plant they doubtless obtain nourishment and some protection. The plant profits greatly by their presence. The ability of clovers and like plants to enrich soils depends upon the action of the root-tubercle bacteria.

The field of biology furnishes numerous cases of mutualism, which will prove of great interest. Additional examples may be found in the literature of the subject, and should be noted by the student.

¹ In order to be mutualists each form must be in better condition than when growing alone. It is not quite clear that this is the case in the lichen, for it is generally believed that the fungus alone is benefited, holding the alga in slavery.

CHAPTER VIII

REPRODUCTION

PLANTS are quite limited in their duration, and before they die must provide for establishment of their successors, or their species will become extinct. Various means are employed by plants for insuring perpetuation, sometimes a single plant reproducing itself in several ways.

LESSON XXIV

Vegetative propagation

Materials.—Young slips of begonia or geranium; some willow branches that have been planted in sand for three or four weeks; the rhizome of such plants as Solomon's-seal and the bracken fern; the root-stalk of some "running" grasses, and those of the dandelion, mullein, sour dock, etc.; tubers of potatoes; bulblets or "sets" of onion or tiger-lily.

Observation and study.—Remove some of the planted slips and note whether roots are developing. If so, where do they arise? Sketch.

Examine the rhizomes to see where new leaves arise and whether several new ones may come from one rhizome.

Make a diagram illustrating the behavior of the root-stalk of one of the "running" grasses. Is a new plant produced before the old root-stalk has become dead? Does a given root-stalk of a mullein or dandelion persist through a

period of several years? Of what advantage is it for these plants to reproduce in this way?

Determine the number of new plants that can be produced from one of the potato-tubers. Is the average number about the same with sweet potatoes as with white potatoes?

In clean, damp sand plant slips of coleus, begonia, geranium, willow, cottonwood, eyes of potatoes, and bulblets of onions or tiger-lily. Keep the sand moist, and observe some of the specimens from day to day to see how soon they begin to establish themselves as new plants. Find how small a piece of begonia or willow will develop into a new plant.¹

LESSON XXV

Reproduction by spores in mosses and ferns

Materials.—Moss plants bearing ripe capsules and various ferns with ripe sporangia.

Mosses.—The leafy shoot has on its tip a long stalk at the end of which is the capsule in which the spores are formed. At the end of the capsule is an adjustment by means of which spores are discharged. Carefully cut off the tip of the capsule, mount it so that it may be seen from an outside view, and note its covering and the teeth which project inward from immediately beneath the margin of the covering. Mount an old capsule so that it may be seen from a side view, and note the position of the teeth. Can you determine how they assist in spore discharge?

¹ If favorable locations are near, a field study should be made of vegetative reproduction. In addition to points mentioned above, the students should notice vegetative reproduction in the strawberry, the raspberry, also several plants that will probably be found in any swampy region. It would be instructive to dig up some of the underground stalks to see their extent and the number of new plants they are establishing.

Open a capsule and observe the number of spores. Do all these probably develop new moss plants?

Ferns.—In brownish patches, usually on the under side of fern leaves, will sometimes be found groups of spore-cases (*sporangia*) in which the spores are formed. Select a leaflet on which there are groups of sporangia, examine with the hand lens, and sketch.

Remove and mount some sporangia. Note the general form and where the spores are borne. Note especially the peculiar row or ring of cells running over the back of the sporangium.

Remove the cover-slip, allow the sporangia to become dry as you observe them with the low-power magnification, and determine just how the spores are discharged. What is the function of the ring of heavy-walled cells? Is there a definite breaking place for the spore-case? Are spores discharged as the case opens or as it closes? How far do you think spores are thrown in this way?

Examine various fern leaves to see where sporangia are borne and how they are grouped. See whether the sporangia in all are similar in structure to those already studied.

These spores, when they germinate, do not produce directly the thing we usually call the fern plant, but produce instead a very small, flat, green body, from which the upright fern plant finally grows.

Sow some fern spores on damp earth and keep covered, so that moisture and temperature may be kept constant. Place in a shaded part of the room. After some weeks the flat body will be seen, and from these after a time the leafy plant may be seen to grow.

LESSON XXVI

Reproduction by seeds—the flower and seed

Materials.—An abundance of any simple flowers, as those of *Potentilla* or *Anemone*. If this is a winter study, and greenhouse specimens are not convenient, good material may often be obtained by standing branches of peach and apple trees in vessels of water and placing them near a window in a room in which the temperature is kept at about 70° Fahrenheit. It will be very much better, however, to plan the work so that these lessons will come at a time when wild flowers may be found.

Observation and study.—The whole flower is concerned in the process of reproduction, some of the parts acting directly and others indirectly in this work. Locate and make sketches illustrating the parts of the flower as follows:

1. The *calyx*, which is the outermost set of leaf-like parts of the flower. Each leaf-like member is a *sepal*. Usually the entire set is green. In a good many flowers the calyx is not present, or is not differentiated from the other structures. Is it present in the flower of the plant you have? Sepals may be in cycles (several placed at the same level on the stem) or may be in spirals. How are they arranged in this plant?

2. The *corolla*. This is the next set of floral leaves, and is usually colored. Each member of the corolla is a *petal*. When the floral leaves are not differentiated into calyx and corolla these names are not used to designate them, but the term *perianth* is used instead. If the parts are in cycles, how many cycles of the corolla are there present, and how many petals in each cycle?

3. The *stamen* set. How many cycles, and how many stamens in each cycle? Draw one stamen showing the elongated part, the *filament*, and the swollen tip, the *anther*. Open an anther and note the dust-like pollen-grains within

it. Mount some of the pollen, examine, and sketch as seen under magnification.

4. The *carpels* or *pistils*, the innermost structures of the flower. Each carpel or pistil usually consists of a swollen base, the *ovary*, from which extends upward an elongated part, the *style*, which style is terminated by an expanded part, the *stigma*. The style may be absent, in which case the stigma rests directly upon the ovary. Sketch the carpel of the flower you have.

Cut across the ovary and observe within it one or more small rounded bodies, the *ovules*. These are the structures that develop into seeds.

In the process of developing a seed one or more of the pollen-grains must be placed upon the stigma of the carpel. This process is known as *pollination*. The stigma usually secretes a sticky and often sweet substance, which holds the pollen-grains when once they have come in contact with it. Meanwhile there have developed within the grain at least two cells, each of which consists of a nucleus surrounded by a small mass of cytoplasm. From the wall of the grain there now develops a tube which pushes its way down through the tissues of the stigma and style, and the cells are carried along in this tube. This tube finally reaches the ovule and penetrates it. While the pollen-tube has been growing, the ovule has developed an egg-cell in its interior. The end of the pollen-tube opens in the immediate region of the egg-cell, the cells within the tube pass out into the ovule, and one of them unites with the egg-cell. The cell thus formed by the union of the two cells begins to grow, and gradually develops into the *embryo* of a new plant. Usually, about the time this new plant has developed far enough to have formed a small root, one or more leaves, and the beginning of a stem, the walls of the ovule become hard and dry, the young plant within stops in its growth, and we have as the result the structure which we call the *seed*. It may re-

main dormant for some time, perhaps for several years, but when conditions again become favorable the embryo plant within begins to grow again, the seed-coats burst, and a new plant, similar to that which bore the flower and seed, is formed.

LESSON XXVII

Reproduction—pollination and fertilization

Materials.—Flowers of various kinds showing adaptation in form to the problems of pollination. Those of pines, willows, walnut, cottonwood, elm, corn, ragweed.

If favorable regions are available, this and the following exercise should be studied in the field, otherwise abundance of good material may be studied in the laboratory.

Suggestions.—That pollination must precede the formation of a seed has been seen. It is known, however, that pollination of certain kinds produces better plantlets than pollination of other kinds. When pollen from the flowers of one plant are deposited upon carpels of other plants stronger embryos are formed than when the pollen is furnished by the flower to which the carpel belongs. This is called *cross-pollination*. It is *close-* or *self-pollination* if the pollen falls upon the stigma of its own flower. Many plants practise close-pollination, but it is generally supposed that cross-pollination is better. The flowers of many plants show most interesting structures for preventing undesirable and securing desirable pollination. The two ordinary agents of pollination are the wind and insects.

Observation and study.—Note the general characters of the flowers of the corn, pine, etc. Note the abundance of pollen, its lightness, and readiness to float in the air. Mount and examine some pine pollen and describe any special devices for distribution. Note the soil where corn or ragweeds have recently discharged their pollen. To see

how abundant pollen-grains are in these places mount a little of the surface of the soil and examine it.

Why do isolated corn-stalks seldom ripen many good grains of corn?

Account for the fact that popcorn and Indian corn growing near each other often become mixed. If the winds were from one direction during the season would the results be those usually found?

Is wind, as an agent, favorable to the prevention of close-pollination? By a study of the various wind-pollinated flowers at hand, determine how close-pollination is prevented in some of these plants. Is an open or closed flower best adapted to close-pollination? What kind of pollen is best suited to it? Do the plants studied have large amounts of pollen? Explain?

Is all pollen from a given plant discharged at one time? Why?

Do you notice any odor or brightly colored floral leaves in these wind-pollinated flowers?

Sketches of flowers and pollen-grains should be made to illustrate the points observed.

LESSON XXVIII

Reproduction—pollination and fertilization—pollination by means of insects

Materials.—Flowers with tubular corollas, as phlox, innocence, etc.; also of pea, bean, alfalfa, wistaria, sweet-flag, and mallow.

Frequently the region about the school building will furnish plants that are better than some of those here mentioned.

