LABORATORY EXERCISES

IN

BOTANY

DESIGNED FOR THE USE OF

COLLEGES AND OTHER SCHOOLS IN WHICH BOTANY IS TAUGHT BY LABORATORY METHODS

BY

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ILLUSTRATED WITH 7 FIGURES IN THE TEXT, AND 87 FULL-PAGE PLATES FROM ORIGINAL DRAWINGS COMPRISING UPWARD OF 250 FIGURES.

PHILADELPHIA
W. B. SAUNDERS
925 WALNUT STREET.
1895.

ELECTROTYPED BY
WESTCOTT & THOMSON, PHILADA.

PRESS OF
W. B. SAUNDERS, PHILADA.

PREFACE.

THIS book has had its birth in the laboratory. It embodies methods that have been evolved during many years of observation and experience in conducting a botanical laboratory for students of pharmacy. It aims to inculcate in the student, by the study of properly-selected examples, a knowledge of the elementary principles of botany, to develop his observing faculties, to stimulate in him the spirit of investigation, and to lead him to take delight in a beautiful science.

While the course here laid down is strictly an elementary one, and aims to cover only a small part of a wide and interesting field, an effort has been made in the selection and arrangement of themes to lay a sound foundation for the pursuit of the more difficult branches of the science. The intelligent student who has completed the course in a thorough manner may not yet be a botanist, but he will have acquired both the methods and the spirit that fit him for original work in the science.

Two things have been kept steadily in view in the preparation of the book: the needs of private students pursuing botany without the aid of a teacher, and the requirements of such schools and colleges as have cast aside the old text-book methods of worrying the students with botanical hard names, and have adopted natural methods of teaching botany. It is believed that the illustrations of plant-structure that accompany each exercise—all of which were drawn by the author from natural objects, and were reproduced for the book by photographic process—will greatly smooth the way for the private student, and also be of considerable service both to teachers and classes in the college laboratory.

The book is written in two parts, the first dealing chiefly with the gross structure of flowering plants, or that which may be observed with no further aid than that of a simple microscope, and the second devoted chiefly to the microscopic structure of plants. The plan pursued is similar in all the exercises. Each is a study, made direct from Nature, of some plant, plant-organ, tissue, or product, and the student is expected first of all to verify the descriptions and drawings by observations of his own, and then to make independently one or more parallel studies of some similar object or objects selected from the list given in the exercise.

It has not been deemed wise to cumber the book with numerous descriptions of processes and methods, but there have been given only the most useful and those whose value has been well proved by experience. While, also, the list of apparatus, reagents, stains, and mounting media might have been lengthened very materially, it is thought to include all the essentials for an elementary course, and to be therefore of more practical value, and less confusing to beginners, than a more extended list.

For many of the formulæ for the preparation of reagents and stains, and for some processes, the author acknowledges his indebtedness to the admirable books of E. Strasburger, A. Zimmermann, and Arthur Bolles Lee.

EDSON S. BASTIN.

PHILADELPHIA, Sept. 15, 1894.

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would be of advantage. Such a book, however, should be constantly on hand during laboratory-work for reference.

The glossary in the book above referred to will also be of service, for while these exercises are not, it is hoped, overburdened with technical terms, it has not been thought wise to omit them altogether. If botany is mastered, its language must also be acquired.

PART I.

ORGANOGRAPHY.

INTRODUCTION.

THE equipment required by the student to pursue the course of study here laid down is simple and inexpensive. A good magnifying-glass, a pair of dissecting needles, a sharp pocket-knife or a scalpel, six glass slides and twice as many cover-glasses for temporarily mounting sections, a camel's-hair brush of medium size, a rule with the metric scale on one edge, a pair of delicate forceps, with drawing- and memorandum-books and pencils for keeping the appropriate records of observations made, are all that are really necessary.

It would be a great advantage, however, if the student were to get, in place of the ordinary pocket-magnifier, a good dissecting microscope, so that he may have both hands free for the work of dissection. Efficient instruments of this kind are easily obtainable at a moderate cost from many different manufacturers and dealers. The instrument shown in the accompanying cut is both

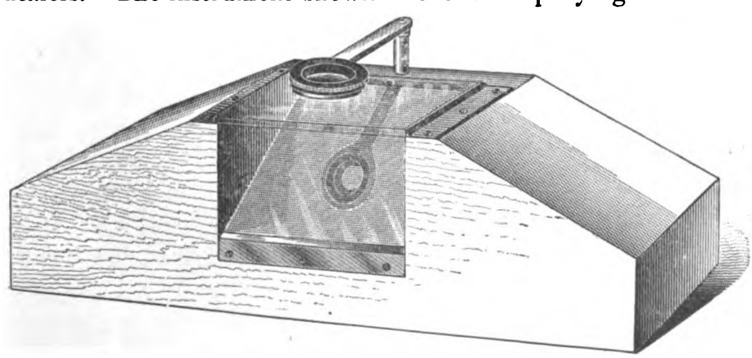


FIG. 1—Dissecting Microscope.

efficient and inexpensive. The body consists of a solid block of hard wood so shaped that the sides serve as hand-rests. The stage is of glass, below which is a mirror, fixed at an angle of 45° for the illumination of a transparent object on the stage, and there is a square rubber plate, one side of which is white and the other black, to insert between the mirror and the stage whenever white- or dark-ground illumination is required. The metallic lens-holder slides in a brass tube driven into a hole in the back of the block, into which the cylindrical column of the holder nicely fits, rendering the lenses easily adjustable for focus. The instrument is provided with two lenses, which may be used singly or in combination, giving a range of powers of from five to fifteen diameters.

The reagents employed are also few and easily prepared, and are as follows:

Iodine Solution.—This solution is thus prepared: Saturate a small quantity of distilled water with potassium iodide, and then dissolve in it all the iodine crystals the solution will take up, and dilute with distilled water until the liquid has a deep wine color. This solution stains proteid matters yellowish-brown, lignified tissues a deep brown, cellulose tissues scarcely at all, and starch-grains a deep blue. In using the solution as a test for starch in sections it is best to dilute it with four or five times its bulk of water, otherwise the grains will be so deeply stained as to appear black.

Another method of detecting the presence of starch in vegetable structures is to boil for a few moments some fragments of the tissue to be tested in a few cc. of distilled water in a test-tube, and then, after the solution has cooled, drop in a little of the strong solution, when, if starch is present, the decoction will immediately acquire a blue color, the depth of which will depend on the quantity of starch present. On boiling the solution the blue color disappears, to reappear when cooling takes place.

Potassium Hydrate.—To prepare this reagent make a 10 per cent. solution of the pure fused potassium hydrate in distilled water, and keep it in well-stopped bottles. If corks are used, they should be paraffined, and if glass-stoppered bottles are employed, the stoppers should first be smeared with vaseline to prevent their sticking. This solution is useful as a clearing agent, since it rapidly dissolves the proteids and starch and saponifies and dissolves fats. It also stains corky tissues yellow or yellowish-brown, especially when warmed in contact with them, and tannin cells are also colored yellow or brown by it, though a better test for tannin is a solution of some ferric salt. For clearing, the chloral-hydrate solution recommended in the Introduction to Part II. may be used instead, and in many cases is superior.

Ferric Chloride.—This solution is prepared by dissolving about 5 grammes of ferric chloride in 50 cc. of distilled water and adding a drop of nitric acid. The solution should be renewed from time to time. A drop of this solution applied to a section containing tannic matters will produce a bluish-black or a greenish-black precipitate, according to the variety of tannin that is present. Rarely, however, other substances present may produce similar precipitates with this reagent. Instead of this, there may be employed, with equal advantage, the ferric-alum solution described in the Introduction to Part II.

Phloroglucin Reagent.—This reagent consists of two liquids, which are to be kept in separate bottles: (1) a 5 per cent. solution of phloroglucin in 95 per cent. alcohol, and (2) strong hydrochloric acid. This is one of the most useful reagents, and is employed for distinguishing between lignified and unlignified tissues. The test is applied as follows: To a section of the tissue to be studied apply first a drop or two of the phloroglucin solution, and then, after a few moments, a similar quantity of the hydrochloric acid. If any lignified tissues are present, they will be stained red, while unlignified ones remain unstained. The arrangement of the bundles and that of bast-fibres and stone-cells may thus be traced with little difficulty.

Alcannin Solution.—This reagent is prepared by adding to a solution of alcannin in absolute alcohol an equal bulk of distilled water and then filtering it. It colors fats, volatile oils, and resins a deep red, and hence is a most convenient test for the presence of these bodies. The best results are obtained by letting sections soak in the solution for two hours or more. (See also Introduction to Part II.)

Preparation of Dried Material for Study.—Many dried materials, such as some medicinal roots, rhizomes, etc., may be studied quite satisfactorily in the dried form by making longitudinal and transverse sections and applying the appropriate tests. But more frequently the dried material is too hard, too friable, or too brittle to be satisfactorily studied in this way, and some preliminary treatment is necessary.

Except in the case of very hard tissues the following treatment is usually satisfactory: First soak the specimen in alcohol to expel the air; then (2) in water for a few hours until thoroughly permeated by the liquid; and then (3), if the tissues are too soft for satisfactory sectioning, as is frequently the case, particularly with herbaceous or succulent specimens, they should be hardened by immersion for at least twenty-four hours in strong alcohol. If now too hard or too brittle for cutting, they should be immersed in a mixture of equal parts of alcohol and glycerin for twenty-four hours.

According to the author's experience, the great majority of specimens of roots, rhizomes, tubers, corms, fruits, and seeds yield the best results when carried through all the stages of the process above described.

In the case of structures which, like gentian root, for example, have shrunken much in the process of drying, it is necessary, in order to restore them to their natural dimensions, to modify the second stage in the above process by using alkaline instead of pure water. A 1 per cent. solution of potassium hydrate in distilled water is suitable for most cases. Before hardening in alcohol it is advisable to wash out the alkali by means of pure water.

In the case of very hard tissues, such as shells of nuts, etc., softening is also effected by the use of the alkaline solution. The strength of the solution employed will depend somewhat on the nature of the tissues, but, as a usual thing, weak solutions, 1 or 2 per cent., are preferable to strong solutions. In some instances an immersion for several days will be required to effect the proper degree of softening. After this has been effected the tissues should be washed to get rid of the alkali, and then be transferred to glycerin, or to a mixture of equal parts of glycerin and alcohol, preparatory to sectioning.

In the case of dried leaves, flowers, or herbarium specimens, which it is desired to restore as nearly as possible to the condition of fresh specimens, it is usually sufficient to immerse them for a few hours either in 1 per cent. potassium-hydrate solution or in a weak solution of ammonium hydrate.

Examining Sections.—Explicit directions for sectioning are given in the Introduction to Part II., to which the student is referred. For the purposes of study by means of the simple microscope it is not usually necessary to make sections so thin that they will freely transmit light; but it is necessary that they be made of nearly even thickness, and made with a very sharp knife, so that the tissues are not torn nor displaced.

For the purposes of this course two different kinds of sections are usually necessary—one transverse, and the other longitudinal—and great care should be taken that the former are strictly transverse or directly across the grain, and that the latter are strictly longitudinal. Oblique sections are worthless.

Immediately after cutting a section it should be transferred to water or to other liquid to prevent the entrance of air-bubbles, which obstruct the view of the structure, and which, having once entered, are very difficult to get rid of.

When sections are tested they should be transferred to a glass slide, and for study they should always be mounted in water, glycerin, or some other transparent liquid on a glass slide, and be covered with a cover-glass; otherwise the object will appear more or less distorted.

Care of Reagents and Apparatus.—The reagents are best kept in glass-capped bottles, such as those illustrated in the Introduction to Part II. Each bottle should contain a small glass tube to be used for transferring a few drops of the solution to the object to be tested, and great care should be exercised not to mix and spoil the reagents by putting the tubes into the wrong bottles. The student should bear in mind that some of the reagents employed are corrosive, and therefore should be on his guard against using them in a way that will injure his apparatus.

Whenever it is necessary to clean the lenses of the microscope, this should be done by means of a clean linen or a cotton cloth, or, better, by means of Japanese filter-paper, otherwise the lenses will be liable to be scratched or their polish impaired, to the detriment of their optical efficiency.

To reduce the labor of description to a minimum, and at the same time to ensure method and thoroughness, forms for the description of roots, stems, leaves, flowers, fruits, and seeds have been inserted at the close of these subjects respectively. These forms are also printed in separate record-books for the use of students.

in distinction from one that springs out laterally from a stem, and which is called *secondary* or *adventitious*. Of the latter sort are the climbing rootlets of Poison Rhus, the air-roots of the Banyan, etc. Also, if, as in the Dandelion, the main root does not almost immediately break up into smaller ones, but maintains its ascendency over its branches until it reaches a considerable depth in the ground, it is called a *tap-root*.

On Plate I. (Fig. 1), *a* is one of the heads, *b* and *c* annular markings on the crown, and just below *c* is the neck.

(2) *Shape.*—The shapes of Dandelion roots vary considerably among themselves, but that of the one in the figure may be described as conical, since it tapers gradually from the crown downward.

(3) *Kind.*—As above stated, the root is primary and a tap-root.

(4) *Branches and Other Appendages.*—The main root frequently gives off one or more large branches, and always a multitude of smaller ones, and all these branches occur without definite order, as is frequently, though not always, the case with roots. In the Radish, for example, the branches occur mostly in two vertical rows on opposite sides of the main root.

It will be observed that the rootlets break up into finer and finer divisions, until the ultimate ones are quite minute, thus exposing a very considerable absorbing surface to the soil. This surface is still further greatly increased by the presence of vast numbers of root-hairs, which thickly clothe all the finer divisions of the root. In fact, these hairs, rather than the roots themselves, are the chief agents for absorbing nutriment from the soil. Some of them may readily be seen with a hand-magnifier or even with the naked eye, but unless the roots have been separated from the soil with extreme care they are mostly destroyed. They may be made to form again in great numbers, however, if, after removing the plant from the ground and washing it, the roots are kept for two or three days in a warm, moist, and dark chamber.

Exceptionally, roots bear buds, which may give rise to new stems, but adventitious buds of this kind seldom if ever occur on Dandelion roots.

(5) *Markings.*—Tuberculose or papillose markings may often be observed on the main root or on its larger branches, from which rootlets formerly issued, but have since disappeared. Frequently

also rough corky patches, caused by wounds that have healed or are in the process of healing, may be seen.

(6) *Color.*—The color of the uninjured root is usually light-brown or yellowish-brown in the younger, becoming darker in the older, portions. This color resides in the corky outside layer.

(7) *Measurements* should also be made of the roots studied, recording the length and greatest thickness. The one figured above, for example, has a length of about 18 cm. and a maximum thickness of about 1 cm., while that of the crown is about 1½ cm.

(8) The student should now make a drawing of the root which he is studying, indicating by aid of letters and lines the important structural points, as suggested in the model drawing (Pl. I. Fig. 1).

II. THE INTERNAL STRUCTURE.—The internal structure should be studied by making transverse and longitudinal sections, and applying to them such reagents as are necessary to reveal their structure more distinctly, and by examining them with a magnifying-glass.