Observation and study.—A great many plants do not depend upon the wind as an agent of pollination, but so adapt their floral organs that this work may be done chiefly

by insects. The insect finds food in the form of nectar and sometimes pollen, and as it is obtaining this food it may be forced to move about in such ways that proper placing of the pollen will result. To be most successful the floral organs must be so arranged that close-pollination will be prevented and cross-pollination secured. The adaptations for effecting these things are extremely varied, and are sometimes quite intricate, though they are by no means always completely successful.

In each flower studied notice:

Form.—Whether open, petals or sepals united into a tube, stamens and carpels enclosed, and whether stamens and carpels are of the same length in all flowers.

Color.—Are the floral leaves bright or somber in color?

Odor.—What function do you think the color and odor may serve.

Nectar.—If present, in what part of the flower is it developed? Does it vary in amount in different flowers? Is it equally abundant in old and young flowers? Is it placed where insects get to it easily? Note whether the insect, in obtaining nectar, probably passes the anthers and stigma, and if so, whether it probably passes one before the other. From the structure of the flower do you think the same part of the insect's body would strike both anthers and stigmas? From the structures do you think the flower prevents close- and obtains cross-pollination? If possible to study flowers while insects are working upon them, observe closely to see just how entrance to the flower is made, and what parts of the insect's body come in contact with anthers and stigma, and the order in which contact is made. Determine whether the plant is successful in cross-pollination. Catch one of the insects and examine under low power of the microscope to see what parts of his body, if any, have pollen-grains upon them.

Does an insect, when leaving a flower, usually retrace

the path of entrance? Is this of any advantage to the plant?

Examine old and young specimens of the common mallow. How do positions of stamens and carpels differ in flowers of different ages? At the time the anthers are ripe has the stigma developed its mucilaginous substance for holding pollen? Explain the advantage of these conditions to this plant.

This study of pollination may be extended with profit if regions favorable for field-work are convenient.

LESSON XXIX

Reproduction—distribution of seeds

Materials.—Seeds of pine, thistle, catalpa, dandelion, ironweed, fleabane, milkweed, cockle-bur, Spanish needle, beggar-tick, sand-bur; also acorns, beechnuts, fruits of honey-locust, coffee-nut, hawthorn, and blackberry; specimens of tumbleweed, Russian thistle, and tumbling grasses, and the seed-pod of the water-lily.

To this list many specimens may be added in each locality.

Observation and study.—There are so many plants trying to grow and to establish new plants over the surface of the earth that it is of great advantage to each to have its seeds germinate in favorable places. Numerous structures exist that aid in placing the seeds in regions distant from those in which the parent plants grow.

Study the various seeds furnished and sketch, showing the structures which you think have to do with their distribution in each case.

Examine the hooks of Spanish needles and cockle-burs under the microscope.

Do the seeds fall from the tumbleweed and Russian

thistle as soon as they are ripe? Has this any special significance?

How long do seeds of the locust usually remain in the pod? How are they set free?

Why are not blackberry-seeds digested in the bodies of the birds which eat the berries? What relation does this have to seed-distribution?

How do you account for the fact that young plants of the cherry, etc., so frequently appear along fence-rows?

How many kinds of agencies which you have proof of are used in seed distribution? Which seem most successful?

In what ways may thorough seed distribution be of advantage to the new plants? In case the parent plants are perennials, what advantage do they receive from seed-distribution that annuals do not?

By counting the seeds in one cone, pod, or head, as the case may be, and by approximating the number of such collections on an entire plant, estimate the number of seeds formed on one plant. Does a large percentage of these develop new plants? What becomes of those that do not form new plants? Is it a waste of energy for plants to form more seeds than those which are to develop into new plants? Explain.

CHAPTER IX

THE ORGANIZATION OF PLANTS INTO SOCIETIES

THERE are certain necessary things that all plants must have in order that they may grow. Some of these things are water, air, light, soil, and favorable temperature. All plants are not obliged to possess these in the same proportion, and some can live with one or two of these things very greatly in excess of the others, while other plants can endure quite unfavorable combinations of these factors. Plants are organized into *societies* in accordance with their relations to these different factors. It is not uncommon to classify these societies upon the basis of the water element. Thus in a general way there are usually recognized three groups:

Hydrophytes, or water societies; *xerophytes*, or those in greatly exposed and dry regions; and *mesophytes*, those in conditions intermediate between those of the other groups. There may be some good objections to this basis of classification, since water can not always be said to be the determining factor in a given environment. Within these groups may be recognized subdivision societies, as swamp society, rock society, etc. Furthermore, a society may take its name from its most conspicuous or most abundantly represented plant, as a beech, cactus, or water-lily society.

Many plants try each year to get possession of a suitable region in which to grow. Those especially favored by their adaptations in structure and habits will, to a greater or less extent, crowd out the others, and these must find

new places for growth, adapt themselves to new conditions, or die. Consequently it can not always be said that plants growing in certain regions are there because it is their best home. They frequently grow where they are because they must remain there or die. In the struggle for existence some plants are frequently forced from their most favorable growing places into less desirable ones.

Plants to grow in a given region must have structures somewhat adapted to the peculiarities of that region. For example, we should not expect the water-lily to grow well in the soil on a windy mountain slope. Although there may be many species growing in a given region, they must have some adaptations in common to enable them to live in the same society.

Work on a few plant societies will be suggested, and this may be extended profitably wherever time and available regions for considerable field-work make such possible.

LESSON XXX

A hydrophyte society

Materials.—Select a region where plenty of water or marsh plants are growing. A pond, lake, or river bayou will usually furnish a fairly good region.

Observation and study.—Make a list of the kinds of plants found in the water, and note the position of each.¹ Observe the following points:

Whether plants are submerged, floating, or rise into the air.

The number, size, and form of leaves. Do you find any plants with two kinds of leaves, one submerged, the other exposed?

Compare submerged leaves in general with those ex-

¹ The teacher should furnish names of the plants, or, if means of identification are present, the students may identify them.

posed to the air. How do they differ in general texture? In breadth and number of subdivisions? Have submerged leaves or plants any advantages relative to temperature?

Floating leaves and those exposed to the air usually have extreme exposure to the light. Do you find anything in their general structure indicating adaptations to this direct exposure?

Note whether plants are free or attached to mud or soil? If attached, does the form of attachment indicate that it serves as an anchor merely or as a support. How are the roots used in the reproduction of these plants?

How do the floating plants obtain their supply of soil substances?

Make sections of the stems of various water-plants and see what structures they have in common. Of what advantage are these?

Show what you believe to be the relative advantages and disadvantages of submerged, floating, and erect plants.

How do running-water societies and those of quiet water differ?

Observe the plants around the pond extending back to "dry land." Are the plants of the same species as those found in the water? Can they be divided into definite areas grading back to dry-land plants? If so, do the areas correspond to changes in moisture or other changes in the soil? In your notes describe in detail the different groups of plants observed about the pond.

LESSON XXXI

A rock or cliff society

Materials.—Select a region where beds of stone crop out, thus forming cliffs or an essentially rock substratum. In the absence of a stone cliff, a steep clay slope or the slope of a rapidly eroding hill will afford a good region for study.

Observation and study.—Character of the soil—clay, sand, rock, loam?

Observe the amount of moisture present. If moisture is abundant the conditions may be those of hydrophytes. If it is scantily supplied, the conditions may be xerophytic. Do you find cliffs showing both conditions?

Observe the exposure to light. Is the slope such as to give direct exposure to the sun?

List the plants found, and notice which are most abundant. Note which ones grow only near the top of the slope, and which grow only at the base. Which ones are found in both places? Are the last-mentioned equally vigorous in both places?

If the slope is quite steep, note how plants hold themselves in place. Examine some specimens from about which the earth is being removed. Is any attempt at readjustment being made?

Do these plants need deep roots for any other purpose than for support? Remove some of the herbaceous plants to see concerning the depth to which their roots penetrate. Do they have many surface roots?

If the exposure to the sun is direct you may expect the foliage to have some devices for protecting the chlorophyll regions. Determine what some of these are.

If you can locate one steep slope that is dry and exposed to direct sunlight, and another shaded and damp, compare the plant life found in each with reference to the following points:

Lists of plants represented.

Luxuriance of growth. Are plants as large on the exposed as on the unexposed slope? Note especially the difference in the leaves. Which slope shows the greater struggle for existence between different plant forms?

Which slope shows the greater struggle with physical environment?

LESSON XXXII

A comparison of the structures of plants of different societies

Materials.—Stems and leaves of plants from different sorts of conditions, as water-lily, water-hyacinth, cat-tail flag, water-crowfoot, duckweed, liverworts; Easter lily, corn, beech, or various herbaceous plants; cactus, oleander, rubber-plant, century-plant; also the root of a plant from each society.

If time for as many as three exercises upon this subject can be had, it will be very much better to divide the work, using plants from one of these groups for each laboratory exercise. Comparisons resulting from such studies will be much more valuable than if all are studied in one lesson.

Stems.—Compare the stems from different regions, noting relative size, solidity, and strength as supporting organs.

Make cross-sections, study the structure, and show in notes and drawings how each structure is adapted to the way in which the plant lives.

Leaves.—Note the relative number of leaves, their breadth, thickness, and strength. Can it be said that plants in any of these groups tend to have more leaves than the others?

Peel off and mount the epidermis from both surfaces of leaves of the different groups. Note where the stomata are placed in different plants. Which plants have most stomata? Would not the stomata of the water-lily be better protected on the other side of the leaf? Why do they not develop on the other side?

Make sections of the leaves and note:

Relative amounts of cuticle and epidermal tissue.

Depth from the leaf surface and protection of guard-cells of the stomata.

Do any stomata have special structures for protection?

Which leaves are compact? Do any have regions or cells for air or for storage of water or food?

Show of what advantage, if any, the different structures observed are to the plants as they attempt to live in their respective environments.

Roots.—Note the variations in the general form of the root system. Do hydrophytes, as a rule, have their roots spreading or running deep into the ground? How about plants of dry regions? Are root-hairs developed in equal abundance in all these regions? Explain any variations.

To make quite clear in what particulars some plants are especially fitted to the regions in which they are found, imagine a water-lily and a cactus to change places, and show why each would probably fail to succeed in the region of the other.

From the above it must not be inferred that all plants are by any means perfectly adapted to their habitats. Some are so far from this condition that they can scarcely exist, grow poorly, and reproduce themselves in a meager way.

Neither must it be inferred that a plant once a hydrophyte is always such. Some plants are hydrophytes part of the time and mesophytes or xerophytes the rest of the year. It is to be noted, for example, that a high temperature and abundant moisture make hydrophytic conditions, while high temperature and dearth of water make desert or xerophytic conditions. Such regions present each of these combinations at different times of the year, and there are plants adapted to living in these regions the year around.

Suggestions for further work.—Outlines for work may well be planned upon mesophytic societies, comparing them with hydrophytes and xerophytes. A study of a forest community will prove profitable. Deserts, heaths, and tropical communities illustrated by native plants or those found in

greenhouses will afford interesting and instructive work. An excellent series of lessons can be planned in studying the seasonal changes in societies. The substitution of one society by another may be well studied in any locality where there are ponds which become dry for quite a period each year.

In planning work on plant societies, as well as in other work, each teacher must adapt his outline to conditions peculiarly favorable for work in his locality.

PART II

THE STRUCTURES OF PLANTS AS THEY
HAVE DEVELOPED IN RELATION TO
THE PROBLEMS OF NUTRITION AND
REPRODUCTION

CHAPTER X

THE ALGÆ

PLANTS that have the simplest bodies and those that grow and form new individuals like themselves in the simplest ways are found in a large group known as *Thallophytes*. There are no roots and leaves in this group, as in the larger plants with which we are more familiar, but bodies that are globular, or thread-like, or stem-like, with this stem often greatly branched. Many of these plants consist of single isolated cells and are extremely small—some so small that in order to study them in the best way they must be more or less magnified. Some members of the group are of enormous length, although in structure they are not complex. The entire group of Thallophytes is divided into two smaller groups, the *Algæ* and *Fungi*, the basis of division being the fact that the Algæ contain a green coloring substance and the Fungi do not. Familiar representatives of the Fungi are the toadstools and mushrooms.

Algæ are found in almost all regions where there is fresh water, also along the coasts and frequently out at sea in salt water, and a few are found out of the water. In the first lesson some general information should be obtained regarding the localities in which Algæ grow and their general appearance.

LESSON XXXIII

Field study of the Algæ¹

Region.—Locate pools of water, some of which are exposed and some shaded; a stream in which the water in some parts runs slowly, and in other parts rapidly; along the stream some damp banks, stones, or tree trunks; an old drinking-trough used by cattle or horses.

Examine these places to find Algæ. In the quiet water they are frequently found floating in masses; in running water, and sometimes in quiet water, they are found attached to various objects, as stones and sticks; in the drinking-troughs they appear as slimy coatings upon the wood; where the earth is damp, they are often on sticks and bark of trees, and also are found frequently growing in blue-green jelly-like balls.

Carry into the laboratory in bottles or jars representatives of all the Algæ found. Place them in the laboratory in as nearly normal conditions as possible, and try to get them to grow. They may serve for future study.

Write notes describing where the Algæ were found, their appearance, whether large or small, whether upon surface of water, deeply submerged, or on ground; free or attached; coarse or fine, slimy or granular; in shade or direct exposure to light; include anything else that will give an idea concerning the Algæ observed.

LESSON XXXIV²**The single-celled Algæ**

Materials.—*Pleurococcus* as a type. Any good unicellular form will answer for this work, provided the one mentioned is not easily found.

¹ This lesson may be used by the entire class or by one or more pupils working separately.

² It is assumed that the exercise on the plant-cell as outlined in the early part of the book has been studied.

General study.—On the shady side of trees, rocks, and fences in rather damp places this plant may be seen as a slimy growth, which when quite damp is bright green, and is grayish or brown as the amount of moisture is diminished. Any group which may be recognized probably contains many thousand individual plants. A piece of bark on which these are growing will be suitable for laboratory study.

Vegetative or growing structures.—Examine the mass of plants with the hand lens. Can you see anything more than a green coating upon the bark? Any separate plant-cells? By using the scalpel remove a small amount of the green mass, place it in a drop of water on the slide, spread it thoroughly, place on the cover-slip, and examine with the low power of the microscope.

Distinguish between the fragments of the bark and the small cells, each of which is one *Pleurococcus* plant. Do the plants tend to group themselves? What is the form of a single plant?

Select a region on the slide where the material is favorable for study, adjust the high power, and study carefully the structure of the plant. Note (a) the *cell-wall*, its color and form; (b) the *protoplasm*, most of which is obscured by the green coloring-matter known as *chlorophyll*. Is the chlorophyll contained in definite *plastids*, as was true in the cell from the moss leaf previously examined? Can you see any of the *cytoplasm* where it is not obscured by the chlorophyll? Usually the cell-nucleus can not be seen in fresh *Pleurococcus* plants. It may sometimes be seen after a small amount of an iodine solution has been added to the mount. Make an accurate drawing of one or two plants, exaggerating considerably the natural size.

Reproduction.—Look over the mount carefully and determine how *Pleurococcus* reproduces itself. How many stages in the process can be found? When one plant has formed two new ones, do the new ones always become free

from each other before they in turn begin to divide? How do you account for the grouping of the plants previously noticed? Drawings should show one plant in the earliest stage at which the process of reproduction may be detected, one when the dividing wall is fairly well established, one as the new individuals are about separated, and other stages illustrating any other important points observed.

General questions.—Why are masses of *Pleurococcus* brighter green in wet than in dry weather? Why do they not grow on the sunny side of trees? Why on isolated trees do they not grow high up in the air? Are the grayish or bright-green masses forming new plants most rapidly? Why? Note the plants late in autumn and early in the spring to see whether growth is inhibited by cold weather.

In your notes give a full description of *Pleurococcus*, telling where it grows, its general structure, and how it reproduces itself, referring by number to the drawings as they illustrate the features mentioned.

LESSON XXXV

Nostoc and Oscillaria

Materials.—Specimens of *Nostoc* and *Oscillaria*. *Gloeocapsa*, *Anabæna*, or *Rivularia* may be used instead of those mentioned. If laboratory periods are short, this should be divided into two exercises.

Nostoc

General study.—In a dish in which there are some of the *Nostoc* balls, note the general appearance, color, form, and texture of the masses. These are composed of many *Nostoc* plants. The jelly-like material that holds them together is formed by the breaking down of the outermost parts of the walls.

Vegetative structures.—Remove, mount, and examine a small piece of the jelly-like material. Throughout the al-

most colorless jelly are seen chains of cells, each chain being a *Nostoc* plant. What is the form of a cell? How are they related to one another? Have different chains similar lengths? Are all the cells of different plants of similar size and structure?

Reproduction.—How does a plant consisting of a few cells become one consisting of many cells? Does this result directly in the production of new plants? In very long plants the large cell—the *heterocyst*—is usually not at the end of the chain, as is the case in the very short plants. Can you find how this fact is related to the reproduction of the *Nostoc* plants?

Make drawings and notes descriptive of this plant.

General questions.—Is *Nostoc* a more or less complex plant than *Pleurococcus*? How do the plants differ in structure and in general appearance? What differences in their reproduction? Of what advantage to *Nostoc* is the jelly surrounding it?

Nostoc usually lives in regions where there is considerable decaying organic matter. It probably uses some of this as nourishment. Plants that do not use these organic substances for food must make their food in some other way. To do this they must have the green coloring-matter—chlorophyll—which, when the sunlight falls upon it, enables these green plants to construct their own food materials.

These food materials are then used by the plant in its growth and in the repair of old parts, just as *Nostoc* uses the organic substances it does not make for itself. *Nostoc* has some chlorophyll, though not so much as the *Pleurococcus*. This indicates that *Nostoc* plants either can not grow as rapidly as *Pleurococcus* plants, or that they obtain more of their food already made. In *Nostoc* the chlorophyll is mixed with a blue coloring-matter.

Oscillaria

General study.—Observe plants in horse-troughs, stagnant pools, and in dishes in the laboratory. Note the free ends of filaments standing out from the supporting substance. Note the color.

Vegetative structures.—Mount a little of the material. Study the general form of the plants, and note the slow gliding or swinging movement. Is this movement in any definite direction? Can you determine whether the movement is caused by currents of water? What is the form of a single *Oscillaria* cell? How are cells arranged in forming the plant? Is there any protection about the cells? Note the end-cell of a plant, and account for any peculiarities.

Reproduction.—In reproduction this plant resembles *Nostoc*. There is usually no specialized cell assisting the plant in its division, but division may occur at any place, each new part becoming a new plant. Select specimens showing how the reproduction takes place, and draw.

LESSONS XXXVI AND XXXVII

Spirogyra

General study.—This species of alga is often seen floating on the surface of rather quiet water, where it makes a mat ranging in color from very bright green to brownish green. Examine carefully some plants which have been placed in an aquarium. How would you distinguish *Spirogyra* from the plants already studied?