(1) *Transverse Section of Root.*—Make two or three transverse sections, one just below the crown, the others lower down. They will differ in size, but it will be observed that they have substantially the same structure, except that possibly a small pith may be found in or near the centre of the upper one, but not in the others. The central yellowish portion, not more than about one-fourth the diameter of the entire section, is called the woody cylinder or *meditullium.* Surrounding this cylinder is the thick white bark, composed of softer tissues, from which, when fresh, there oozes a copious white milk-juice. This fluid, it will be observed, does not issue from the meditullium. The zone of junction between the meditullium and the bark constitutes the *cambium* zone, in which, in the roots and stems of gymnosperms and dicotyls during the growing season, increase in thickness takes place by the formation of new cells. To the naked eye or under an ordinary magnifier the cambium looks like a mere line, but it really consists of several layers of small very thin-walled cells.

The bark really consists of three layers. The outer, called the *epiphlœum,* is the thin, brownish, corky covering of the root;

the middle and inner layers are called respectively the *mesophlœum* and the *endophlœum*. In many roots these two layers appear quite distinct to the eye, but in the Dandelion their similarity in appearance is too close for this, and they can only be delimited clearly by aid of the compound microscope. With a magnifying power of about fifty diameters the inner bark shows a radial structure which the middle bark does not possess.

The milk-vessels are confined to these two layers, and their distribution in this root is quite peculiar. Observation shows that they are grouped in interrupted concentric circles (Pl. I. Fig. 3). The ringed appearance of the cross-section, observable even in the dried root, is due to this.

In the roots of most biennial and perennial dicotyls, and in those of gymnosperms, the meditullium shows a distinct radial structure consisting of medullary rays running from the centre across the cambium zone to the limits of the inner layer of the bark, and separating the wood into wedge-shaped bundles. This structure is present in the Dandelion root, though impossible to trace without the aid of a compound microscope. But no such structure exists in the roots of monocotyls.

(2) *Longitudinal Section.*—This section, if made through the centre of the root, shows that the meditullium is a ligneous cylinder extending from one end of the root to the other. Moreover, it sends branches not only into the larger, but also into all the finer, subdivisions of the root.

(3) *Tests.*—Certain reagents applied to the sections will enable one to learn some additional facts about the structure.

(*a*) *The Iodine Test.*—The thick, fleshy root evidently has stored within it much nutritive matter, to which is due the rapid unfolding of the leaves and flowers in the spring. Is a part of this food-material in the form of starch or not? The iodine test will answer the question. Applying a drop of potassium-iodide iodine to a cross-section, only a yellowish-brown color is produced. Had starch been present the reagent would have produced immediately a deep-blue color, appearing almost black if the solution used were a strong one. Whatever food-materials may be present, then, starch is certainly not one of them, widely distributed as this substance is in the vegetable world. The fact is, that in this plant, and in most others of the natural order to which it belongs, the Compositæ, a related substance, inulin, which does not react blue with iodine, replaces starch as a reserve food-material.

Observing more closely the color-changes produced in the specimen by the iodine, it is found that the white tissues of the middle and inner bark have acquired a light yellowish-brown color, while the tissues of the meditullium have been stained a deep yellowish-brown. The color of the former is chiefly due to the presence of albuminous matters in the bark-cells, while that of the latter is caused by the presence of lignin or woody matter in the cell-walls of the meditullium. It is thus learned that the iodine stains albuminous substances light yellowish-brown, lignified cell-walls deep yellowish-brown, and the walls of ordinary thin-walled cells scarcely at all.

(*b*) *The Phloroglucin Test.*—To a fresh cross-section apply first two or three drops of a 5 per cent. alcoholic solution of phloroglucin, and, after a few moments, two or three drops of strong hydrochloric acid. Presently a deep-red color will be developed in the meditullium, while the rest of the section will remain wholly unstained. Since this reagent stains no tissues red excepting lignified ones, it confirms one of the results obtained by the iodine test. This test is of great value in the investigation of roots and stems, for it often beautifully differentiates structures which without its aid might not easily be distinguished.

(*c*) *The Ferric-chloride Test.*—If tannic matters occur in tissues, the fact is revealed by applying a little of this reagent to a section, when a greenish-black or bluish-black precipitate will be produced. Other than tannic matters, however, capable of similar reactions with ferric chloride, sometimes occur in plants, so one should be cautious about drawing conclusions based on this test alone. But the test is of value in another way. If tannic or other matters producing a precipitate be present, their greater abundance in some tissues than in others, or their total absence in some and abundance in others, are often a means of revealing structure more clearly; for example, by bringing the medullary rays into greater prominence, rendering the bark more distinct from the wood, or the cambium zone more conspicuous.

In the present case, however, a drop of the reagent applied to the surface of a fresh section produces scarcely any change of color. Dandelion root, therefore, ordinarily at least, contains little if any tannin.

(4) *Drawing.*—On a scale large enough clearly to indicate the important points in the structure make a drawing of the transverse section, indicating the different parts by aid of letters and lines as suggested on Plate I. (Fig. 3).

(5) *Transverse Section of the Crown.*—Make two or three transverse sections at different levels, and compare them carefully with the ones already studied of the root. It will be observed that the woody cylinder is relatively thicker than in the latter; that it has a distinct pith; that the radial structure of the meditullium is much more distinct than in the root; and that these differences are more conspicuous a few millimetres above and below the neck than they are near it, where there is a gradual transition of one organ into the other. Draw a diagram of one of the cross-sections and indicate the parts, as in Figure 2 (Pl. I.).

If the tips of any one of the hundreds of small root-branches of the Dandelion were examined under a compound microscope, each would be found to possess a cap of older and thicker-walled cells, whose function it is to protect the growing point, which lies a little way back of the apex, during the movements of the rootlets through the soil. The structure is shown in Figure 4 (Pl. I). This protective covering is called the *root-cap*. In some plants, as the Duckweeds (Lemna minor and L. polyrrhiza), it is large enough to be seen easily with the naked eye.

Now, in a similar manner, study, describe, and figure one of the five following roots: Yellow Dock, Burdock, Carrot, Radish, or Salsify, all dicotyls, and afterward compare the selected root carefully with the roots of Maize or of Smilax, which are monocotyls. Note carefully all the important points of difference in structure and habit.

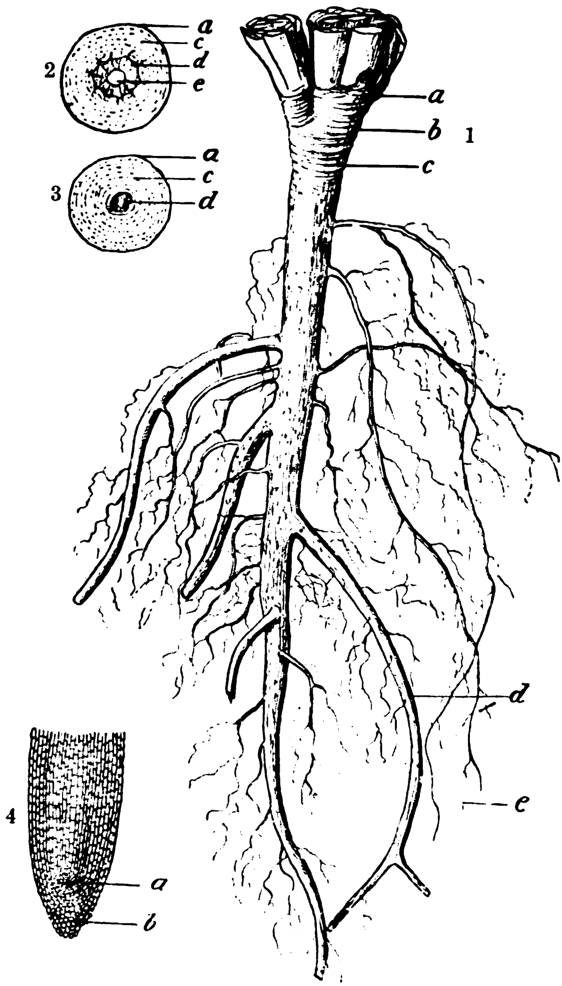


PLATE I., FIG. 1.—Root of Dandelion ($\frac{2}{3}$ natural size): *a*, one of the heads; *b*, annular markings; *c*, annular marking immediately above the neck of the root; *d*, one of the larger root-branches; *e*, one of the finer branches or fibrils.

FIG. 2.—Diagram of Cross-section of the Crown (magnified $1\frac{1}{2}$ diameters): *a*, corky layer of the bark: *c*, circularly arranged milk-vessels; *d*, woody cylinder crossed by medullary rays and containing a pith, *e*, in the centre.

FIG. 3.—Diagram of the Cross-section of the Main Root a little below the neck (magnified $1\frac{1}{4}$ diameters): *a*, corky layer of bark; *c*, concentrically arranged milk-vessels; *d*, central cylinder.

FIG. 4.—Tip of Small Root (magnified about 50 diameters), showing growing-point (*a*) and root-cap (*b*).

FORM FOR STUDY OF ROOTS.

I. KIND.
1. Primary.
2. Adventitious.

II. FORM.
1. Simple.
2. Branching.
3. Conical.
4. Fusiform.
5. Napiform.
6. Fasciculate
7. Fibrous.

III. SIZE.
1. Length.
2. Greatest thickness.

IV. COMPOSITION.
1. Many-headed.
2. Few-headed.
3. Single-headed

V. MARKINGS.
1. Annulate.
2. Warty.
3. Wrinkled.
4. Keeled.
5. Fissured.
Transversely.
Longitudinally.

VI. FRACTURE.
1. Short.
2. Brittle.
3. Splintery.
4. Fibrous.
5. Horny.
6. Corky.
7. Mealy.
8. Friable.

VII. COLOR.
1. Exterior.
2. Interior.

VIII. TASTE.
1. Insipid.
2. Bland.
3. Sweet.
4. Bitter.
5. Mucilaginous.
6. Pungent.
7. Acrid.
8. Warm.
9. Cooling.
10. Astringent.
11. Nauseous.
12. Burning.
13. Prickling.
14. Saline.
15. Alkaline.
16. Acidulous.

IX. ODOR.
1. Odorless.
2. Faint.
3. Agreeable.
4. Aromatic.
5. Mint-like.
6. Balsamic.
7. Camphoraceous.
8. Terebinthinous.
9. Pungent.
10. Musky.
11. Disagreeable.
12. Irritating.
13. Nauseous.
14. Narcotic.
15. Putrid.
16. Fetid.

X. INTERNAL STRUCTURE.
1. *Monocotyl type.*
(1) Cylinder-sheath.
a. Distinct.
b. Indistinct.
c. Lignified.
d. Unlignified.
(2) Cortex.
a. Thickness compared with central cylinder.
b. Bundles in:
Numerous.
Few or none.
Lignified.
Unlignified.
(3) Central cylinder.
a. Rays in:
Numerous.
Few.
Lignified.
Unlignified.
(4) Starch.
a. Most abundant in cortex.
b. Most abundant in central cylinder.
(5) Tannic matters.
a. Most abundant in cortex.
b. Most abundant in central cylinder.
2. *Dicotyl type.*
(1) Cambium zone.
a. Distinct.
b. Indistinct.
(2) Bark.
a. Thickness relative to wood.
b. Layers.
Indistinct.
Distinct.
Relative thickness of—
Exophlœum.
Mesophlœum.
Endophlœum.
c. Mesophlœum.
Stone-cells.
Numerous.
Few.
d. Endophlœum.
Distinctly radiate.
Indistinctly "
Not radiate.
Bast-masses.
Stratified.
Unstratified.
Shape.
Conical.
Linear.
Oblique.
Curved.
Bast-fibres.
Numerous.
Few.
Strongly lignified.
Slightly "
Unlignified.
(3) Woody cylinder.
a. Distinctly radiate.
b. Indistinctly radiate.
c. Annulate.
d. Medullary rays.
Narrow.
Medium.
Broad.
Lignified.
Unlignified.
e. Xylem wedges.
Narrow.
Medium.
Broad.
Lignified.
Unlignified.
f. Ducts.
Conspicuous.
Inconspicuous.
Numerous.
Few.
g. Fissuring.
Fissured.
Entire.
(4) Starch.
a. Most abundant in—
Mesophlœum.
Endophlœum.
Medullary rays.
Xylem wedges.
b. No starch.
(5) Tannic matters.
a. Most abundant in—
Exophlœum.
Mesophlœum.
Endophlœum.
Cambium zone.
Medullary rays.
Xylem wedges.
b. No tannic matters.

In some other members of the Walnut family, to which the Hickory belongs—as, for example, the Bitternut Hickory—these vertically arranged supernumerary buds are nearly always present. A more common arrangement of these buds is seen in the Red Maple, the Tartarian Honeysuckle, and the wild Black Currant, where the supernumeraries occur alongside of or on the same level with, and not above, the axillary bud.

(2) Some distance down the twig from the terminal bud will be seen a series of closely-arranged, ring-like scars. These mark the position of the terminal bud of the previous year; they are, in fact, the scars left by the falling off of its scales. They are indicated at *f* in Figure I (Pl. II.).

(3) Minute dots, slight elevations in its corky exterior layer, may also be seen freely sprinkled over the surface of the twig. These dots are called *lenticels*, and are probably serviceable in the respiration of the plant. Their structure cannot well be understood without the aid of a compound microscope.

(4) Enough of the twig which the student is studying should now be drawn to show a little more than the last year's growth, and the following parts should be pointed out: A terminal bud, an axillary bud, a supernumerary bud (if present), a leaf-scar, a lenticel, and one of the ring-like scale-scars at the base of the year's growth.

II. Structure of the Terminal Bud.—(1) Cut the twig in two, transversely, about ½ cm. below the terminal bud; split the part bearing the latter from below upward, letting the section pass as nearly as possible through the centre of the bud. If the section has been well made with a thoroughly sharpened knife, the structure may now be distinctly seen. It will be observed that the bud consists of a series of thin layers or scales, one within the other, and each inserted upon the short-conical prolongation of the axis or stem. The scales, in fact, represent leaves, and the leaves, as is always the case with these organs, are borne upon a stem. A bud, therefore, is a short stem with leaves very compactly arranged upon it.

(2) From one-half of the divided bud remove the scales one by one, beginning with the outer. It will be seen that they are not all alike. The outer ones are not so large as those next interior, and are thicker and more woody. They are, moreover,

smooth or nearly so, while the thin interior ones are densely clothed with appressed silky hairs. These two kinds of scales are leaves modified for the protection of the delicate true leaves which they enclose. When the bud unfolds in the spring, the outer scales fall away unchanged, but the inner ones, especially those next the true leaves, make a feeble effort to become foliage: they increase considerably in size and acquire some greenness of color, but soon fall away, yielding to the expanding foliage leaves. The more woody outer scales doubtless protect the true leaves from mechanical violence, such, for example, as that due to the lashing of the branches during a storm; while the plush-covered inner ones protect them from sudden changes of temperature and from the entrance of water. This latter is accomplished partly by the closeness with which the scales are applied to one another, and partly by their downy covering, which is somewhat oily and so repels the water. If water were permitted free access to the interior, its freezing and thawing in winter would, beyond question, harm or destroy the young and delicate foliage leaves within.

Examining now the true leaves, it will be found that there are several of these, small in size, but with their parts distinctly recognizable under the magnifying-glass. They occur very near to, but just back of, the stem-apex, the youngest and smallest nearest of all. The glass shows that these leaves are already compound, thus contrasting strongly with the scales, which are simple.

The leaflets are densely clothed with hairs, partly glandular and partly of the ordinary kind, both probably protective in their function, but the former, in particular, useful in defending the young and growing leaves from the attacks of injurious insects.

Packed away in small compass within the bud is the leafy branch of the coming year, awaiting only the genial warmth and moisture of spring to bring it to its full development.

(3) Make a drawing of one-half of the bud, enlarged about three diameters, as suggested on Plate II. (Fig. 2), and point out one of the outer bud-scales, one of the inner hairy scales, one of the true leaves, the stem-apex, the pith, the wood, and the bark.

III. Internal Structure of the Stem.—For this part of our study transverse and longitudinal sections must be made and suitable reagents must be applied to bring out the structure more distinctly. Make several cross-sections, one through the younger portion of the stem, the growth of last year, one through a portion two years old, and a third through a part still older.

(1) Without staining them, examine these sections successively with a magnifying-glass. Each will be seen to possess in the centre an angular *pith* surrounded by a layer of white *wood*, which in the first section is rather thin, in the second thicker and made up of two rings called *rings of growth*, and in the third still thicker and made up of three or more rings, one ring being added, as a rule, for each year's growth. It will also be seen that the wood is crossed in a radial direction by very numerous delicate lines which have their origin in the pith and terminate in the bark. These are called *medullary rays*.

Outside the wood occurs the bark, which is also thinner in the younger part of the stem and thicker in the older portions, though this difference is less marked than in the case of the wood. With care the bark may, as in the root of Dandelion, be distinguished into three layers: an outer, the grayish or brownish corky layer, called the epiphlœum; next the latter a middle layer composed chiefly of green cells, and hence called the green layer, or, from its position, the mesophlœum; and an inner layer or zone called the endophlœum, or bast-layer, which may be observed to contain numerous masses of bast-fibres distributed through softer tissues. The former appear whitish under the magnifying-glass.

The delicate tissue constituting a thin boundary-zone between wood and bark is also called *cambium*, and here, as in the Dandelion root, throughout the season of growth new cells are formed which add to the thickness of the wood on the outside and to that of the bark on the inside.

(2) *Apply the phloroglucin test.* The purpose of this test is to differentiate the parts, so that the structure may be more easily understood. Apply to each of the three sections the test in the same manner as directed in Exercise I. The pith and wood in each case, it will be observed, are stained red, though of somewhat different shades, and in the older portions of the stem, at least, the bast-fibres in the inner layer of the bark also stain, so that they are now more distinctly recognizable. All the other tissues remain unstained. The bast-fibres form wedge-shaped masses, with the thinner end of the wedge outward and each mass crossed

both radially and tangentially by softer tissues. In the older stems these wedges are larger, particularly longer in a radial direction.

The staining of the fibres aids in tracing the limits of the inner bark, since the latter constitutes a zone bounded on the outside by a circular line joining the outer limits of the bast-wedges. Moreover, the ends of the medullary rays which penetrate the bark may now be traced more easily. The coarser rays are made up of the soft tissues which separate laterally the bast-wedges; and the finer, of those which traverse the wedges in a radial direction. The rays extend to, but do not penetrate, the middle bark. The inner bark may therefore usually be distinguished from the middle by its radial structure.

In many stems, though not in the Hickory, the phloroglucin test also enables one to see the medullary rays in the wood more distinctly.

(3) *Apply the iodine test.* This test is used as directed in Exercise I., and for the same purpose. It will be observed that starch occurs in the bark (particularly in the middle layer), in the pith (especially in its outer portion), and in the medullary rays. The latter are therefore rendered very distinct by this test.

(4) *Apply the ferric-chloride test.* Using this test as directed in Exercise I., it will be found that tannic matters occur more abundantly in the medullary rays than in the wood, that the pith contains but little tannin, and that the bark contains it in abundance.

(5) *Draw a diagram of the cross-section of the stem,* selecting for the purpose a part which is at least two years old. Let the structure be represented as magnified about five diameters, as in Pl. II. Fig. 3. Point out the epiphlœum, the mesophlœum, the endophlœum, the cambium zone, a wood wedge, a medullary ray, a ring of growth, and the pith.

(6) *Study the longitudinal section.* Take a fresh twig, and with a sharp knife make a section lengthwise through the middle, preferably from the base upward, so guiding the knife that one of the axillary buds will be bisected. Apply to the cut surfaces such tests as are necessary to render the structure distinct. Observe that the pith traverses the stem lengthwise from end to end, penetrating even the axis of the terminal bud and sending off branches

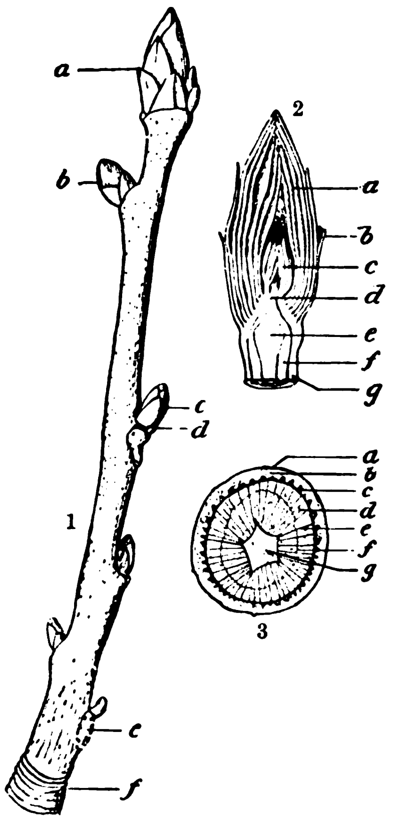


PLATE II., Fig. 1.—Drawing of a Hickory Twig, including about one year's growth (¾ natural size): *a*, terminal bud; *b*, *d*, axillary buds; *c*, supernumerary bud; *e*, leaf-scar; *f*, scars of scales of last year's terminal bud.

Fig. 2.—Drawing of Vertical Section of Terminal Bud of Hickory (magnified about 2 diameters): *a*, one of the inner, hairy scales; *b*, one of the outer, woody scales; *c*, one of the true leaves; *d*, the stem-apex; *e*, the pith; *f*, the wood; *g*, the bark.

Fig. 3.—Diagram of Cross-section of Hickory Twig, representing two years' growth (magnified about 3 diameters): *a*, outer bark or epiphlœum; *b*, middle bark or mesophlœum; *c*, inner bark or endophlœum; *d*, wood; *e*, medullary ray; *f*, ring of growth; *g*, pith.

plants. In the Hickory the arrangement is different from that in the Beech, and different still from both in the Ash. In fact, two different types of arrangement may be distinguished—the *alternate* and the *whorled*. In the former only one leaf occurs at a node; in the latter two or more; but there are many varieties of each of these. The Beech presents a very simple variety of the former, and the leaf-arrangement—or *phyllotaxy*, as it is technically called—is expressed by the fraction one-half. In this fraction the numerator expresses the number of turns about the stem to complete a cycle, and the denominator the number of leaves included in the cycle. The fraction also expresses the angular distance between successive leaves, one-half the circumference of the stem, or 180°, intervening between one leaf and the next in the cycle. The denominator of the fraction, moreover, expresses the number of vertical rows of leaves, or *orthostachies*, on the stem.

If the phyllotaxy of the Beech be compared with that of the Hickory twig, it will be found that the latter also is alternate; but the fraction which expresses it is different. If, as in studying the Beech twig, the start be made with a leaf-scar low down on the stem, and a line be traced around it to the next scar, and so on until the scar is reached directly over the one from which the start was made, it will be found that it is the sixth leaf instead of the third that is directly over the first; that five scars have been passed in going from one to the other, not counting the last; and that two circuits of the stem have been made. The fraction which expresses the phyllotaxy is therefore two-fifths.

Similarly examining other alternate-leaved twigs, it will be found that the phyllotaxies $\frac{1}{3}$, $\frac{3}{8}$, or $\frac{5}{13}$ also exist. Putting these fractions together in order, it will be found that they form a series, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, etc., which includes by far the larger proportion of all alternate forms of phyllotaxy. The members of this series bear a very curious relation to each other. If the numerators of the first two be added together for a new numerator, and their denominators for a new denominator, the third fraction in the series is obtained; if the second and third be similarly treated, the fourth term is obtained; and so on.

The Basswood twig agrees with the Beech in its phyllotaxy, and that of the Balsam Poplar with the Hickory; but in the twig of the Ash there are two leaf-scars and two buds at a node;

this affords an illustration of the other type of phyllotaxy—namely, the *whorled*. It is also the simplest form of this arrangement. It will be observed that the leaves composing the whorl are as far apart as possible—namely, opposite each other on the stem, and this variety of the whorled node has hence been called the opposite. It is almost universally the case, whether the leaves in the whorl be few or many, that they are placed at equal distances apart; if two, 180° apart; if three, 120°; and so on.

It will furthermore be seen that the successive whorls alternate; that is, if a line were drawn through the centre of a pair of leaf-scars, this line would cross at right angles one drawn through the centre of the pair of scars next below or of the ones next above. The whorls, in other words, are *decussate*, and this, too, is nearly always true of whorled leaves. Thus, in the phyllotaxy where the leaves are opposite or in whorls of two there will be four vertical rows of leaves on the stem; where they are in whorls of three, six rows; and, in general, there are twice as many vertical rows as there are leaves in the whorl.

All this doubtless has reference to securing for the leaves their due proportion of light—a thing necessary to the proper performance of their functions and to the prevention of interference between the nutritive currents that flow between the leaves and the stem.

(2) *Leaf-scars.*—Comparing the scars on the different twigs studied, very considerable differences will be found between them, not only in size, number, and arrangement, but in their shape, in their markings, and in their position as respects the axillary bud. In the Beech they are small, nearly semicircular in outline, dotted with the scars of several (about seven) leaf-bundles arranged in a semicircle, and bordered on either side by line-like stipule scars. The bud is not located directly in the axil of the leaf-scar, but above and somewhat to one side. Those of the Basswood are similar in shape, but larger, the buds are strictly axillary, and the bundle-dots in the leaf-scars are unequal in size and usually about six in number.

In the Balsam Poplar the scar is conspicuous, few-dotted, usually with a broadly rounded sinus above, into which the bud fits, and the lower end is pointed.

The leaf-scars of the Ash are still more prominent, many-dotted, rounded on the sides and lower edge, and either straight on the upper margin or with a shallow sinus into which the bud fits.

Many other interesting variations in the scars would be found if other twigs were studied; for example, those of the Ailanthus, the Sumach, and the Aralia spinosa are enormously large, and those of the Sycamore completely encircle the bud, the leaf-base fitting over it in the growing season like a candle-extinguisher.

(3) *Bud-scales.*—Since these are modified leaves or portions of leaves, one would naturally expect to find their phyllotaxy in agreement with that of the foliage leaves of the same plant. This is, in fact, the case in most instances, but there are some exceptions, apparent or real. In the Beech, for example, there are four vertical rows of scales in the bud, and but two of ordinary leaves. This deviation can be accounted for readily by supposing that the scales represent the pairs of stipules at the bases of leaves rather than the leaf-blade; and this is probably the fact.

In the Ash, the Basswood, and the Balsam Poplar, however, the arrangement of the scales is precisely that of the true leaves.

So many interesting peculiarities do the buds and leaf-scars of the branches of different trees and shrubs present that it would probably be possible, by aid of them, to construct a key for identification of our native species.

The student should now make drawings and descriptions of an equal number of twigs taken from other trees or shrubs.

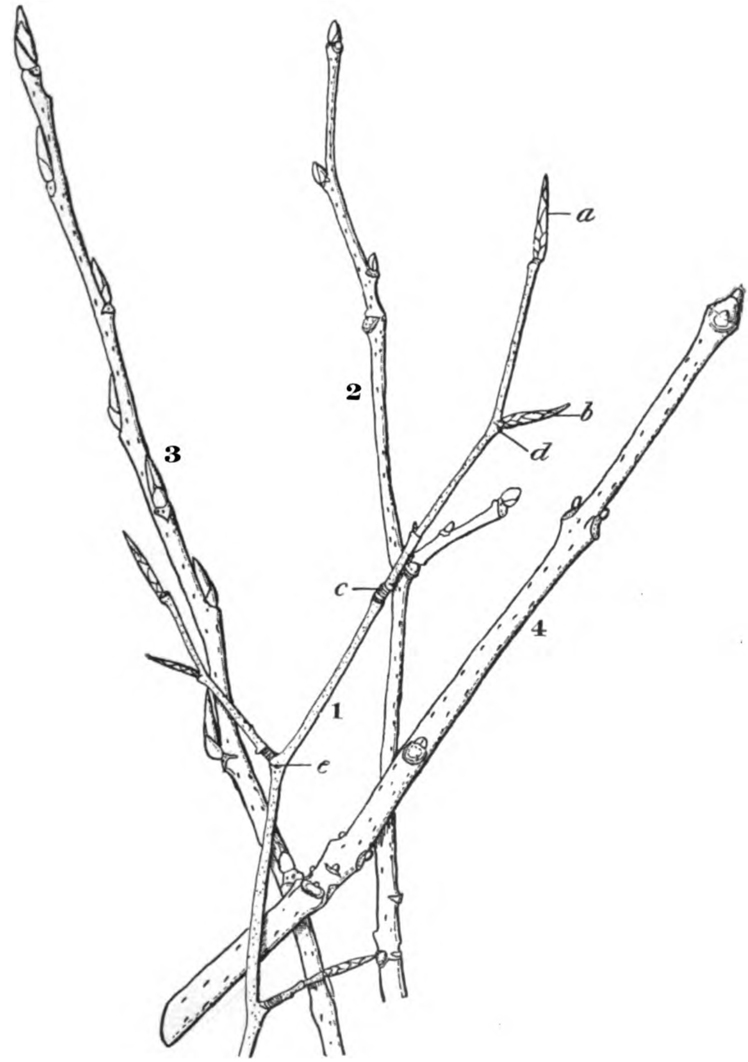


PLATE III., FIG. 1.—Twig of Beech, showing, *a*, slender terminal scaly bud; *b*, a similar axillary bud; *c*, ring-like scale-scars marking position of last year's terminal bud; *d*, leaf-scar; *e*, stipule-scar. The small dots sprinkled over the stem represent the lenticels.

FIG. 2.—Twig of Basswood, showing one-half phyllotaxy, like that of Beech.

FIG. 3.—Twig of Balsam Poplar, showing two-fifths phyllotaxy.

FIG. 4.—Twig of Ash, showing opposite phyllotaxy. (Each about ⅔ natural size.)

come detached from the parent rhizome, a large number of new plants must ultimately originate.

It will be observed further that the rhizome is thick and fleshy, containing large stores of food-material to supply the growth of above-ground parts when the warm spring sunshine stimulates the vital processes of the plant to renewed activity.