Vegetative structures.—With the forceps remove and mount a few of the plants. Note how the cells are arranged to make up the plant. How do the cells compare in size and form with those of plants previously studied? Is there a sheath about all the cells of one plant? Can you determine whether the ends of a plant are alike? If unlike, this might

indicate a division of labor not yet found, in which one end is a fixed, supporting end, the other one free. Study one or two cells in detail. Observe (*a*) cell-wall; (*b*) the chloroplastid, a peculiar spiral affair, of which sometimes several are found in one cell, and within the plastid at intervals small rounded bodies—the *pyrenoids*—which are used as storage regions for surplus food substances; (*c*) the cytoplasm, almost colorless, but usually appearing just within the cell-wall; (*d*) the nucleus, in the interior of the cell, and suspended by threads of cytoplasm.¹ To what part of the cell do the cytoplasmic threads run from the nucleus? What function do you think these cytoplasmic threads serve? If the nucleus is obscure, the addition of an iodine solution will usually serve to make it plain.

How are new cells formed in the elongation of the plant? Draw one or two cells in detail.

Reproduction.—Under certain conditions *Spirogyra* reproduces itself in a way quite unlike any plant yet studied. Two of the plant-threads come into close proximity, when some of their cells unite in pairs by means of outgrowths from the walls. Through the tube thus formed the protoplasm from one cell unites with the protoplasm of the other cell. This united mass of protoplasm is considerably condensed, and develops a heavy wall about itself. By the decay and breaking down of the old cell-wall this heavy-walled body is set free, when it usually falls to the bottom of the pond and passes through a resting-period, which may be through a drought or the winter season. When conditions again become favorable this resting-body grows, becoming a new plant similar to those which form it. This resting-body is a special cell, known as a *spore*, and is set apart for

¹ Well-prepared permanent mounts of *Spirogyra* and various other forms to be studied may be had at reasonable expense and will add greatly to the efficiency of the student's work. For suggestions see list of addresses at close of manual.

the purpose of reproducing the plant. Any such specialized cell is a spore, though such cells may differ considerably in the manner of their formation. Spores formed, as this one, by the yoking together of two cells similar in size, are known as *zygospores*, which means "yoke-spores." The masses of protoplasm which unite to form spores are known as *gametes*, and the process of uniting similar gametes is known as *conjugation*.

Study favorable *Spirogyra* material, and draw the following stages in its reproduction, being careful to label properly the different structures concerned in the process:

(a) Where two plants are placed side by side and the cells of one are beginning to send out protuberances to meet similar protuberances from the cells of the other plant.

(b) Where protuberances have united to form a tube.

(c) Where one gamete is passing through the tube.

(d) Completed zygospores ready for resting period.

General questions.—Is the vegetative structure of *Spirogyra* more or less complex than that of plants already studied? In what respects? Of what advantage to the plant is this heavy-walled resting-spore? Of what advantage to have the protoplasm of two cells unite to form this spore? Is this vegetative production? When several cells from two plants conjugate in pairs, does one plant always contain all the ripe zygospores? Does one cell ever conjugate with more than one other cell?

LESSON XXXVIII

*Cladophora*¹

General study.—*Cladophora*, an alga of very wide distribution, is found in both running and standing water, and is usually attached to some object that serves to anchor it.

¹ If *Ulothrix* is to be had it should be introduced at this point, or any zoospore-forming plant may be used.

Its general character may be studied best in the laboratory by placing a stick or stone supporting some of the plants in a dish of water. By observation and handling determine its general characters as compared with Spirogyra.

Vegetative structures.—Mount and examine. Has the plant distinctly organized basal and apical regions? Is it a simple straight thread as Spirogyra? Make a sketch showing the general structure of the plant. Study one or two cells in detail, and draw.

Reproduction.—If some Cladophora plants are kept in a dish containing a little water, and in a dark place, reproductive bodies may be formed. At such times certain cells have their nuclei divided into large numbers.

Around each of these nuclei a mass of cytoplasm is organized, and the result is a distinct, pear-shaped body. At the smaller end there are formed two fine hair-like extensions known as *cilia*, which serve to move the whole cell about. These bodies are so small and have such a rapid movement that they are not easily seen. They finally escape from the cell that formed them—their *mother-cell*—and after swimming about for a while attach themselves to some support and grow, becoming new plants similar to the parents. Therefore these swimming bodies are spores, and since they swim they are called *zoospores*, which means “animal spores.” They are unlike the zygospores of Spirogyra, since they are not formed by the union of gametes, but they are like them in having the power of reproducing the parent-plant. A cell which produces spores from its contents directly (no cell union) is a *sporangium*.

Study your material, and draw, showing as much of the process of reproduction as you can. Put some of the zoospore material in a favorable place and examine from day to day to see the development of new plants.

General suggestions.—Bearing in mind that plants must have their chlorophyll exposed to the light in order to grow,

show how the plant body of *Cladophora* is better fitted for growth than *Spirogyra*. Is it an advantage for *Cladophora* to be attached to a support? Can it grow where *Spirogyra* could not? Of what advantage to the plant is it to have spores which can swim?

These zoospores are very much simpler than the zygospores of *Spirogyra*. Why are they said to be so?

LESSON XXXIX

*Vaucheria*¹

General study.—This plant is almost always found in greenhouses, on the damp earth under benches and in pots; out-of-doors it may be found on earth in damp, shady places, and sometimes floating upon quiet water.

It forms a heavy green felt-like mat, and is so large that many of its characteristics may be seen without magnification. About a week before the plant is to be studied two or three mats should be thrown into a dish of water and placed near the laboratory window, when quite favorable material will develop.

Vegetative structure.—Does the plant branch? Is it divided by cell-walls? A plant containing many nuclei not separated from one another by walls is called a *cænocyte*. How are the plastids arranged? How are new plastids formed? Draw a part of one plant.

Reproduction.—(a) *Reproduction by zoospores*—asexual reproduction.

Note the end of a branch where a large region has been cut off by a wall. The enclosed mass forms one very large zoospore. Note how these move about when they are set free. Try to find some just beginning to grow. Draw.

(b) *Reproduction by gametes*—sexual reproduction.

Note outgrowths from side of filament. These may be

¹ *Cedogonium* may be used instead of *Vaucheria*.

of two kinds and one may have rebranched. The large round cell forms one large gamete—the *egg* or *oosphere*. The curved structure produces small gametes—the *sperms*. One sperm unites with the egg, thus forming a spore, called an *oospore* because it is formed by union of a sperm and an *oosphere* or *egg*. The oospore passes through a resting-period, and then reproduces the *Vaucheria* plant.

The large cell being specially set apart to form an oosphere is called an *oogonium*. The curved structure that bears the sperms is called the *antheridium*.

The process of union of the sperm and the egg—that is, union of dissimilar gametes, is known as *fertilization*.

Draw an antheridium, an oogonium containing an oosphere or egg, and one with an oospore. How does the appearance of the oospore differ from that of an oosphere?

General questions.—Why is *Vaucheria* found in damp places only? Could *Vaucheria* live in direct exposure to strong light? Why? Why do the plants which are growing deep in the aquarium elongate toward the light? Do you find separated antheridia and oogonia? What advantage in this arrangement? How is the structure of antheridia and oogonia especially adapted to the work of fertilization? How do these reproductive organs differ in origin from those of plants before studied? In how many ways may *Vaucheria* reproduce itself?

LESSON XL

General study of Algæ

If in the vicinity there is a good representation of Algæ, a general field study should be made of as many kinds as possible. The student should note the various types, where they live, and how their structure is adapted to the place in which they live. Places visited at the time of the first lesson should be revisited and studied from the view-point

of the knowledge since obtained in the laboratory. Much that is new will now be observed. It is not essential to learn the names of all the Algæ found, but those studied in the laboratory should, if possible, be located in their natural growing places.

If abundant representatives of the Algæ are not to be found in the time allotted to an exercise, it may be possible for different students to secure for the laboratory a large number of forms that may then be observed by all. If some herbarium specimens of Algæ from the sea may be had, they will help to give an idea of the varied forms, structures, and colors to be found in the group.

CHAPTER XI

FUNGI

THE Fungi are Thallophytes which do not contain chlorophyll, consequently do not possess the power of making their own food. They must obtain it from some source outside themselves, and with different kinds of Fungi the source of food materials is subject to great variations. The structures of various Fungi are developed with reference to the different ways in which they obtain their food, as well as with reference to their peculiar problems of reproduction.

LESSON XLI

Mucor, a mold

General study.—A few days before this plant is to be studied, some damp bread, over which a little old mold has been rubbed, should be placed under a glass cover. This will almost always produce an excellent growth of material. Abundance of material can usually be found upon damp bread or fruit that has been neglected for a few days.

Make a careful observation of the plants, noting the gray mat upon the bread and the stalks that arise from it. Frequently upon these upright stalks there are sporangia. Examine to see whether the mat penetrates the bread. The woven mat is the *mycelium*, a single thread of which is a *hypha*.

Details of vegetative structures.—Mount some material from which the surplus bread has been carefully removed.

Study the general structure of the mycelium. Study the

structure of a single hypha. Draw. Note rhizoids (root-like structures) at the lower end of some of the upright stalks. What is their function? Draw.

In case the mold is young, the plants are usually divided into groups. What is the connection between them? How may new groups arise?

Reproduction.—(a) *Asexual reproduction.* Note upright stalks, sporangia, and spores. Are the contents of the spores well protected? Can you approximate the number of spores in one sporangium? Draw sporangium and spores. Determine how the sporangium develops.

(b) *Sexual reproduction.*—Sometimes, though very infrequently, *Mucor* reproduces itself in another way. The tips of two branches come in contact, and each cuts off an end-cell. These cells unite, thus forming a very heavy-walled spore, which eventually forms a new *Mucor* plant. Discover and draw stages in this process. What kind of spore is this? How does this kind of reproduction compare with that of *Spirogyra*?