Examining carefully the brownish surface, there will be found between the more conspicuous nodes angular scars, the scars of scales that have decayed. These, since they represent leaves, prove the rhizome to be a stem rather than a root, because roots never bear leaves.

On the upper sides of the enlarged nodes will be observed conspicuous circular scars, shown at *d* on Plate IV. (Fig. 1). These are either cup-shaped or there is a central conical elevation, in reality a small bud. The former are scars of the above-ground stems; the latter, scars of the large radical leaves of previous seasons.

From the sides and lower surfaces of the rhizome, at or near the enlarged nodes, arise numerous small roots. These differ in origin from the Dandelion root, being outgrowths from the side of the stem, and not from its end. They are therefore adventitious, and not primary roots. The lateral roots borne by rhizomes must, of course, always be adventitious.

Ascending, or sometimes arising nearly at right angles, from the end of the rhizome and from the ends of each of the main branches will be observed conspicuous buds, which remind one, except from the texture of the scales, of the terminal bud of the Hickory. These buds give origin to an above-ground stem or leaf, which, when it decays in autumn, leaves a large circular scar, such as has already been observed at the swollen nodes. In the mean time, through the summer, the rhizome is pushing onward through the soil, and at the close of summer has formed a new bud at its apex. The number of circular scars, therefore, may indicate the age of the rhizome.

(2) Now make a drawing of the rhizome, pointing out the following parts: one of the angular scale-scars; the terminal bud; a branch; one of the large circular scars; and one of the secondary roots.

II. Structure of the Terminal Bud.—(1) Cut the rhizome in two a little way back from the terminal bud, and then split it from below upward through the middle. Some specimens will show the structure illustrated on Plate IV. (Fig. 2). The scales are much alike except for size, and they are not dry, like those of the Hickory, nor are any of them clothed with hairs or otherwise constructed with reference to the exclusion of water or the prevention of sudden changes of temperature. Being under ground, they do not need to be thus protected, the soil itself serving the purpose perfectly. Their main use seems to be to protect the true leaves and stem-apex from mechanical injury as it grows onward through the soil.

Some of the inner scales, like the corresponding ones of the Hickory, develop considerably in the spring, and often even rise a little above the soil; but they soon wither away, leaving ring-like scars on the part of the rhizome which bore them. These are shown at *e* on Plate IV. (Fig. 1).

Interior to the scales, and enclosed by them, will be found a single well-developed peltate leaf having its lobed blade plicately folded down over the cylindrical petiole, as shown in the figure. These leaves, when mature, may reach to the height of a foot, or even two feet, above the soil, and the blades may attain the diameter of a foot.

The section of the bud shows at the base of the petiole a very minute bud; in fact, the petiole fits over the latter like a candle-extinguisher. When, in the autumn, the leaf falls away, this bud appears as the conical point, already alluded to, in the centre of the large circular scar that marks the insertion of the petiole.

Besides this bud, the section shows still another, indicated at *c* in the figure. It usually occurs, as in the case illustrated, on the under side of the rhizome in the axil of one of the outer scales of the terminal bud. This axillary bud serves to continue the growth of the rhizome under ground, and the angular scars already referred to are the scars of its scales, the latter being carried apart by the lengthening of the bud-axis, and then withering away.

There may also be other buds situated just back of the apical ones, giving rise to lateral offshoots from the rhizome.

(2) Make a drawing of such a bud, magnified about two diameters, and point out a bud-scale, the petiole of the true leaf, the

gether with those portions of the medullary rays exterior to the cambium zone, constitute the inner bark; the soft white tissues still farther exterior make up the middle bark; and the exterior brownish, corky layer is the outer bark.

It is thus seen that in all the essential features of its structure this stem agrees with that of the Hickory. It clearly belongs to the same type. In many details, however, it differs from the latter. For example, it has but little lignified tissue; its vasal bundles are shorter, broader, and fewer; there are either no bast-fibres or rarely very imperfectly developed ones; the pith is relatively larger, is cylindrical, and is not composed of dead cells; and its soft tissues contain a much greater abundance of starch, as revealed by the iodine test.

(2) Make a drawing of the cross-section, magnified three or four diameters, and point out the following parts: the outer bark; the middle bark; a bast-bundle in the inner bark; the cambium zone; the wood of a bundle; and the pith.

B.—The rhizome of a monocotyl will now be studied, that of Solomon's Seal (Polygonatum biflorum) being selected for the purpose.

I. External Appearance and Characteristics.—(1) Note first the more obvious resemblances and differences between this rhizome and that of the Mayapple, just studied. The former resembles the latter in the following particulars: it creeps horizontally; it has numerous scale-scars along its sides; it has circular depressed scars on its upper surface; it has prominent nodes at the points where these scars occur; it has a conspicuous terminal bud; it sends off lateral shoots; it bears secondary roots on its sides and inferior surface, especially on the larger nodes; and it grows annually at the apex while dying away at the base.

The rhizome of Solomon's Seal differs from that of the Mayapple in the following points: it is more fleshy; it is less extensively creeping; its swollen nodes are even more swollen, nearer together, and flattened horizontally; its scale-scars are more crowded and less angular; and the depressed scars on the upper surface are all of one kind, none of them having a bud in the centre; they are, in fact, all stem-scars. There are other minor differences, as those of color, surface, length of rootlets, etc.

So far, however, the differences noted are only such as might occur between rhizomes of closely-related plants. The student must learn that the most important resemblances and differences are not always the ones that are the most obvious. In this instance the differences of greatest significance will be found by studying the internal structure of the bud and the stem.

(2) Now make a drawing of the rhizome about natural size, and point out the following: one of the cup-shaped scars on the upper side of a swollen node; a scale-scar; a bud on one of the lateral branches; the terminal bud; and a root.

II. INTERNAL STRUCTURE OF THE TERMINAL BUD.—(1) As directed in the former study, divide the terminal bud longitudinally and observe the internal structure. But little difference is seen in the texture and arrangement of the scales, but close scrutiny of their structure shows that the venation is of the parallel or nerved type, while in the scales of the Mayapple a network is distinctly visible. This difference is significant, for nearly all monocotyls have parallel-veined leaves, while nearly all dicotyls have reticulate or netted ones.

In the interior of the bud of Solomon's Seal, as in that of the Mayapple, is to be found, packed away in small compass, the shoot of the coming season. In this case the shoot consists of a tolerably well-formed leafy stem with numerous alternate, two-ranked leaves having minute flower-buds already formed in their axils. The difference between the venation of these true leaves and those in the bud of the Mayapple is still more conspicuous than in the case of the scales—a fact which will be better understood when more particular study is given to leaves.

Note that here also, in the axils of some of the outer bud-scales, on the lower side of the rhizome, is a minute bud whose function it is to continue the underground growth while the above-ground stem and its leaves and flowers are developing.

(2) Make a careful drawing of the bud-section, magnified two or three diameters, and point out the following parts: a bud-scale; the enclosed stem; and the bud that continues the growth of the rhizome.

III. INTERNAL STRUCTURE OF THE RHIZOME.—(1) Make three different cross-sections, preferably between the large nodes, and treat one with the phloroglucin reagent, another with iodine medullary rays; and such a stem increases in thickness by growth in the cambium zone, some of the newly-formed cells adding to the thickness of the wood on its exterior and to the inner bark on its interior. On the other hand, a monocotyl stem has no distinct bark and no cambium zone; its vasal bundles are not arranged in a circle, but scattered through the central cylinder; there are no medullary rays; and, although the centre of such a stem is usually softer than the exterior, there is no proper pith.

The two groups may therefore nearly always be distinguished by merely inspecting cross-sections of their stems, and it makes little difference whether the stems selected for the purpose be above-ground or subterranean ones.

This general rule, however, has a few exceptions. A curious instance in point is the above-ground stem of the Mayapple. The bundles which form a circle in the rhizome send off numerous branches which, rising into the above-ground stem, become scattered irregularly through it, instead of preserving their radial arrangement, so that this stem closely resembles in structure a monocotyl.

In a few other plants the stems exhibit a structure somewhat intermediate between the two types, possessing characteristics of both.

(2) Make a diagram of the cross-section of the stem of Solomon's Seal, magnified three or four diameters, and point out the following: the cortex; the boundary between cortex and central cylinder; a rootlet, if present; and one of the vasal bundles.

The cross-section of the root of the same plant shows a structure quite different from that of the stem. Instead of many scattered small bundles, it has a single large central one, which shows a radial structure of its elements, and is surrounded by a sheath, as shown on Plate V. (Fig. 4). *a* is a root-hair; *b*, the cortex; *c*, the bundle. These differences are usual between the stems and the roots of monocotyls, so that, by examining the structure of a small fragment, the root may easily be distinguished from the stem. These differences will be considered more fully hereafter, when the study of the microscopic structure of roots and stems is reached.

Now study, describe, and illustrate one of the other monocotyl rhizomes mentioned at the beginning of this exercise.

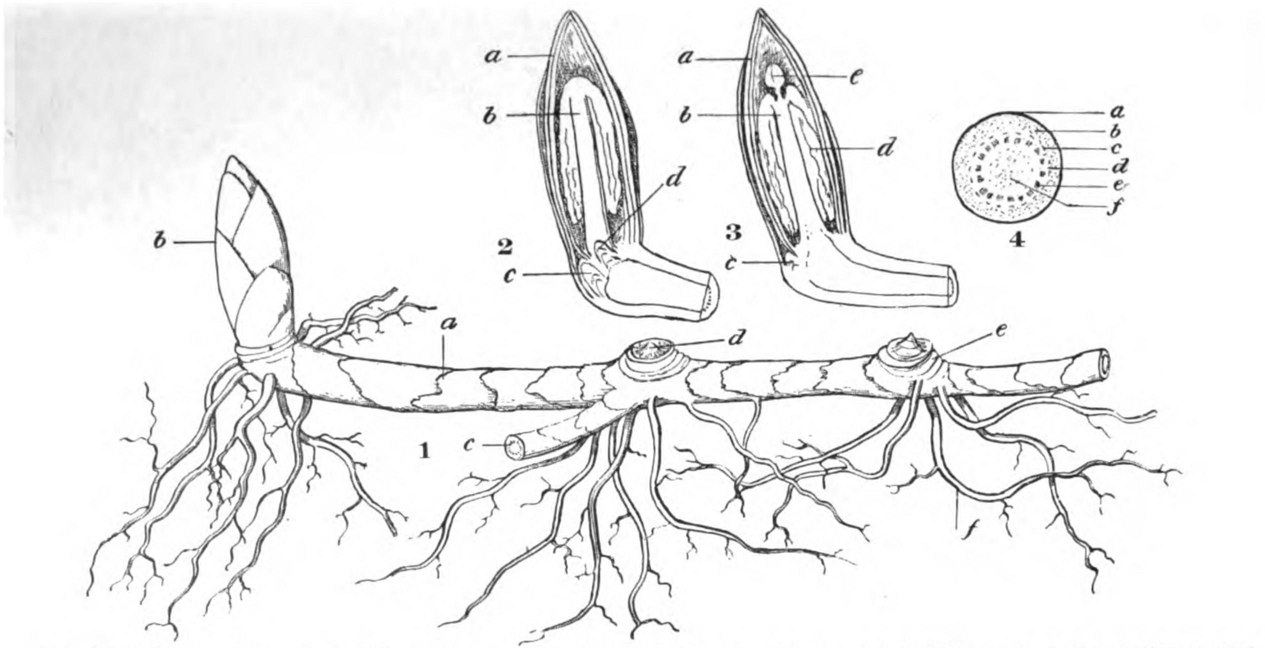


PLATE IV., FIG. 1.—Drawing (about ⅔ natural size) of the Anterior Portion of a Rhizome of Podophyllum peltatum: *a*, a scale-scar; *b*, the terminal bud; *c*, a branch; *d*, a circular leaf-scar; *e*, ring-like scale-scars.

FIG. 2.—Drawing of Vertical Section of Leaf-bud of same Plant (magnified about 2 diameters): *a*, bud-scale; *b*, petiole of leaf; *c*, bud for continuing growth of rhizome; *d*, bud underneath petiole of leaf.

FIG. 3.—Drawing of Vertical Section of another Terminal Bud of same Plant, containing undeveloped stem, leaves, and flower: *a*, bud-scale; *b*, young stem; *c*, bud for continuing growth of rhizome; *d*, true leaf. (The magnification is the same as that of the preceding figure.)

FIG. 4.—Diagram of Transverse Section of Rhizome (magnified about 3 diameters): *a*, corky or outer layer of bark; *b*, middle bark; *c*, bast; *d*, medullary ray; *e*, xylem of a bundle; *f*, pith.

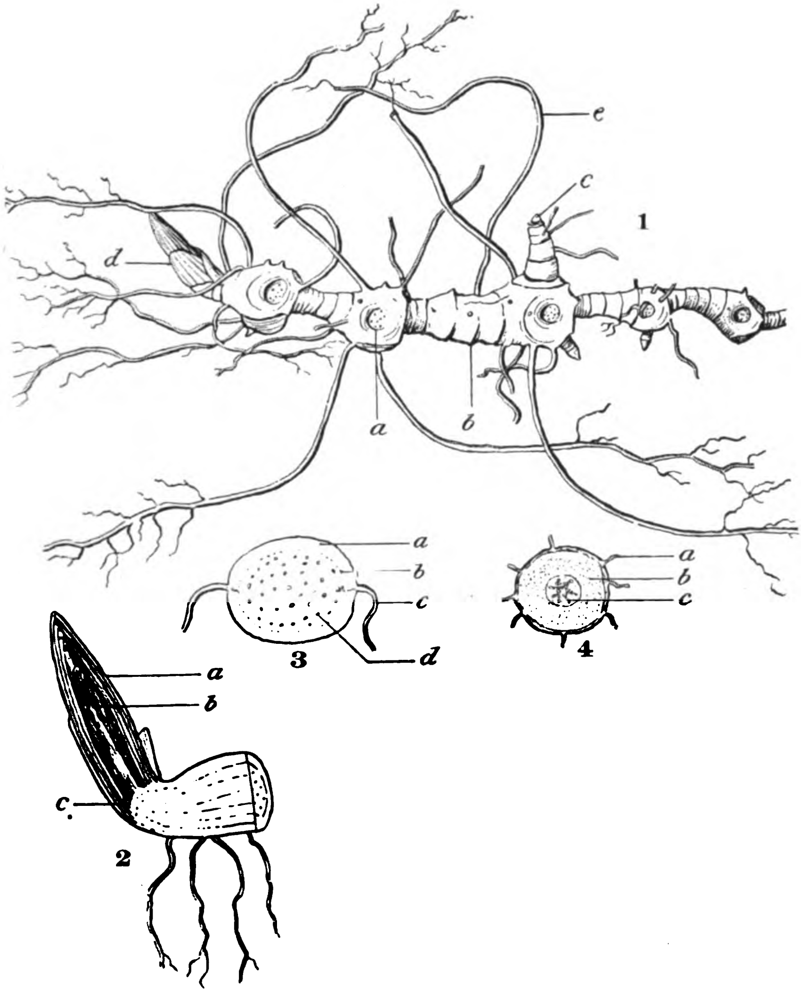


PLATE V., FIG. 1.—Drawing of Rhizome of Polygonatum biflorum (about ⅗ natural size): *a*, cup-shaped stem-scar on upper surface of enlarged node; *b*, scale-scar; *c*, bud on lateral branch; d, terminal bud; *e*, adventitious root.