General questions.—How is the mold nourished? What is the advantage in growing the mold under a glass cover? Why are molds so frequently found in dark, damp places? Why do the sporangia stand up in the air instead of being embedded in the mycelium? How do you account for the fact that new molds arise readily wherever there is good nutrient material? Look for molds as you go about, note where they grow, and bring into the laboratory for observation as many kinds as you may find.

LESSON XLII

A toadstool¹

General study.—Some of the mycelium of a toadstool is within the nourishing medium. Above this there is the *stalk*, and upon it the expanded part, the *pileus*. About the stalk there is sometimes a *ring*, while from the margin of the pileus sometimes hangs a *veil*. On the under side of the pileus are plates or gills, pores, or spines. Observe both young and old specimens. Where is the pileus in a young specimen? When present, how are the ring and veil formed? Draw.

Structure.—Mount a little of the drier earth or wood in which the mycelium is growing and try to discover some of the hyphæ. From the stalk and pileus remove small pieces, dissect carefully, then mount and examine. Determine what composes these parts of the toadstool. Are the hyphæ from the interior of the stalk as heavy-walled as those on the exterior? Why? Draw.

Reproduction.—Remove a small piece of gill, spine, or wall of pore, and examine. Where are spores developed? Can you determine just how they are supported? Draw. How are spores set free? How are they distributed? Does the specimen you have become dry or gelatinous as it becomes old? Does this bear any relation to distribution of spores?

General questions.—Where do toadstools grow? Why do we expect to find more toadstools shortly after a warm rain? What furnishes food material for toadstools and puffballs?

Examine the spores of various toadstools, puffballs, etc. Do most of these spores form new plants? Why are so many

¹ *Coprinus*, *Agaricus*, or any other common toadstool will suffice for this work.

developed? Is it a waste of energy for plants to develop so many spores? What advantage is it to the puffballs to have some spores retained for a long time in the old plant?

LESSON XLIII

A mildew—lilac-mildew or smartweed-mildew

General study.—Examine leaves of the plants on which the fungus is growing. Draw, showing the distribution of the mold-like mycelium and the small, dark, sphere-like bodies which contain the spores.

Vegetative structure.—Examine a section of the leaf, note the mycelium on the surface, and see how it enters the leaf. What are the functions of those branches of the hyphæ that enter the leaf?

Where is most of the fungus plant with reference to its host?

Reproduction.—On the surface of the leaf will be seen small dark bodies, the closed cups, or *cleistothecia*, from the walls of which extend appendages with tips peculiar to each mildew. In these bodies are sacs, each of which contains spores. Crush open the “fruiting bodies,” or cups, and study. How many sacs? How many spores in each sac? Draw.

General suggestions.—The “fruiting bodies” are heavy walled and are suited to protect the spores through the winter season. How are spores set free in spring? Observe the lilacs, smartweeds, grape-vines, etc., to see how general is the distribution of these mildews. Of what economic importance are they?

LESSON XLIV

General exercise on Fungi

Let each student bring into the laboratory as many kinds of Fungi as he can find. Look for specimens of the

rust upon wheat and oats; the smut that forms the black powdery or sticky masses upon corn; the cedar-apples, which are fungous growths forming peculiar hard or gelatinous balls on branches of various evergreen trees; puff-balls and toadstools of various kinds. Place some ordinary yeast in some water to which a little sugar has been added. For a study of bacteria obtain some water containing decaying organic matter, and put two or three dishes of it in a warm place, where the bacteria will reproduce rapidly.

Note the general form of these various Fungi and try to determine how they live and how they affect the things that furnish them nourishment. A good notion of the yeasts and bacteria can be had only by means of strong magnification. The last two groups of Fungi mentioned are very simple in structure, but their economic importance is very great. Why?

Sketches should be made of the different kinds of Fungi observed in this exercise.

LESSON XLV

A lichen

If Part I of the manual is not to be used, introduce here the exercise on the lichen in Lesson XXIII.

CHAPTER XII

BRYOPHYTES

LESSONS XLVI AND XLVII

The moss plant

WHEN the asexual spores of the moss plant develop they produce a thready or filamentous growth—the *protonema*—which is not unlike some Algæ. This grows in damp places, such as wet earth and decaying timber, and appears as a green coating. Sometimes from the cells of the protonema there grow small buds, which enlarge, finally becoming the leafy shoots of the moss plant.

Vegetative structures.—(a) *Protonema*. After noting its general appearance, mount and study, and make a sketch showing the general structure. Are filaments all of one kind? How can you tell whether all are equally vigorous? Does the protonema differ from the filamentous Algæ? If any buds of leafy shoots are present, make sketches showing their relation to the protonema. If your material is especially favorable, show stages in the development of the leafy shoot from the bud.

(b) *The leafy shoot*. Observe the arrangement of stem, leaves, and rhizoids. Sketch in detail a few cells from the leaf. How do you account for the different kinds of cells composing the leaf?

Sexual reproduction.—(a) *Antheridia and sperms*. At the tops of some leafy shoots the leaves are spread out as an inverted umbrella, and at the tip of the stem, surrounded

by leaves, may be seen a group of antheridia. When fresh and ripe they may be seen with a hand lens as small reddish-brown bodies. Carefully remove the leaves from about the antheridia and sketch. Among the antheridia are slender stalks composed of two to four cells. These are the *paraphyses*. What function do they probably serve? Study one antheridium carefully and draw. If you have fresh material try to find the sperms escaping. What is the form of the sperm? Are many developed?

(b) *Archegonia and eggs*. Sometimes antheridia and archegonia are borne on the same plant, though this is not usually the case. Plants bearing archegonia usually have the tip leaves drawn together more closely than do the antheridial plants. From plants which you think may bear archegonia remove the tip leaves and examine. Archegonia, if present, will be seen to be slender flask-like bodies, not so conspicuous as the antheridia.

Each archegonium consists of the basal part, the *stalk*; the elongated part, the *neck*; the swollen part, the *venter*; a row of *canal-cells* in the neck; and the large egg within the venter. The egg is fertilized without leaving the archegonium, forming the oospore. How is fertilization brought about? Draw an archegonium.

How does the antheridium of a moss differ from that of the Algæ? How does an archegonium differ from the oogonium of the Algæ?

Since this leafy shoot is the part of the plant that bears the gametes, it is called the *gametophyte* (gamete plant).

Asexual reproduction.—After the oospore is formed it begins to grow, elongating until one end has pushed out considerably beyond the tip of the leafy shoot. Note and sketch cases where it has begun to emerge from the leaves. Also older stages where the tip has become a swollen structure—the *capsule*. Open the capsule and observe spores. Can you determine the arrangement of the teeth (*peristome*)

and the covering (*operculum*) of the mouth? Of what use are these structures?

These asexual spores fall, after which they grow, producing protonema, and begin another life cycle. Since this latter phase of the plant produces the asexual spores, it is called the *sporophyte* (spore plant).

General suggestions.—It is noted that in this plant we have one phase producing spores by means of gametes, and another producing them asexually. These two phases are called the gametophyte and sporophyte generations respectively, and as each one produces a spore which develops the other we have *alternation of generations*. In this case one generation never produces both kinds of spores.

In what respect are mosses more complex in their reproduction than Algæ and Fungi? Does the way the protonema lives have anything to do with the wide distribution of mosses? How is the leafy moss shoot better fitted for nutritive work than such Algæ as *Vaucheria* and *Spirogyra*? Is the position of the stem of any especial significance? Does a moss need any greater supporting power than an alga? Any greater power of carrying materials?

LESSONS XLVIII AND XLIX

A liverwort—*Marchantia*¹

The liverworts usually live in shady, secluded places, although some may be exposed to direct sunlight. They generally have prostrate bodies, that bear rhizoids on their lower surface. Sometimes they have leaf-like expansions from the main axis of the body. The latter are called the *leafy liverworts*, the former the *thallose liverworts*.

¹ In order of development liverworts precede mosses. The mosses, however, illustrate more clearly the alternation of generations, and through them the liverworts are more easily understood.

Vegetative structure.—Note the form of the body and its position with reference to its support. Where is the youngest part of the plant? In what direction does growth take place? How does the plant branch? Are rhizoids equally distributed over all parts of lower surface? Make a sketch of a plant. On the dorsal (upper) surface note the diamond or irregularly shaped areas, in the center of each of which there is an opening. This opening—the so-called “breathing-pore”—leads into an air-chamber into which extend peculiar cells that bear chlorophyll. Sketch a few of the areas. Make a very thin cross-section of the plant and note how these chlorophyll-bearing cells are arranged in the air-chamber. Is chlorophyll borne in all the cells below the air-pore? Note the partitions between the air-chambers. How do rhizoids arise from the lower cells? Draw a part of a cross-section, showing the kinds of tissues and their arrangement.

Vegetative reproduction.—On the dorsal side of the liverwort body there are frequently cup-like outgrowths—*cupules*—in which are small bud-like bodies—the *gemmae*—which, when set free, may grow directly into new plants. Note some of the cupules, remove the *gemmae*, and study their structure. Draw.

Sexual reproduction.—From the midrib of the liverwort thallus there arises a branch with expanded top bearing sex organs. A thallus produces only one branch, a male or a female. The *archegonial heads* have finger-like branches and resemble a starfish, while the *antheridial heads* are disks with lobed margin. Make a general sketch of each branch upon its thallus.