FIG. 2.—Drawing of Vertical Section of Terminal Bud (enlarged about 1½ diameters): *a*, bud-scale; *b*, young stem within the bud, bearing undeveloped leaves and flower-buds; *c*, bud serving to continue underground growth of rhizome.

FIG. 3.—Diagram of Cross-section of Rhizome (enlarged about 2 diameters): *a*, cortex; *b*, boundary between cortex and central cylinder; *c*, rootlet; *d*, one of the vasal bundles.

FIG. 4.—Diagram of Cross-section of Root (magnified about 7 diameters): *a*, root-hair; *b*, cortex; *c*, central radial bundle enclosed in the bundle-sheath.

has learned that after the first set of sprouts have been removed others spring from near the same place, so that the tedious operation may have to be repeated. The first set of sprouts are from axillary, the others from supernumerary, buds.

(2) *Leaf-scars.*—Just below this cluster of buds may be seen a transversely elongated scar with a minute scaly point at its middle. This point, rudimentary as it is, really represents a leaf. It is a leaf which has wholly lost its functions and is on the verge of disappearance altogether. This is a good illustration of a not uncommon fact in the organic world. There are few of the higher plants or animals that do not show in some portion of their structure a rudimentary organ wholly useless or perhaps even more or less injurious to its possessor, yet highly significant to the student as showing the relationships of the organism or indicating the course of its descent from pre-existing organisms. So in this case these leaf-scars show unmistakably that the organ which bears them is a stem, and not a root, and that this stem was probably modified or specialized from one of the ordinary forms, thus suiting it to new functions. What these functions are is evident from the study of the habits of the plant. The above-ground parts, and even the roots, perish in the autumn, but the tubers, each stored with abundant nutriment, persist and give rise to a multitude of new plants the succeeding year. The tubers are stems specially adapted to the propagation of the species.

(3) *Terminal Bud.*—But there are other resemblances between this and an ordinary stem which must not be passed by. It has a lower or basal end, and an upper or apical one. At the former will be found the scar of its attachment to the thin rhizome on which it was borne. At the opposite end will be noted a terminal bud, as in other stems. This bud does not differ essentially in structure from the axillary ones, save that it is not subtended by a scale, and is apt to be stronger than they, and therefore to be capable of a more vigorous growth. Partly because of this fact, and partly because the axillary buds are more numerous and stronger toward this than toward the basal end, this end of the potato is often called the "seed end."

The greater development and the crowded character of the buds toward the apex are other points of resemblance between this tuber and most ordinary stems.

(4) *Phyllotaxy.*—Here, again, stem-characters are clearly shown, but to study the phyllotaxy successfully it is necessary that a tuber should be selected which is not too distorted and irregular in its growth. Having made the proper selection, inspection will disclose the fact that the "eyes" appear in spirals, as shown on Plate VI. (Fig. 1), where, to render the fact still more evident, they are connected by dotted lines. This renders it certain that the arrangement is orderly and definite, though by the usual method it might be somewhat difficult to determine the precise phyllotaxy. This can, however, easily be ascertained by the aid of the spiral lines shown. Several sets of spirals might be traced, some running nearly horizontal, others nearly perpendicular, and some passing from right to left, others from left to right. For this purpose there must be selected two sets, one including those spirals nearest the perpendicular which pass from left to right, and the other including those nearest the perpendicular which pass from right to left. Counting the number of spirals in each direction, it will usually be found that there are three of one and five of the other. The smaller number, three, gives the numerator of the fraction expressing the phyllotaxy, and the sum of the two numbers, eight, gives the denominator. The phyllotaxy is therefore three-eighths. The same method is applicable to other short stems on which the leaves or scales are much crowded—as, for example, to the cones of the pines and firs.

II. INTERNAL STRUCTURE.—(1) *Arrangement of Tissues.*—Making a cross-section through the tuber in such a manner that it will pass through one of the axillary buds, the following facts will be observed:

First, a rather distinct circle of dots (as shown at *c*, Pl. VI. Fig. 2) a considerable distance within the margin of the section, except where the bud occurs; here, however, the circle approaches the margin and passes into the bud. Each one of these dots really represents the outer end of a wood wedge, each homologous with the ones observed in the Hickory twig, but here possessing but little lignified matter. Immediately outside this circle is the cambium zone.

Secondly, there will be observed, interior to this, scattered dots which are really fragments of the inner portions of the same bundles. These dots, it will be noted, do not occur all through the interior, but there is an area of greater or less size that is free from them—the pith (*f*, Pl. VI. Fig. 2), and from this outward may be traced many curved and more or less irregular branches which separate the bundles above referred to. These are the medullary rays. One of them is shown at *k* on Plate VI.

Thirdly, in the bark—that is, in the region outside the cambium zone above referred to, and about midway between it and the outside—will be found another circle of dots, fainter than the first, shown at *d* on Plate VI. These dots constitute the outer portion of the bast, and their outer limit marks that of the inner layer of the bark, or endophlœum. From this to the brownish exterior layer is the mesophlœum, and the exterior brownish, corky layer is the exophlœum.

It will thus be seen that in its essential features the internal structure of this stem agrees with that of other stems, and particularly with that of the Hickory and other dicotyl plants. It is, in fact, modified from the type only so much as is necessitated by its very succulent habit.

(2) *Tests.*—Applying the phloroglucin test, there will be found, as might be expected, very little lignified tissue. There are faint indications of it in the row of dots at *c*, and, if these could be examined with the compound microscope, it would be found that the cells which show this reaction are ducts—large tubes formed of coalesced cells found in wood.

The iodine test shows great abundance of starch. It is this substance which gives to the tuber its chief value and causes it to be so extensively employed for food. It is this also which nourishes the buds and enables them to develop into new plants when the tuber is planted. The starch-grains of the potato are unusually large, and can readily be seen with a magnifying-glass, appearing as glistening white particles.

If the test be applied with care, it will readily be seen that the starch is not quite equally distributed through the tuber. It is a little less abundant next the corky outside than it is farther interior. Here, in fact, albuminous matters are abundant, while starch is small in quantity. The reverse is the case with the interior cells. These facts are worthy of consideration in the preparation of the potato for food.

Applying the ferric-chloride test, it will be found that a faint green color is produced in the section, showing that tannic matters are present. This accounts for the tarnishing of a bright knife-blade when used for paring the tubers, the tannin acting upon the iron to produce tannate of iron.

Another fact worthy of note in connection with the potato tuber is that, when exposed for some time to strong light, it becomes green. This is due to the development of chlorophyll in the cells of the mesophlœum; but accompanying this change is the development of a poisonous principle which communicates an acrid taste to the tuber even when cooked. Cattle, in fact, have been poisoned by feeding upon potatoes which have turned green by exposure.

The above-ground green parts of the potato plant contain poisonous matter also, and it is worth remembering that the family to which the plant belongs—the Solanaceæ—contains many of the most dangerous of the vegetable poisons, as belladonna, stramonium, and hyoscyamus.

The student should now make a parallel study of one or more of the other tubers mentioned at the beginning of this exercise.

because it bears leaf-scales and axillary buds. Its surface is punctate with numerous depressed points, and is also distinctly furrowed longitudinally. The lower or rooting end is deeply depressed, and the terminal bud arises from a similar deep depression in its upper or apical end. Aside from these depressions, however, the corm is usually nearly twice as broad as high. The lower end gives rise to numerous nearly simple adventitious roots.

If now the corm be cut transversely into two nearly equal portions, two regions are clearly distinguishable: a central cylinder region, in which there are numerous scattered vasal bundles, and which is more or less angular in its outline, and a thick cortical region which exudes a copious yellow milk-juice and which is crossed by occasional bundles. Toward its periphery also it is dotted with cells containing red or other coloring-matter.

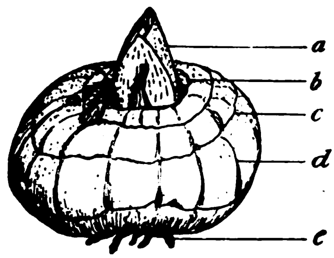
The few scattered bundles found in the cortex are those which pass out from the central cylinder to supply the leaves and buds. Aside from this unusual thickness of the cortex, the stem-structure is clearly like that of other monocotyls which have been studied.

(3) *Tests.*—Applying the phloroglucin test, there will be found, as in other succulent stems, but little lignified tissue, and that confined to the vasal bundles.

Applying the iodine test, abundance of starch will be found. The parenchyma cells, particularly those of the cortex, are, in fact, well filled with it.

The ferric-chloride test also reveals the presence of tannic matters, both in the outer cortex and in the vicinity of the cylinder-sheath, and also within the latter.

Let, now, one or more of the other corms mentioned at the beginning of this exercise be studied and described by the student.



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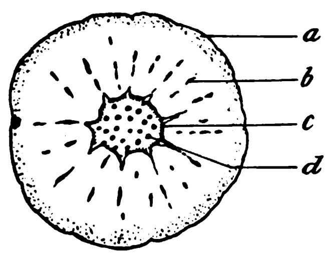

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PLATE VII., FIG. 1.—Corm of Gladiolus (about ⅔ natural size), deprived of its outer covering of scales: *a*, terminal bud; *b*, axillary bud; *c*, scar of one of the scales; *d*, one of the longitudinal furrows; *e*, adventitious root.

FIG. 2.—Transverse Section of same Corm: *a*, outer cortex dotted with cells containing coloring matter; *b*, one of the vasal bundles on its way through the cortex from the central cylinder to supply a scale; *c*, cylinder-sheath; *d*, one of the vasal bundles in the central cylinder.

occasionally at least, bear buds in their axils in the same manner as do ordinary leaves. Still further evidence, if any were needed, could be found by tracing the gradations between the outer or lower scales and the inner or upper ones. The latter develop into true leaves, while the former do not, and yet they grade insensibly one into the other.

(3) *Likeness of a Bulb to a Bud.*—A bud has been defined as a very short axis on which imperfectly-developed leaves are compactly arranged. If a longitudinal section through the lily-bulb be made, it will be seen how closely this definition applies to the bulb. Buds may, in fact, under certain conditions become bulbs. For example, the Tiger Lily of the gardens bears axillary buds which are precisely similar to ordinary axillary buds except that the scales in development become fleshy, and after a time the buds separate from the plant and fall to the ground. Each one of these, when planted in the soil, becomes a bulb essentially like the one being studied. Such fleshy buds, or *bulbils,* as they are technically called, are also produced by other plants, notably by different species of the genus Allium, and they are efficient means of propagating the species.

(4) *The Roots.*—The bulb-axis shows its resemblance to other stems not only in the fact that it bears leaves, but also in the fact that it bears roots. In this instance the roots are of the fibrous variety and numerous, and it may easily be seen that they arise laterally from the stem and are not downward continuations of it. In fact, they may often be found originating above some of the lower scale-scars. They are therefore adventitious roots.

(5) *Venation of Scales.*—Studying carefully the surface of the scales, and examining cross-sections of them, it will easily be determined that the venation is parallel, or the kind that usually occurs in monocotyl plants, the group to which the Lily belongs.

(6) Making a cross-section of the stem, there will also be observed the same scattered arrangement of the vasal bundles that belongs to the stems of monocotyls.

II. THE TUNICATED BULB OF AMARYLLIS FORMOSISSIMA.—This might at first be taken for a corm, to which it bears a greater external resemblance than it does to the Lily bulb. This mistake will be corrected, however, when a longitudinal section of the bulb is made and its structure is studied. It will now be found that, as in the Lily bulb, the great bulk is composed of fleshy scales, and these are also inserted on a short, inconspicuous axis.

(1) *Why called Tunicated.*—The most conspicuous difference is in the arrangement of the scales. Each is a leaf whose attachment to the stem extends all the way around, and each leaf in succession encloses and conceals from view all those interior to it or inserted higher up on the axis. They form thus a succession of coats, one within the other; hence a bulb of this kind is called a *coated* or *tunicated* bulb, to distinguish it from one like that of the Lily, which is termed *scaly*.

(2) *Kinds of Scales.*—Another difference is observed. The exterior dark-brown or blackish scales are dry or scarious, and serve purely a protective purpose, while the interior colorless ones are used, like those of the Lily, as storehouses for food.

In the Amaryllis also, even more easily than in the Lily, can be traced the relations between the scales and ordinary leaves. Many of the interior scales may, indeed, be traced directly upward into true leaves. They are, in fact, leaf-bases.

The scales are all distinctly parallel-veined, and the stem shows the characteristic structure of monocotyl stems.

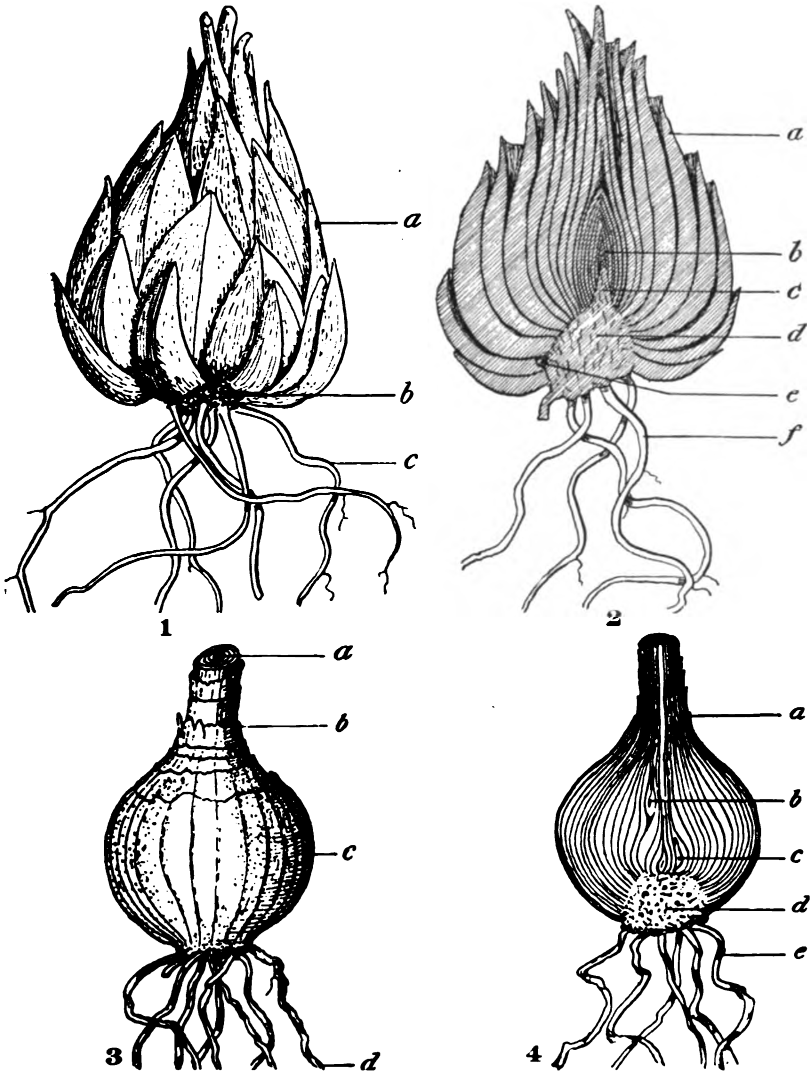


PLATE VIII., FIG. 1.—Drawing (½ natural size) of bulb of Lilium candidum: *a*, one of the bulb-scales; *b*, lower or exposed part of the stem or axis; *c*, an adventitious root.