By means of sections or dissections study the archegonia and antheridia. Note how archegonia are suspended from the head and how the antheridia are embedded within it. Younger heads will show the best archegonia. Draw, showing the structure of each sex organ.

How do you think fertilization is effected in *Marchantia*?

Asexual reproduction.—The oospore germinates where it is formed, producing a sporophyte which is comparatively inconspicuous. By examining old archegonial heads the sporophytes may be found. Remove one, examine, and sketch, showing the short foot region and the swollen capsule region.

Crush the capsule. Note the spores and the *elaters* among them. Remove the cover-slip and allow the material to dry as you observe it, and determine the function of the elaters. Draw.

General questions.—What is the gametophyte of the liverwort? Is this gametophyte as well adapted to nutritive work as that of the moss plant? Is its position more or less favorable to nutritive work? Has the moss or the liverwort the better sporophyte? In what respects? Why are liverworts usually found in very shady places?

LESSON L

General exercise on mosses and liverworts

If favorable regions and abundant material are convenient, this study would better be made in the field; otherwise numerous specimens may be studied in the laboratory.

Make a general study and produce sketches of such mosses as the broad-leaved *Mnium* forms, and the *Sphagnum*—the peat-bog moss.

Of liverworts, some leafy form as *Porella*, and *Anthoceros* bearing sporophytes should be studied and sketched.

CHAPTER XIII

PTERIDOPHYTES

LESSONS LI, LII, AND LIII

The study of a true fern

ANY ordinary fern, such as the bracken fern (*Pteris aquilina*), or the maidenhair fern (*Adiantum pedatum*), will furnish good material for this work. A few weeks before this study is begun some fern spores should be sown on damp earth in a vessel that should be kept covered in order that a regular temperature and moisture may be maintained. These spores develop into very small gametophyte plant bodies. Upon these bodies gametes are produced, and from the oospore formed from them the sporophyte grows. The sporophyte is the part of the plant usually called the fern.

A. THE GAMETOPHYTE:

1. **The vegetative body.**—Note the green covering made upon the soil by the young plants. See whether you can distinguish any separate gametophyte plants. The older ones are thin heart-shaped bodies, while the younger have not yet assumed this form. Mount some of the youngest material and note how the gametophyte develops by studying and drawing the following stages:

- (a) Cases where the spore is beginning to germinate. Can you determine where the first rhizoid arises? Does the very young gametophyte

bear any resemblance to an alga, or to the protonema of a moss?

b. Cases where the body is beginning to be a flattened structure. In what directions do cells divide in order to produce this structure? From what cells do the rhizoids arise? Does the body bear any resemblance to a liverwort gametophyte?

c. A fully formed gametophyte. Make a general sketch showing its form and parts.

2. Reproduction (sexual).

a. *Antheridium and sperms*.—On the under side and margin of younger as well as fully formed gametophytes the antheridia may be seen as conical projections from the surface. They are best studied when they are mounted, so that a side view is obtained. Note the wall-cells and the centrally placed region in which sperms are formed. Draw.

With fresh material it is usually easy to find antheridia from which sperms are escaping. If you can make such a mount, note the form of the sperms, and how and where they escape. Are there many in each antheridium? Are there more than are needed?

b. *Archegonia and eggs*.—On the under side of the gametophyte, nearer the apical region than the antheridia, are the archegonia. Only the necks extend beyond the surface of the gametophyte, the ventral part of the archegonium being embedded. It may be possible to mount the material you have so as to see the protruding necks. If so, do you see sperms trying to gain entrance to the archegonia? What advantage in having the archegonial

necks bend backward? How would a section have to be cut to show the venter and neck canal-cells? If prepared mounts are obtainable, study and draw an archegonium and the cells adjacent to it. Compare it with the moss archegonium in position and structure. Fertilization takes place with the egg thus embedded in the gametophyte tissue.

B. THE SPOROPHYTE.

1. **Development and general structure.**—The oospore begins its growth without leaving the place where it was formed. It soon develops so large a structure that it forces its way out, and the leaf and root and stem of the so-called fern plant begin to appear from the lower surface of the gametophyte.

Examine young specimens which show the young sporophyte not yet free from the gametophyte. Sketch, showing the relations between the two.

Locate specimens which are somewhat older and note the condition of the gametophyte. If abundant material is at hand observe the stages of growth of the sporophyte until it has reached its adult size.

In an old sporophyte note the strong leaf-stem, and the leaflets. Sketch, showing part of leaf-stem and the leaflet, with its veining. Note the amount of chlorophyll-bearing surface which is exposed to the light.

2. **Reproduction (asexual).**—From the margin of the leaflet or from its epidermis there are frequently flap-like or shield-like outgrowths that cover groups of sporangia. These sporangia produce the spores, which are capable of beginning again the gametophyte phase of the life history. Sketch this

epidermal outgrowth (*the indusium*), the sporangia, and the spores. Allow some sporangia to dry under a low power and determine how they distribute their spores.

General questions.—Which generation of a fern does the greater amount of nutritive work? What are its structural advantages for this work? In what way does this sporophyte differ from that of a moss plant? Compare the moss, the liverwort, and the fern with reference to their gametophyte structures; also with reference to their devices for asexual spore distribution.

LESSON LIV

General exercise on Pteridophytes¹

Specimens of the horsetail or scouring-rush (*Equisetum*), of the ground-pine or club-moss (*Lycopodium* or *Selaginella*), and ordinary ferns showing varying habits, should be studied as to their general characters, both as to the general structure and habit of the plant body and the methods of asexual reproduction. Make sketches of forms studied.

The gametophyte stage becomes so obscure in the higher forms that the casual observer never sees it. It finally becomes devoid of chlorophyll, and so small that it is seen only by means of magnification. But it continues to retain its ability to develop the gametes, which form the sex spore, and this of course proves it to be a gametophyte.

A further complication that arises in some of the highest ferns, and one that is difficult to understand, is found in the fact that the asexual spores are unlike, one being very large and one very small. These dissimilar asexual spores produce unlike gametophytes. The small gametophyte, developed from the small spore, produces the male gamete,

¹ If there is abundant time, this work should occupy two lessons.

and hence is called the male gametophyte. The relatively large gametophyte, developed from the large spore, produces the female gamete, and hence is the female gametophyte. Fertilization takes place in connection with the female gametophyte, and the young sporophyte begins to grow where the oospore is formed. This condition of asexual spores and gametophytes is found among all the higher plants, the reduction of the gametophyte often becoming so great that it is not much more than a sex organ. Furthermore, the large spore is sometimes retained in the sporangium, and develops the gametophyte, the oospore, and eventually the young sporophyte within itself. It is evident that in such plants the gametophyte is very greatly reduced from its condition in the lower ferns and the mosses.

CHAPTER XIV

THE GYMNOSPERMS

THE pine (*Pinus*) as a type. Any of the ordinary species of pine will answer for this work.

LESSONS LV, LVI, AND LVII

The *Spermatophytes* are divided into two great divisions, the *Gymnosperms* and the *Angiosperms*. The name "gymnosperm" refers to the fact that the seeds are naked or exposed on the outside of the structure that bears them. This group includes nearly all of the evergreen trees, and one of the most common of these is selected to represent it.

General study.—Points to be observed are the prominent nutritive body, composed of roots, stem, branches, and leaves; general form of the tree, and the length and position of the branches as they contribute toward making up this form; general characteristics and appearance of the foliage.

The vegetative structures.—Remove a small branch. Study it carefully to see how much it has grown each year. Is it a rapid grower? Do branches near the ends of limbs grow as rapidly as those farther back?

At the cut end of the branch note the woody core, around which is the resinous, green region, the latter being surrounded by the dead bark. Sketch as seen with the hand lens.

The leaves.—The pointed leaves are called the needle leaves. Is there any regularity in the way they are borne?

Note the scale leaves appearing on the stem in the younger growth, and as sheaths about the bases of the needle leaves. Remove one group of needle leaves, and after taking the sheath away see how the pair or group of leaves is arranged at the base. Sketch such a group. Is there any regularity in the way the different groups of needle leaves are arranged on the branch?

Observe the hardness and toughness of the leaves. Make a thin cross-section of one, and note the following regions: (1) The heavy epidermal and strengthening regions. How many layers of cells? Where most numerous? (2) The chlorophyll-bearing tissue, in which are the *resin-ducts* definitely bounded by wall-cells. (3) The central light-colored pith region, bounded by a definite sheath of cells. (4) Within the pith region two groups of conducting cells—the *vascular bundles*.

What assists this leaf in persisting through the severe winter weather? Does the resinous matter have anything to do with this protection?

Reproduction.—In the ferns the sporangia are borne sometimes on chlorophyll-bearing leaves and sometimes on specialized spore-bearing leaves, while in Spermatophytes they are usually borne on specialized leaves—*sporophylls*—and these are grouped in cones or clusters. The pines have two distinct kinds of *cones*—those producing sporangia that contain small spores, and those producing sporangia that contain large spores.

a. The cone bearing the small spores is called the *staminate* cone, and each sporophyll is a *stamen*. The spores are usually mature in May or June. Study material collected just before the spores are ripe.

Sketch the cone, showing the outside appearance and arrangement of the sporophylls that compose it. Are cones borne separately or in clusters? Remove one or two sporophylls (stamens) and sketch, showing the very short stalk,

the long sporangia, and the flap-like projection that was seen in the surface view of the cone.

Tear open the sporangia, mount, study, and draw some of the spores. Note the peculiar wings on each spore. What is the function of these wings? Can you approximate the number of spores formed in one cone?

The spores are frequently called *pollen-grains* or *microspores*, and the sporangia *pollen-sacs*.

b. The other cone, when fully formed, is very much more prominent than the staminate cone, and its sporophylls are very much larger and stronger. Usually at the time the pollen-grains are ripe there may be found cones of three ages—very young ones, which are not so large as staminate cones, one-year-old cones, and the two-year-old cones. Study one-year-old cones first. Draw, showing the general structure and arrangement of sporophylls. Remove some of the sporophylls and note how they are held together. On the upper surface and near the axils of some of them will be seen the sporangia, frequently called *ovules*. By use of the hand lens an opening at the lower end of the sporangium can be seen. Draw, showing sporangia on the sporophyll. The sporophyll which bears the large sporangium is frequently called a *carpel* or *pistil*, and the cone the *carpellate* or *pistillate* cone.

The spore is formed within the sporangium and is never set free. It germinates and forms the gametophyte, which develops the egg entirely enclosed within the ovule (sporangium). It is evident that this egg is deeply embedded in the ovule and presents problems for fertilization not met among the Pteridophytes.

The pollen-grains fall upon the very young carpellate cones, and many of them fall in between the carpels or sporophylls. This happens while the carpellate cones are smaller than the staminate cones. The pollen-grains are thus brought to the lower end of the ovule, and this transfer

of pollen-grains from the stamen to the tip of the ovule is called *pollination*. Then the wall of the pollen-grain develops a tube, which pushes its ways through the ovule toward the egg. Meanwhile there have been developed either within the pollen-grain or the tube two male gametes, beside some other cells, and these are carried by the tube to the egg within the ovule. One male gamete fuses with the egg. From the oospore thus formed a young sporophyte begins to develop, and about the time it has developed the regions for the root, the stem, and the leaves, the walls of the ovule become hard, the embryo stops growing, and the whole structure now known as the *seed* passes into a resting-condition. It requires more than two years for the completion of a pine seed. After a period of rest, this seed, under favorable conditions, will develop a new pine plant. It is evident that the young pine plant is already in the seed, and needs only favorable conditions to begin to escape.

Examine two-year-old cones. Remove sporophylls and note the seeds to which wings are attached. Sketch seed and wing. What is the wing for? Dissect the seed, note the heavy coatings, the abundant food material stored within it, and the straight embryo. Of the latter note the root, stem, and leaf regions. Draw. Plant a number of good seeds and see how the young plant comes up. See how many leaves (seeds leaves) it has when it first appears. How does the plant get free from the seed-coats?

General questions.—Of what advantage is it to the pine to have its leaves narrow and so heavy-walled? Could they be protected so economically if they were very broad and thin? Does the structure of the leaf place any limitations on the rapidity of its growth? Of what advantage is it to have the cones so thoroughly sealed by the resinous matter?

Do pines expose more chlorophyll to the light than do ferns? Which have better devices for the distribution of their young plants?

CHAPTER XV

THE ANGIOSPERMS

THIS is the group of plants which formerly occupied almost all the attention of students of botany. It is probably the youngest of all the groups, is certainly the most numerous and most conspicuous, and from some points of view it is the most interesting of all. The name of the group indicates the fact that the seeds are enclosed within the structure that bears them, and not exposed, as in Gymnosperms. Nearly all the members of the group have true floral leaves, though this is not a constant character throughout the group. These structures, together with the sporophylls, constitute the *flower*.

LESSONS LVIII, LIX, AND LX

The *wild lily*, the *buttercup*, the *tulip*, or the *primrose* will serve well as a type of the entire group. Any simple flower showing all the parts will serve for this lesson.

General study.—Note the general plan of the plant body. Is it essentially similar to that seen in the pine? Make a general sketch showing roots, stem, and leaves.

The vegetative structures.—1. *The roots.*—Make a detailed sketch of a part of the root system, showing the organization into large roots, then somewhat smaller branches, and so on until the smallest divisions are reached. Do these roots have more wood-fiber as they approach the stem? The wood-fiber is made up of bundles of tissue composed of elongated or tubular cells, which serve to carry water, and

other materials which are in solution, to the stem of the plant.

2. *The stem.*—Cut across the stem and with the hand lens or low power of the microscope note the bundles of tissue mentioned above. Make a diagram showing how they are arranged in the cross-section of the stem. Usually there will be seen some of the very large cells of the pith tissue among the bundles, while around all of this is the bark tissue.

3. *The leaf.*—*a.* Draw a leaf showing (1) its attachment to the stem; (2) its form, whether the margin is notched; (3) its system of veining—how the veins branch, their relative size, and how they terminate. These veins are continuations of the fibrous bundles from the roots and stem.

b. Carefully peel off a little of the epidermis from both surfaces of the leaf, mount with the outside up, and study the general form of the epidermal cells and the *stomata*. Each stoma consists of two *guard-cells* and an opening, the outer part of which may be seen between the guard-cells. Draw.

The stomata assist in regulating the amount of water in the leaf, and may also serve to transmit gases to and from the leaf.

c. Make a thin cross-section of the leaf, mount, and examine, noting (1) the epidermis on upper and lower sides; (2) the chlorophyll-bearing tissue, that which is near the upper epidermis, because of its arrangement and form, being known as *palisade* tissue, and that below as *spongy* tissue; (3) the cross-sections of veins; (4) the stomata, usually in the lower epidermis. Draw. What part of the leaf does most chlorophyll work? What part is best adapted to the transportation of materials?

Reproduction.—*The flower.*—When all the floral leaves are alike in color they are designated by the term *perianth*.

But this perianth is usually differentiated into two sets of leaves—an outer green set, known as the *calyx*, each leaf of which is a *sepal*, and an inner more or less colored set known as the *corolla*, each leaf of which is a *petal*. Just inside the petals are the *stamens* or *microsporophylls*, so called because they bear the *microspores* or pollen-grains, and inside the stamen group are one or more *megasporophylls* (*carpels* or *pistils*), so called because they bear the *megaspores*—the large cell within the ovule that finally develops into the *embryo-sac*.

How many sepals, petals, stamens, and pistils are there in the flower you have? Is there any regularity in their positions? Make a diagram showing the number of each, and how they are placed with reference to each other?

Draw one member of each floral set. Of the stamen, the tip part which contains the pollen-grains is the *anther*, and the stalk is the *filament*. The anther usually contains four sporangia. Of the pistil, the swollen part is the *ovary*, the elongated part the *style*, and the tip the *stigma*. Use these names in labeling your drawings.

Remove, examine, and sketch some pollen-grains. Make a section across the ovary, and see how the ovules are arranged within it. Has the ovary a single cavity or several cavities. The presence of several cavities indicates that several megasporophylls have united. What is the form of the ovule?

Within the ovule the large spore develops into the embryo-sac, which contains beside other structures the female gamete—the egg. It is evident that the gametophyte stage is very brief, and that it is entirely hidden within the ovule. The pollen-grain alights upon the stigma and develops a pollen-tube, which grows down the style, and finally reaches the ovule, which it penetrates, thus reaching the embryo-sac. The contents of the pollen-grain have meantime formed two male gametes, and when the pollen-tube reaches

the embryo-sac these are discharged into the sac, when one of them fertilizes the egg, thus producing an oospore. It is evident that the structure which grows from the pollen-grain, and which produces the male gametes, is even more inconspicuous and transient as are the structures which produce the female gamete. An essential thing to remember is that the pollen-grain is an asexual spore and not the male gamete, but that it produces male gametes; and that one of these gametes fertilizes an egg which is formed within an embryo-sac entirely embedded within the ovule.

The oospore germinates while within the embryo-sac and soon differentiates the root, stem, and leaf regions of the new sporophyte plant. At this time the wall of the ovule hardens, the embryo sporophyte stops growing, and the *seed* is completed. This may remain in a dormant condition for a long time, but when conditions become favorable, the young plant within bursts the seed-coats and the new plant establishes itself and continues its growth under new conditions.

If prepared sections can be had it will be found of interest to study the phenomena above described, though it will not be easy to make out all the different stages in the process.

Compare this Angiosperm with the Gymnosperm studied with reference to the following points:

Amount of chlorophyll work done.

Protection given to chlorophyll tissue.

Floral structures.

Where ovules are borne and how fertilization is effected.

Time required to ripen the seed.

LESSON LXI

A comparison of the chief groups of Angiosperms

The form studied in the last lesson may be the one with which comparison is made. Such plants as the lily, tulip, water-plantain, Solomon's-seal, etc., will serve to represent the first group of Angiosperms, while such as the buttercup, five-finger, innocence, etc., will make good illustrations of the second group.

The Angiosperm division of the Spermatophytes is further subdivided into two groups—the *Monocotyledons* and *Dicotyledons*. With the specimens furnished, compare a representative of each group with reference to the following points, making drawings and notes setting forth the distinctive features.

1. **Leaves.**—How attached to stems; veining; margins; alternate or opposite on stems.

2. **Roots.**—Bulbous or fibrous.

3. **Stems.**—(Cross-sections). Fibro-vascular bundles in form of a cylinder or scattered throughout the stem.

4. **Flowers.**—Number of cycles composing the flower, and number of parts in each cycle.

In the notes make a summary of the distinguishing characters of the two groups of Angiosperms.

LESSON LXII¹

The remaining lessons take up a few prominent families of Monocotyledons and Dicotyledons. Several plants are suggested in most of the lessons. One of these may be selected from which to obtain an idea of the family. Very brief suggestions as to the work to be done are made. The

¹ If time and material make some work in identification and classification possible, such work should be done, following the outline for the study of leading groups.

student should look at these families for the purpose of making comparisons, and should obtain a definite idea of the kinds of plants found in each family. Carefully written notes describing the distinguishing characters of each family should be prepared. The first three lessons are upon Monocotyledons, the rest upon Dicotyledons.