FIG. 2.—Longitudinal Section of the Bulb of Lilium candidum (½ natural size): *a*, one of the succulent scales; *b*, one of the imperfectly developed true leaves; *c*, imperfectly formed stem, destined to rise above ground and to bear leaves and flowers; *d*, bulb-axis; *e*, axillary bud; *f*, adventitious root.

FIG. 3.—Bulb of Amaryllis formosissimum (⅔ natural size): *a*, section of leaves concentrically arranged; *b*, frayed upper margin of one of the scales; *c*, one of the exterior, dry scales; *d*, an adventitious root.

FIG. 4.—Longitudinal Section of the same: *a*, one of the outer, dry scales; *b*, section of one of the axillary buds; *c*, section of another axillary bud; *d*, the bulb-axis, showing numerous scattered fibro-bundles; *e*, an adventitious root.

FORM FOR STUDY OF STEMS.

I. KIND.
- 1. *Aërial.*
  - (1) Caulis.
  - (2) Caudex.
  - (3) Culm.
  - (4) Scape.
  - (5) Tendril.
  - (6) Runner.
  - (7) Sucker.
  - (8) Offset.
  - (9) Stolon.
  - (10) Thorn.
  - (11) Cladophyll.
- 2. *Subterranean.*
  - (1) Rhizome.
    - Slender.
    - Fleshy.
  - (2) Tuber.
  - (3) Corm.
  - (4) Bulb.
    - Scaly.
    - Tunicated.

II. SHAPE.
- 1. Terete.
- 2. Flattened.
- 3. Alate.
- 4. Triquetrous.
- 5. Quadrangular.
- 6. Pentangular.
- 7. Fluted.
- 8. Solid.
- 9. Hollow.
- 10. Irregular.
- 11. Jointed.

III. DIRECTION AND HABIT.
- 1. Erect.
- 2. Ascending.
- 3. Reclinate.
- 4. Decumbent.
- 5. Procumbent.
- 6. Repent.
- 7. Voluble.
- 8. Scandent.

IV. SURFACE.
- 1. Glabrous.
- 2. Glaucous.
- 3. Glandular.
- 4. Rugose.
- 5. Scabrous.
- 6. Verrucose.
- 7. Pubescent.
- 8. Puberulent.
- 9. Sericeous.
- 10. Lanuginous.
- 11. Tomentose.
- 12. Villose.
- 13. Pilose.
- 14. Floccose.
- 15. Hispid.
- 16. Strigose.
- 17. Spinose.
- 18. Echinate.
- 19. Aculeate.
- 20. Annulate.
- 21. Channelled.
- 22. Fissured.
  - Transversely.
  - Longitudinally.

V. TEXTURE.
- 1. Succulent.
- 2. Woody.

VI. DURATION.
- 1. Herbaceous.
  - Annual.
  - Biennial.
  - Perennial.
- 2. Suffruticose.
- 3. Fruticose.
- 4. Arborescent.
- 5. Arboreous.

VII. FRACTURE.
- 1. Short.
- 2. Brittle.
- 3. Splintery.
- 4. Fibrous.
- 5. Horny.
- 6. Corky.
- 7. Mealy.
- 8. Friable.

VIII. CLEAVAGE.
- 1. Regular.
- 2. Irregular.
- 3. Difficult.
- 4. Easy.

IX. COLOR.
- 1. Exterior.
- 2. Interior.

X. TASTE.
- 1. Insipid.
- 2. Bland.
- 3. Sweet.
- 4. Bitter.
- 5. Mucilaginous.
- 6. Pungent.
- 7. Acrid.
- 8. Warm.
- 9. Cooling.
- 10. Astringent.
- 11. Nauseous.
- 12. Burning.
- 13. Prickling.
- 14. Saline.
- 15. Alkaline.
- 16. Acidulous.

XI. ODOR.
- 1. Odorless.
- 2. Faint.
- 3. Agreeable.
- 4. Aromatic.
- 5. Fragrant.
- 6. Mint-like.
- 7. Balsamic.
- 8. Camphoraceous.
- 9. Terebinthinate.
- 10. Pungent.
- 11. Musky.
- 12. Disagreeable.
- 13. Irritating.
- 14. Nauseous.
- 15. Narcotic.
- 16. Fetid.
- 17. Putrid.

XII. INTERNAL STRUCTURE.
- 1. *Fern type.*
  - (1) Cortex.
    - *a.* Thickness compared with that of central cylinder.
    - *b.* Bundles in:
      - Numerous.
      - Few.
      - Lignified.
      - Unlignified.
    - *c.* Sclerenchyma-fibres.
  - (2) Central cylinder.
    - *a.* Bundles in:
      - Numerous.
      - Few.
      - All in one circle.
      - In more than one circle.
      - One circle with extra bundles in centre.
      - Lignified.
      - Unlignified.
  - (3) Masses of lignified tissues not a part of the bundles.
  - (4) Starch.
    - *a.* Most abundant in cortex.
    - *b.* Most abundant in central cylinder.
  - (5) Tannic matters.
    - *a.* Most abundant in cortex.

base of the petiole; in others they are partly attached to the petiole and partly to the stem; in others still they are partly or wholly adnate to the sides of the petiole, and not infrequently are so blended with it as to have lost their identity, forming a sheathing base to the petiole which partially or wholly clasps the stem; and, lastly, in a few plants the two stipules not only grow fast to the petiole by one edge, but adhere to each other by the other edge, forming a sheath or *ochrea* about the stem. They are also sometimes modified into thorns or tendrils or honey-glands, and in many plants are wanting altogether.

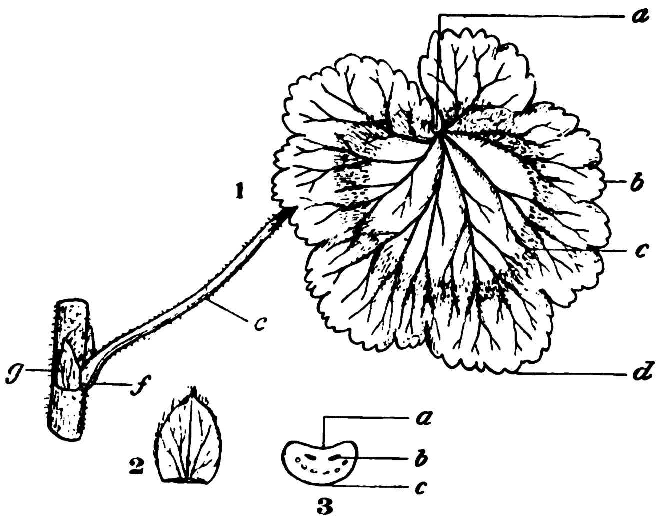


PLATE IX., FIG. 1.—Leaf of Pelargonium zonale (¾ natural size): *a*, cordate base; *b*, bicrenate margin; *c*, dark-colored zone on upper surface; *d*, obtuse apex of blade; *e*, petiole; *f*, pulvinus, or enlarged base of petiole; *g*, one of the stipules.

FIG. 2.—A Stipule separated (about natural size).

FIG. 3.—Somewhat magnified Cross-section of Petiole through Pulvinus: *a*, channelled upper surface; *b*, one of the vasal bundles; *c*, convex lower surface.

EXERCISE IX.

STUDY OF PREFOLIATION.

THE following plants afford variety and interest from this standpoint: the Beech (Fagus ferruginea, *Ait.*), the Tulip Tree (Liriodendron tulipifera, *L.*), the Azalea (Rhododendron arborescens, *Torr.*), the Cherry (Prunus avium, *L.*), the Clover (Trifolium pratense, *L.*), the Violet (Viola palmata, *L.*, var. cucullata, *Gray*), the Shield Fern (Aspidium acrostichoides, *Swartz.*), the Royal Fern (Osmunda regalis, *L.*), the Yellow Dock (Rumex crispus, *L.*), the Blue Flag (Iris versicolor, *L.*), the Water-Lily (Nuphar advena, *Ait.*).

The term "prefoliation" has reference to the arrangement of leaves in the bud; not to their phyllotaxy, which has already been explained, but to the coiling, folding, or overlapping of the leaves.

Prefoliation may be considered in two aspects: first, with reference to the *individual leaf*—how it is bent, folded, rolled, etc.; or with reference to the relative arrangement of the leaves composing a whorl or cycle—whether they overlap or not, and, if they do, what is the manner of the overlapping. The subject is best studied in early spring when the buds begin to unfold.

For the first study let the bud of the Beech be selected.

(1) *Prefoliation of Beech.*—The mature leaf is illustrated on Plate X. (Fig. 1), and the young leaf, just issued from the bud, but not yet fully unfolded, is shown on Plate X. (Fig. 2). In the latter the scarious and deciduous stipules are seen still attached to the base. They have served their purpose as bud-scales, and are now about to disappear. A careful inspection of this young leaf-blade shows that the two sides have each been thrown into numerous regular parallel folds, one for each rib of the leaf, and these folds have been pressed closely upward against the midrib—a mode of prefoliation which is appropriately called *plicate*. By this arrangement the young leaf is made to occupy a relatively small space in

the bud, and even this space is still further diminished by an inward curvature of the edges which renders the inner or ventral surface somewhat trough-shaped. The leaf is therefore also somewhat *involute*. Into this concavity fits closely the convex side of the next higher and somewhat smaller leaf in the cycle, and so on.

An examination of the arrangement discloses the fact that Nature has done a wonderfully skilful piece of packing in the construction of the bud. The study also enables one to account for the gracefully elongated form of the buds.

But Nature does not always accomplish her results by the same methods. There is an endless variety both in methods and results. A different but scarcely less interesting prefoliation is seen in the Clover.

(2) *Prefoliation of Clover.*—Figure 3 (Pl. X.) represents a branch of Trifolium pratense with two leaves fully developed, and another just emerging from the bud, and not yet unfolded. It will be observed that each leaf consists of a ternately compound blade, a long petiole, and a pair of adnate stipules. These last, as is true of most stipules, play an important part in the prefoliation.

Examining now the blade of the youngest of the three leaves in the figure, it will be perceived that each leaflet is folded lengthwise on its midrib in such a manner that the ventral surface is interior and that the three leaflets are pressed close together side by side. The arrangement will easily be understood by reference to Plate X. (Fig. 4), which shows the same leaf removed from the plant and having its leaflets slightly separated from each other.

Before their emergence from the bud their relative arrangement and folding were the same, but the blade was much smaller and wholly enclosed by the two stipules of the leaf immediately below. In fact, on Plate X. (Fig. 4) the stipules (*a*) are wrapped about and conceal a still younger leaf, which is folded as already described, but whose edges face in the opposite direction. This is called the *conduplicate* mode of prefoliation, and, although quite different from the last, serves the purpose of compactness equally well. A third and quite different mode still is that illustrated in the Yellow Dock.

(3) *Prefoliation of Yellow Dock.*—Figure 5 (Pl. X.) also shows a branch with two nearly mature leaves and one, younger, not yet

unfolded. The leaves here consist of a long lanceolate blade having a toothed and crispate margin, a strongly-developed petiole which is flat on its upper surface and convex below, and stipules which have coalesced to form a membranous ochrea which continues to enclose the younger leaves even until the latter have attained a length of an inch or more, when the ochrea ruptures and scales off. Each of these young leaves is rolled from its two margins in such a manner that the dorsal or lower surface is interior. This mode of prefoliation is called the *revolute*.

Figure 6 (Pl. X.) represents two of the young leaves as they appear in transverse section, slightly separated from each other and partly unrolled. As a matter of fact, in the bud the leaves are very closely rolled, and the flattened upper surface of the rolled leaf lies close against the flat upper side of the petiole of the next older leaf.

The student by studying the other plants mentioned at the beginning of this exercise will get a good idea of all the principal modes of prefoliation, though there are endless variations in detail in different plants.

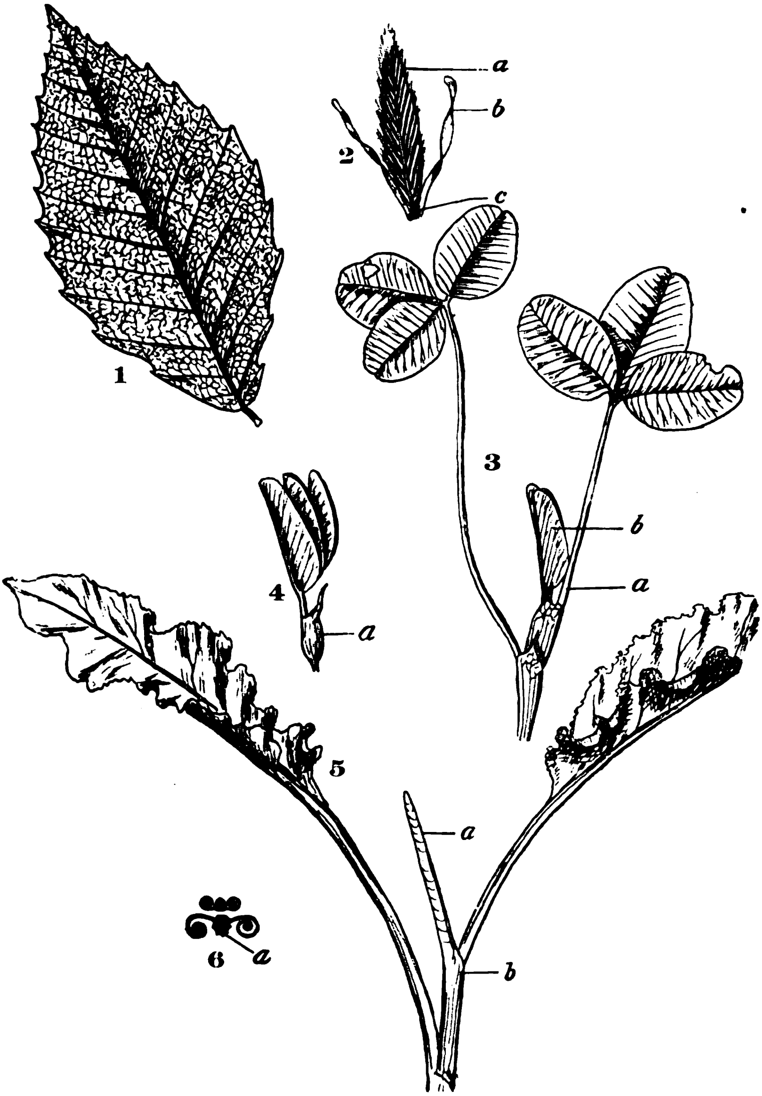


PLATE X., FIG. 1.—Leaf of Fagus ferruginea (1/3 natural size).
FIG. 2.—Young Leaf (about 2/3 natural size), showing, *a*, plicate blade; *b*, one of the thin, scarious stipules; *c*, the petiole.
FIG. 3.—Branch of Trifolium pratense (1/2 natural size), showing two leaves nearly mature, and a young and still folded leaf, *b*, just emerged from between the stipules of the leaf *a*.
FIG. 4.—The Young Leaf in Figure 3 removed, and its leaflets somewhat separated from each other, showing the conduplicate prefoliation. The adnate stipules overlap at their edges, *a*, and enclose a still younger leaf, similarly folded, but much smaller.
FIG. 5.—Branch of Rumex crispus, showing two nearly mature leaves, and a still folded younger one that has partly emerged from its stipular enclosure: *a*, young leaf; *b*, stipular sheath or ochrea of next older leaf.
FIG. 6.—Cross-sections of two very young Leaves of Rumex, somewhat unrolled and separated to show the mode of vernation (magnified about 2 diameters): *a*, dorsal surface of midrib of the older of the two leaves.

EXERCISE X.

TYPES OF LEAF-VENATION.

A SELECTION for study may be made from—(*a*) The leaves of almost any species of Jungermannia, or Moss; as, for example, Jungermannia Schraderi, *Martius;* J. barbata, *Schreb.;* Jubula Hutchinsiæ, *Dumort.;* Funaria hygrometrica, *Sibth.*; Bryum roseum, *Schreb.;* Minium serratum, *Laich.* (*b*) Leaves of the following ferns and gymnosperms: the Common Polypody (Polypodium vulgare, *L.*), the Maidenhair Fern (Adiantum pedatum, *L.*), the Venus-hair Fern (Adiantum capillus-veneris, *L.*), the Shield Fern (Aspidium acrostichoides, *Swartz.*), the Royal Fern (Osmunda regalis, *L.*), and the Ginkho Tree (Salisburia adiantifolia, *Sm.*). (*c*) Leaves of the following monocotyls: the Wandering Jew (Callisia repens, *Willd.*), the Lily of the Valley (Convallaria majalis, *L.*), the Clintonia (Clintonia borealis, *Raf.*), the Bell-wort (Uvularia grandiflora, *Smith*), Solomon's Seal (Polygonatum giganteum, *Dietrich*), the Egyptian Calla (Richardia africana, *Kunth.*), and the Palmetto (Sabal Palmetto, *R. and S.*). (*d*) Leaves of the following dicotyls: the Common Deutzia (Deutzia scabra, *L.*), the Beech (Fagus ferruginea, *Ait.*), the Chestnut (Castanea sativa, *Mill.*, var. Americana), the English Ivy (Hedera helix, *L.*), the Sugar Maple (Acer saccharinum, *Wang.*), the Common Mallow (Malva rotundifolia, *L.*), the Wild Yam (Dioscorea villosa, *L.*), the Common Plantain (Plantago major, *L.*), and the Begonia (Begonia nitida, *Willd.*).

(1) *A Moss Leaf.*—Selecting a leaf from one of the plants mentioned in list *a*, and examining it under a magnifying-glass, it will be found exceedingly simple in structure as compared with that of the Geranium. In no moss or liverwort is to be found any differentiation of the leaf into petiole, blade, and stipules. There may be traced with a magnifying-glass, or in some species even with the naked eye, a very delicate network pervading the leaf, and this at first might be mistaken for the venation; but it

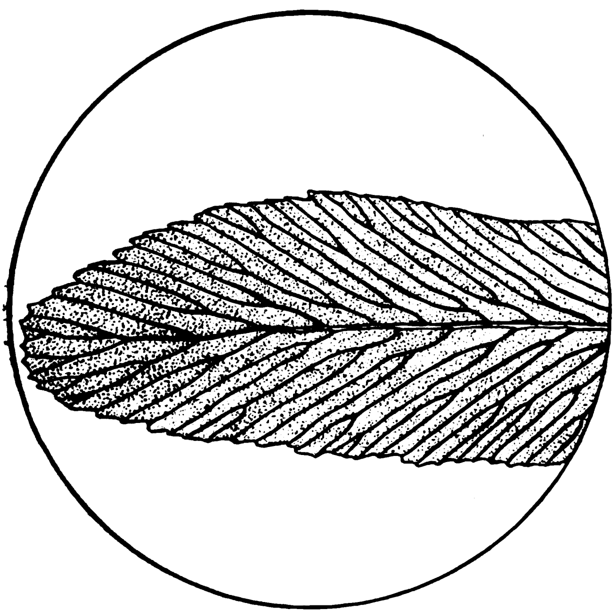
a support and as a means of distributing nutriment to the mesophyll cells, and it is found, as would naturally be expected, the prevalent mode of venation in the highest group of plants, the dicotyls.

(*a*) The *pinni-reticulate*, or pinnately-netted, venation is the particular variety represented in the leaf of Deutzia. It has a main rib or *midrib* running from base to apex, from which issue laterally the *ribs;* these in turn send off *veins*, and these branch into *veinlets*. It is the possession of a midrib which specially distinguishes this variety from the others of the type.

(*b*) *The Palmi-reticulate Leaf.*—This is well illustrated in the Common Ivy (Hedera helix, Pl. XII.), and is distinguished from the preceding by the fact that there are several large veins springing from the top of the petiole and diverging to the margin. These branch repeatedly to form a network similar to that already described. Since the main veins are arranged in a radiating manner, this variety is also called the *radiately-reticulate* leaf.

(*c*) *The Costate-reticulate or Rib-netted Leaf.*—This variety is rarer than the other forms, but is occasionally met with. The Cinnamon and Wild Yam afford illustrations. The peculiarity of this form of venation consists in the fact that two or more large veins spring from the top of the petiole, and, after diverging somewhat, come together again at the apex of the blade, the spaces between being filled with a network similar to that in other reticulate forms.

The reticulate type is pre-eminently that found among dicotyls. Only in very rare instances are the foliage leaves of the members of this group nerved or parallel veined. Netted veined leaves, however, differ from each other very considerably in the closeness of the network. In many cases the meshes are very intricate and fine; in others the network is much less complex and relatively coarse, showing even a close approach to the nerved or parallel forms, and so in leaf-structure the two great groups sometimes overlap.



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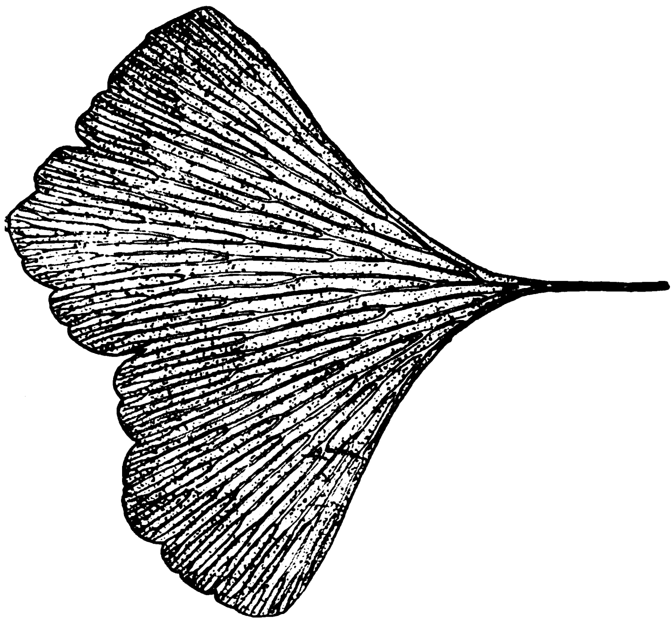

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PLATE XI., FIG. 1.—Part of Leaflet of Osmunda regalis, showing pinni-furcate venation (magnified about 4 diameters).

FIG. 2.—Leaf of Salisburia adiantifolia, showing palmi-furcate venation (⅔ natural size).

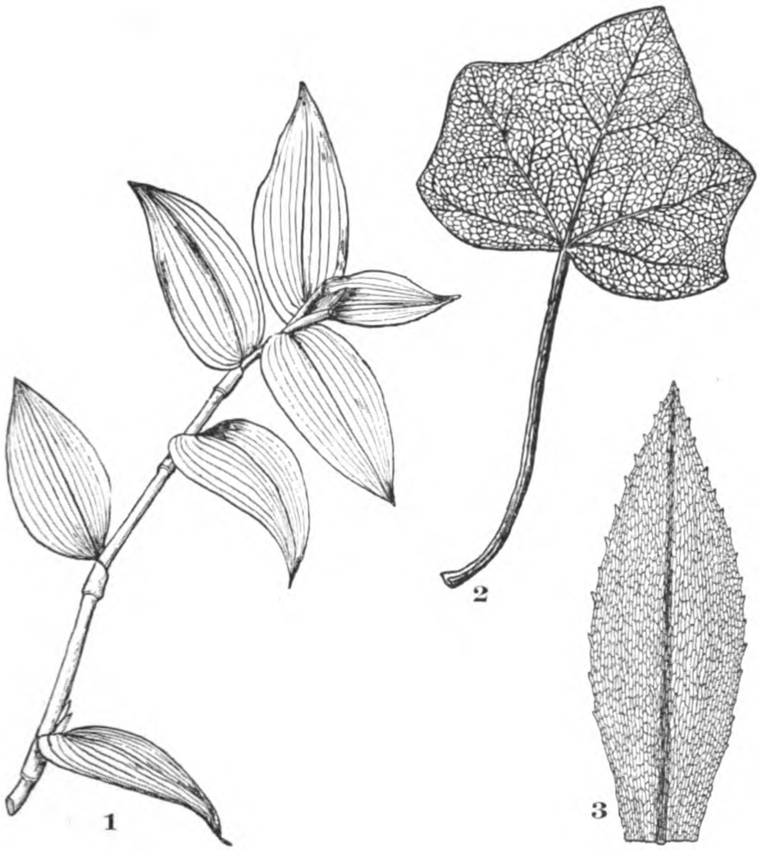

PLATE XII., FIG. 1.—Branch of Callisia repens, showing sheathing, two-ranked leaves which are basi-nerved in their venation (2/3 natural size).

FIG. 2.—Leaf of Hedera helix, showing palmi-reticulate venation (2/3 natural size).

FIG. 3.—Leaf of Moss (magnified about 15 diameters), showing that, with the exception of the midrib, it is composed of a one-layered sheet of similar cells.

EXERCISE XI.

THE BRANCHING OF LEAVES.

THE leaves of the following plants may be studied and compared: the Basswood (Tilia Americana, *L.*), the Dandelion (Taraxacum officinale, *Weber*), the White Oak (Quercus alba, *L.*), the Shepherd's Purse (Capsella bursa-pastoris, *Moench*), the Celandine (Chelidonium majus, *L.*), the Rue (Ruta graveolens, *L.*), the Smooth Rose (Rosa blanda, *Ait.*), the Silver Weed (Potentilla anserina, *L.*), the Trumpet Creeper (Tecoma radicans, *Juss.*), Common Polypody (Polypodium vulgare, *L.*), the American Mountain Ash (Pyrus Americana, *DC.*), the Agrimony (Agrimonia parviflora, *Ait.*), the Silver Maple (Acer dasycarpum, *Ehrh.*), the Cranesbill (Geranium maculatum, *L.*), the Castor Bean (Ricinus communis, *L.*), the Summer Grape (Vitis æstivalis, *Michx.*), the Strawberry (Fragaria Virginiana, *Mill.*), the Cinquefoil (Potentilla Canadensis, *L.*), and the Meadow Rue (Thalictrum dioicum, *L.*).

In comparing different leaves it will be found that some have blades composed of a single piece, and that this is entire or plain-margined; in others the blade is more or less wavy, scalloped, or toothed in various ways; in still others the indentation becomes so deep as evidently to forecast those forms in which the blade is separated into several distinct pieces, as in the Clover leaf already studied, the more deeply indented forms being variously described, according to the character or depth of the indentations, as incised, cleft, parted, or divided; and, lastly, there are the truly compound forms, where, as in the Locust and Rose, the blade is separated into two or more distinct pieces.

Between the blade that is barely toothed on its margin and the one that is compound there is every possible gradation. Even on the same plant there may sometimes be found leaves that are entire or nearly so, and others that are very much divided or even compound. In the Cruciferæ or Cress family numerous examples it is still regarded as simple and is called a *divided* leaf. But if the leaflets are distinctly stalked, or if, whether stalked or sessile, they are connected with the rachis by a joint, or even if, possessing neither stalk nor joint, they are so strongly contracted at the base as to separate the leaf-pulp from the rachis, the leaf is regarded as compound.

In the compound leaf the part corresponding to the midrib of the simple leaf, if present, is called the *rachis;* the stalks of the leaflets which join them to the rachis are called the *petiolules;* and one of the leaflets is called a *foliole* or foliolum.

In the leaf of the Trumpet Creeper, shown on Plate XIV. (Fig. 2), *a* is the petiole, *b* is the rachis, *c* is the petiolule of the terminal foliole. The leaf is *pinnately compound,* since its leaflets are arranged along a lengthened rachis; but, this leaf having an odd terminal leaflet, it is important to distinguish it from a pinnate leaf having an even number of leaflets, so it is called an *imparipinnate* leaf. The leaflets may be described as would be the blades of a simple leaf. In this instance they are ovate in general outline, obtuse at the base, acute or acuminate at the apex, and coarsely serrate on the margin. The venation is pinni-reticulate, the texture membranous and herbaceous, and the surface glabrous.

It should be observed that the leaves of this species commonly possess either nine or eleven leaflets.

(3) *The Leaf of the Silver Maple.*—Here, as in the Dandelion, may be found the simple leaf tending to a compound form, but, the venation being palmate instead of pinnate, and there being five main veins radiating from the top of the petiole, the blade is parted into five radiating main divisions or lobes. Since the principal incisions extend from an imaginary general outline rather more than halfway to the top of the petiole, the blade may be described as *palmately five-cleft.* To this description of the margin, however, to render it complete, must be added the statement that the segments are *incised* and *serrately toothed.* The leaf is also petiolate, exstipulate, cordate, membranous and herbaceous, glabrous on the ventral surface, and both pubescent and glaucous on the dorsal surface. The leaf is shown, one-half natural size, on Plate XIV. (Fig. 3).

(4) *The Leaf of the Lupine.*—This leaf is complete, having lamina, petiole, and stipules. The stipules are adnate at the base

and free above. They are linear and entire. The petiole is elongated and somewhat channelled on the upper surface toward its base, and from its apex radiate the numerous leaflets, which vary in number from seven to eleven or more. These are sessile, jointed to the petiole, pinnately reticulate, oblanceolate in outline, mucronate at the apex, entire-margined, membranous-herbaceous in texture, and pubescent above and below—as, in fact, are also the other parts of the leaf.

Such a leaf as that illustrated on Plate XIV. (Fig. 4) might be briefly described as a *palmately octo-foliolate leaf*, or, still more briefly, as an *octonate* leaf.