Jack-in-the-pulpit allies.—Jack-in-the-pulpit (*Arisæma*) as a type.

Study and make drawings showing general characters of root and bulb, stem, leaves, and spathe. Note in detail the spathe, the column—the *spadix*—within it, and the flowers borne on the spadix. Stamens and pistils in separate flowers. Note their positions. Do they ripen at the same time? Is there any adaptation to effect pollination in any particular way? Is the leaf of this plant a typical Monocotyledon leaf?

LESSON LXIII

Lily allies.—Lily (*Lilium*), or sweet flag (*Iris*) as types.

Note roots, bulb, stem, leaves, and flowers. Make a diagram of the floral organs.

LESSON LXIV

Pondweed allies.—Pondweed (*Potamogeton*), or cat-tail (*Typha*) as types.

Besides noting features above mentioned, note especially the manner of bearing the flowers and the habitat of these plants.

LESSON LXV

Poplar allies.—Poplar (*Populus*), willow (*Salix*), chestnut (*Castanea*), oak (*Quercus*), and elm (*Ulmus*) as types.

In addition to points mentioned above, special attention should be given to the tree or shrub habit, the naked flowers, and the separation of the sporophylls into staminate and pistillate catkins.

LESSON LXVI

Rose allies.—Wild rose (*Rosa*), raspberry or blackberry (*Rubus*), and wild strawberry (*Fragaria*) as types.

LESSON LXVII

Pea and bean allies.—Honey locust (*Gleditschia*), bean (*Phaseolus*), pea (*Pisum*), broom (*Cytisus*), and clover (*Trifolium*) as types.

LESSON LXVIII

Mint allies.—Mint (*Mentha*) as a type.

LESSON LXIX

Composites.—Sunflower (*Helianthus*), black-eyed Susan (*Rudbeckia hirta*), bur-marigold (*Bidens*), and ox-eye daisy (*Chrysanthemum*) as types.

Note especially that the flowers are gathered into dense heads; that the outside ones have their corollas greatly enlarged into strap-like *ray-flowers*, while those in the center of the head are reduced into inconspicuous *disk* flowers. Are all floral organs present in both ray and disk flowers? Draw the parts of both kinds of flowers and make their floral diagrams.

In what respects are composite flowers an advance over other flowers studied?

Is cross-pollination more easily secured in this type of flower? Discover some methods for preventing close-pollination. Is this to be regarded as a successful family?

REFERENCE LISTS

I. *Laboratory apparatus, supplies, materials for study, etc., may be had from the following addresses:*

1. Bausch & Lomb Optical Co., Rochester, N. Y., or Stewart Building, Chicago. Microscopes, glassware, chemicals, and general supplies for the laboratory.
2. Cambridge Botanical Supply Company, Cambridge, Mass. Preserved materials for study.
3. Eimer & Amend, 205 Third Avenue, New York. General supplies.
4. Ithaca Botanical Supply Company, Ithaca, N. Y. Materials for study.
5. L. E. Knott Apparatus Company, Ashburton Place, Boston, Mass. General apparatus.
6. William Krafft, 411 West Fifty-ninth Street, New York, or E. Leitz, 659 W. Congress Street, Chicago. The Leitz microscopes.
7. McCallum & Coulter, Washington University, St. Louis, Mo. Prepared slides for the microscope and lantern slides.
8. Queen & Co., 1010 Chestnut Street, Philadelphia. Microscopes and general supplies.
9. Richards & Co., 46 Park Place, New York. Reichert microscopes.
10. Spencer Lens Company, Buffalo, New York. Microscopes and general supplies.

II. *List of books suggested for collateral work.*

- Atkinson, G. F., *Elementary Botany*. Henry Holt & Co., New York, 1898.
- Atkinson, G. F., *First Studies in Plant Life*. Ginn & Co., Boston, 1901.
- Bailey, L. H., *Lessons with Plants*. The Macmillan Company, New York, 1898.
- Bailey, L. H., *An Elementary Text-book of Botany*. The Macmillan Company, New York, 1901.
- Bailey, L. H., *The Survival of the Unlike*. The Macmillan Company, New York, 1896.
- Barnes, C. R., *Plant Life*. Henry Holt & Co., New York, 1898.
- Bergen, J. Y., *The Foundations of Botany*. Ginn & Co., Boston, 1901.
- Bessey, C. E., *Essentials of Botany*. Henry Holt & Co., New York.
- Britton & Brown, *Flora of the Northeastern United States and Canada*. Charles Scribner's Sons, New York, 1898.
- Campbell, D. H., *The Evolution of Plants*. The Macmillan Company, New York, 1899.
- Chamberlain, C. J., *Methods in Plant Histology*. The University of Chicago Press, Chicago, 1901.
- Chapman, *Flora of the Southern States*. Cambridge Botanical Supply Company, Cambridge, Mass.
- Coulter & Chamberlain, *Seed Plants*, Part I. The Gymnosperms. D. Appleton and Company, New York, 1901.
- Coulter, J. M., *Plant Relations*. D. Appleton and Company, New York, 1899.
- Coulter, J. M., *Plant Structures*. D. Appleton and Company, New York, 1899.
- Coulter, J. M., *Manual of Rocky Mountain Botany*. American Book Company, New York.

- Dana, Mrs. W. S., *How to Know the Wild Flowers*. Charles Scribner's Sons, New York, 1899.
- Darwin, Charles, *Insectivorous Plants*. D. Appleton and Company, New York.
- Darwin, Charles, *The Power of Movement in Plants*. D. Appleton and Company, New York.
- Ganong, W. F., *The Teaching Botanist*. The Macmillan Company, New York, 1899.
- Gray, Asa, *Manual of Botany*. American Book Company, New York.
- Kerner & Oliver, *The Natural History of Plants*. Henry Holt & Co., New York.
- MacDougal, D. T., *Plant Physiology*. Henry Holt & Co., New York, 1895.
- MacDougal, D. T., *The Nature and Work of Plants*. The Macmillan Company, New York, 1901.
- Müller, *The Fertilization of Flowers*. The Macmillan Company, New York.
- Spalding, V. N., *Introduction to Botany*. D. C. Heath & Co., Boston, 1895.
- Strasburger, Noll, Schenck, & Schimper, *A Text-book of Botany*, translated by Porter. The Macmillan Company, New York, 1898.
- Underwood, L. M., *Our Native Ferns and their Allies*. Henry Holt & Co., New York.
- Willis, O. R., *Practical Flora* (containing an abundance of suggestions on economic botany). American Book Company, New York, 1894.

III. Prepared mounts for the microscope

Although work should be done with fresh material whenever possible, it is frequently very helpful to have preparations made by persons experienced in the technique of botany. Because of excellence in sectioning, staining, and

mounting, such prepared mounts will often enable the pupil to observe some things not to be seen in his own preparations. Whenever it is possible the student should make his own preparations, and merely further extend his study by use of the prepared slides. The list suggested may be increased considerably with profit.

1. Cross-sections of Easter lily, or of a similar leaf from some other plant.
2. Sections of leaves of wild lettuce. One from a leaf which grew in direct exposure to the sun, and another which grew in the shade.
3. Section of a pine leaf.
4. Section of oleander leaf.
5. Section of leaf of rubber plant.
6. Sections of stems and leaves of hydrophytes, mesophytes, and xerophytes.
7. Hairs from leaves and stems of various plants.
8. Sections illustrating food-storage tissues.
9. Nostoc or Anabæna.
10. Ulothrix, with cells containing gametes and zoospores.
11. Spirogyra, both vegetative and reproductive.
12. CEdogonium, both vegetative and reproductive.
13. Mucor, mycelium, asexual, and sexual reproduction.
14. Section of a toadstool showing method of spore formation.
15. Leaf of grape, or Capsella, showing hyphæ of parasitic fungus within it.
16. A slide of the leading forms of bacteria.
17. Section of a lichen thallus.
18. Section of a lichen "fruiting cup."
19. Moss protonema with buds.
20. Section of moss plant having antheridia.
21. Section of moss plant bearing archegonia.
22. Section of thallus of a liverwort.

23. Section of archegonial head of a liverwort.
24. Section of antheridial head of a liverwort.
25. Fern gametophyte bearing antheridia.
26. Section of fern gametophyte bearing archegonia.
27. Section of fern gametophyte bearing a young sporophyte.
28. Section of fern leaf.
29. Sections of fern rhizome, transverse and longitudinal.
30. Section of pine ovule, showing embryo-sac.
31. Section of Angiosperm ovule, showing embryo-sac.
32. Cross-section of Angiosperm anther, showing arrangement of sporangia, pollen-sacs, and spores.

THE END

TWENTIETH CENTURY TEXT-BOOKS.

The closing years of the nineteenth century witnessed a remarkable awakening of interest in American educational problems. There has been elaborate discussion in every part of our land on the co-ordination of studies, the balancing of contending elements in school programmes, the professional training of teachers, the proper age of pupils at different stages of study, the elimination of pedantic and lifeless methods of teaching, the improvement of text-books, uniformity of college-entrance requirements, and other questions of like character.

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“It is a really beautiful book, the illustrations being in many cases simply exquisite, and is written in the clear, direct, and simple style that the author knows so well how to use. A very strong feature of the work is the prominence given to ecological relations, which I agree with Dr. Coulter should be made the leading subject of study in the botany of the preparatory schools.”—*V. M. Spalding, University of Michigan.*

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“It marks the passage of the pioneer stage in botanical work, and affords the student a glimpse of a field of inquiry higher than the mere tabulation and classification of facts.”—*C. H. Gordon, Superintendent of Schools, Lincoln, Neb.*

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