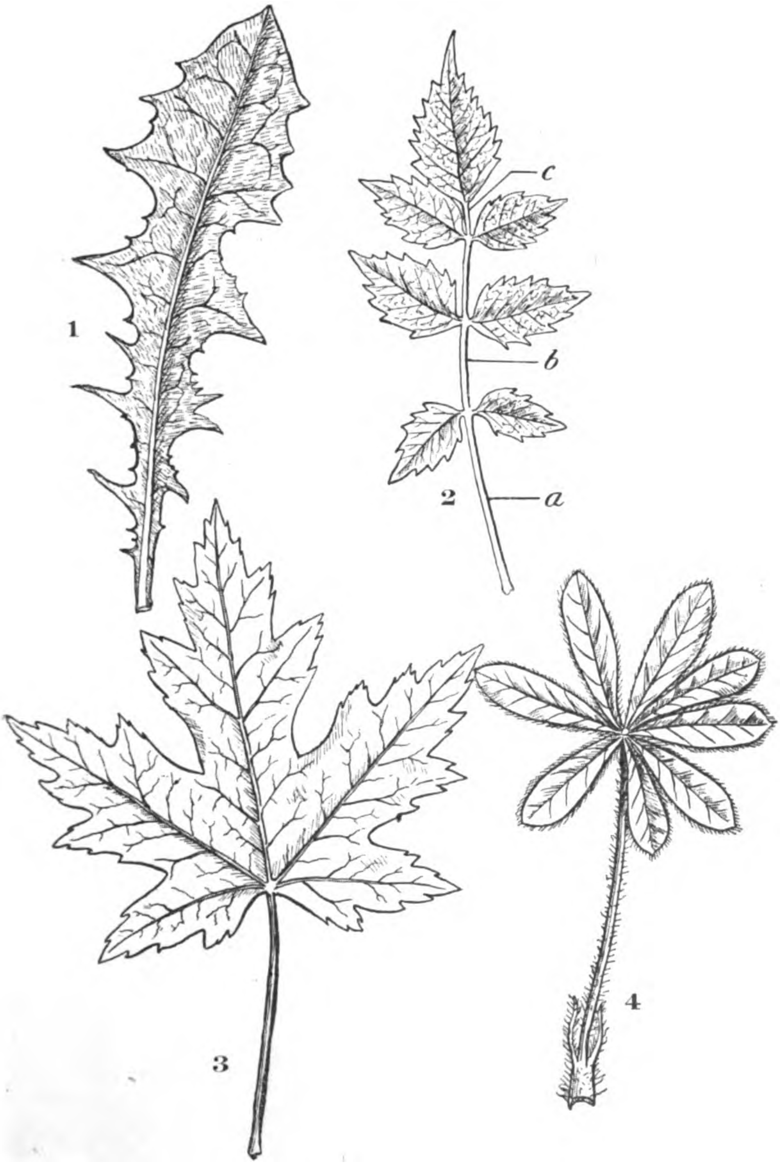

PLATE XIV., FIG. 1.—The Runcinate Leaf of the Common Dandelion.

FIG. 2.—The Impari-pinnate Leaf of the Trumpet Creeper: *a*, petiole of leaf; *b*, rachis; *c*, petiolule of terminal leaflet.

FIG. 3.—Palmately-cleft Leaf of the Silver Maple.

FIG. 4.—The Octonate Leaf of the Common Lupine. (All of the figures ½ natural size.)

ple flowers, which are remarkable for the large, shield-shaped, five-pointed, persistent stigmas.

Each leaf consists of an upper part (Pl. XV. Fig. 1, *a*), called the *lip;* a hollow portion (*b*) which is usually filled, or partly so, with water, and which may be called the ***bowl;*** a flattened expansion (*c*) on the ventral surface, called the *wing;* and a short ***stalk*** (*d*). The venation, it will be observed, is costate-reticulate; the exterior of the pitcher is smooth, more or less purple-blotched, and slightly glandular along the wing. The interior is partly hairy and partly very smooth, and the water may usually be observed to contain the remains of numerous insects in various stages of decomposition.

It is not easy to trace the structural relations between this and an ordinary leaf, but there are reasons, derived from analogy and from the study of the very young leaves, for believing that the lip represents the lamina, and the rest, including the wing, bowl, and stalk, represents the petiole. The petiole is thus analogous to the vertically flattened ones, called phyllodia, of the Australian acacias, differing from them chiefly in the fact that a part of it has become hollow. In the very young leaf, however, the hollow does not exist, and the analogy is then closer still.

The stipules are not present, unless the lateral widening at the base of the petiole may be regarded as due to stipules which have become adnate.

The water found in the bowl may partly be caught from rains; but it cannot be wholly so, for it is present, though in diminished quantity, even in dry weather and in pitchers which have not yet opened. Moreover, in some other Sarracenias, and in Darlingtonia, a California relation of the genus, the orifice is protected from the entrance of rain, and yet water in considerable quantity is usually present in the bowl. The water is therefore partly a secretion of the plant. Besides the fact that in this water, when the leaf is mature, are usually to be found in great numbers insects drowned and in various stages of putrefaction, there is much other evidence to show that the leaf is adapted to the function of insect-trapping, the plant making use of the captured creatures for food. This is shown not only by the structure, but by direct observation of the process of capture, which may readily be seen where the plants are abundant.

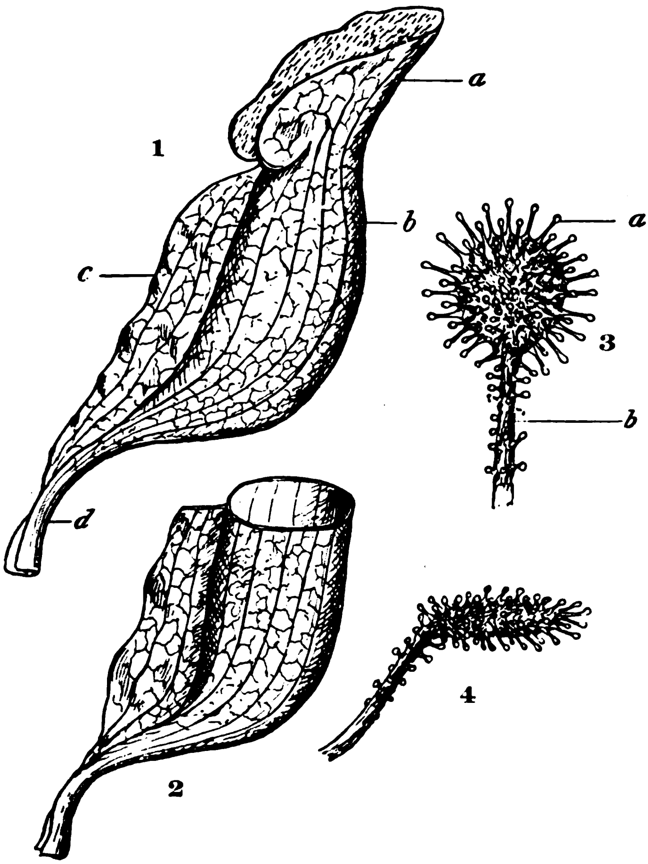

PLATE XV., FIG. 1.—Leaf of Sarracenia purpurea (⅔ natural size): *a*, lip; *b*, bowl; *c*, wing; *d*, stalk, or lower part of petiole.

FIG. 2.—The same Leaf cut through transversely, showing interior cavity.

FIG. 3.—Leaf of Drosera rotundifolia (natural size): *a*, one of the tentacles; *b*, petiole. The figure shows the upper surface, the lower surface not being provided with tentacles.

FIG. 4.—Edge view of Leaf of Drosera.

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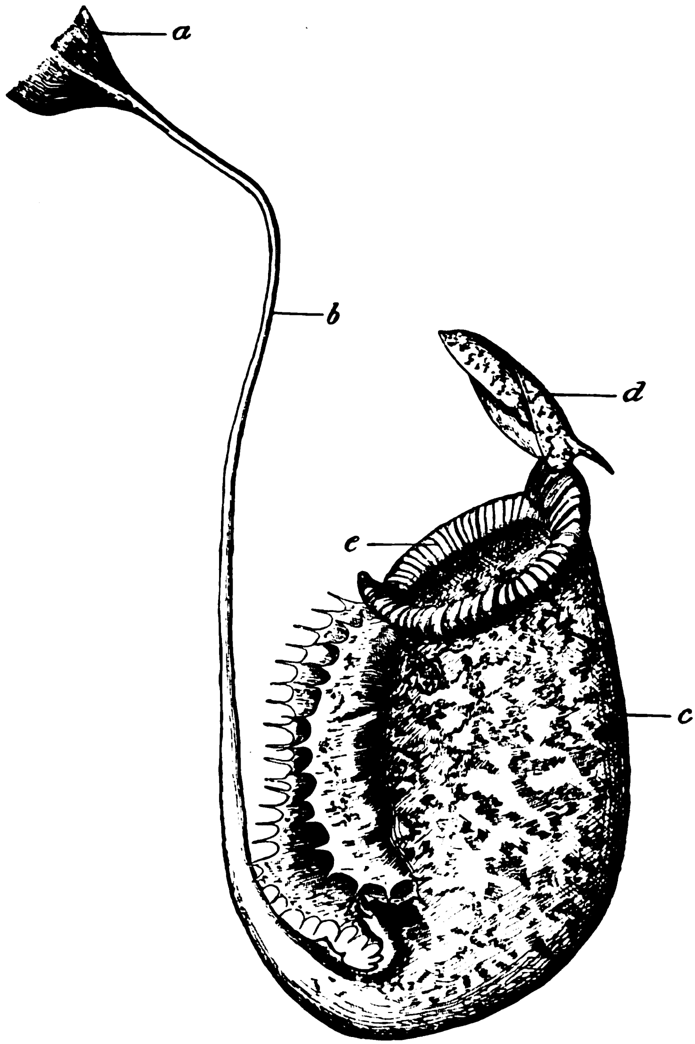


PLATE XVI.—Pitcher-like Insect-trap of one of the East Indian Pitcher-plants, Nepenthes Chelsoni (½ natural size). The lower part, a small portion of which is seen at *a*, is flat, like an ordinary leaf-blade, and serves the same purpose. The middle portion is developed into a tendril, *b*, which serves the purpose of climbing, and at the end of this tendril is developed the pitcher, *c*, which serves as an insect-trap. This is surmounted by a lid, *d*, which serves to keep out much useless extraneous matter and any excess of water from rains, while permitting the access of insects. The latter are attracted by sweet secretions on the lid and about the mouth of the pitcher on the inside. At the throat is a strong fold, *e*, bordered with downwardly-pointing spines to prevent the escape of the prey. The inner surface is provided with numerous glands which secrete the fluid that serves at once to drown the insects and to digest their bodies.

FORM FOR THE STUDY OF LEAVES.

I. **Kind.**
1. Foliage leaf.
2. Ascidium.
3. Insect-trap.
4. Spine.
5. Tendril.
6. Scale.
7. Phyllodium.

II. **Prefoliation.**
1. Reclinate.
2. Conduplicate.
3. Convolute.
4. Circinate.
5. Involute.
6. Revolute.
7. Equitant.
8. Obvolute.
9. Triquetrous.

III. **Phyllotaxy.**
1. *Whorled.*
   a. Opposite.
   b. Decussate.
   c. In threes.
   d. In fours.
   e. In fives.
   f. Leaves numerous in each whorl.
2. *Alternate.*
   a. Distichous, or two-ranked.
   b. Tristichous, or three-ranked.
   c. Pentastichous, or five-ranked.
   d. Octastichous, or eight-ranked.
   e. Triskaidekastichous, or thirteen-ranked.
   f. Twenty-one ranked.

IV. **Duration.**
1. Persistent.
2. Deciduous.
3. Fugacious.

V. **Position.**
1. Cauline.
2. Rameal.
3. Radical.

VI. **Parts Present.**
1. Lamina.
2. Petiole.
3. Stipules.

VII. **Lamina.**
1. *Simple.*
   (1) Terete.
   (2) Awl-shaped.
   (3) Filiform.
   (4) Flattened.
   a. General outline.
      Orbicular.
      Linear.
      Oblong.
      Elliptical.
      Ovate.
      Obovate.
      Lanceolate.
      Oblanceolate.
      Hastate.
      Auriculate.
      Sagittate.
      Cordate.
      Obcordate.
      Panduriform.
      Flabelliform.
      Peltate.
      Reniform.
      Length.
   b. Base.
      Acute or cuneate.
      Acuminate.
      Obtuse or rounded.
      Truncate.
      Retuse.
      Cordate.
      Reniform.
      Auriculate.
      Hastate.
      Sagittate.
      Oblique.
   c. Apex.
      Acute.
      Acuminate.
      Obtuse.
      Retuse.
      Emarginate.
      Obcordate.
      Mucronate.
      Cuspidate.
      Aristate.
   d. Margin (indentations shallow or none).
      Entire.
      Serrate.
      Serrulate.
      Biserrate.
      Dentate.
      Denticulate.
      Bidentate.
      Crenate.
      Crenulate.
      Bicrenate.
      Repand.
      Undulate.
      Sinuate.
      Spinose.
      Crispate.
   e. Margin (indentations deep).
      a. Palmate forms.
         Incised.
         Lobate:
            Bilobate.
            Trilobate.
            Quadrilobate.
            Quinquelobate.
            Sexilobate.
            Septilobate.
         Cleft:
            Bifid.
            Trifid.
            Quadrifid.
            Quinquefid.
            Sexifid.
            Septifid.
            Multifid.
         Parted:
            Bipartite.
            Tripartite.
            Quadripartite.
            Quinquepartite.
            Sexipartite.
            Septipartite.
            Multipartite.
            Pedate.
         Divided:
            Bisect.
            Trisect.
            Quadrisect.
            Quinquesect.
            Sexisect.
            Septisect.
            Multisect.
      b. Pinnate forms.
         Incised.
         Runcinate.
         Lobate:
            Trilobate.
            Quadrilobate.
            Quinquelobate.
            Sexilobate.
            Septilobate.
            Multilobate.
            Lyrately-lobed.
         Cleft:
            Trifid.
            Quadrifid.
            Quinquefid.
            Sexifid.
            Septifid.
            Multifid.
            Lyrately-cleft.
         Parted:
            Tripartite.
            Quadripartite.
            Quinquepartite.
            Sexipartite.
            Septipartite.
            Multipartite.
            Lyrately-parted.
            Pectinate.
         Divided:
            Trisect.
            Quadrisect.
            Quinquesect.
            Sexisect.
            Septisect.
            Multisect.
            Lyrately-divided.
            Bi-pinnatisect.
            Pinnately-dissected.

2. *Compound.*
   (1) Palmate forms.
   a. Binate or bifoliolate.
   b. Ternate.
   c. Biternate.
   d. Triternate.
   e. Quadriternate.
   f. Ternately-decompound.
   g. Quadrate.
   h. Quinate.
   i. Sextate.
   j. Septinate.
   k. Octate.
   l. Palmately multifoliolate.
   (2) Pinnate forms.
   a. Paripinnate (number of leaflets).
   b. Imparipinnate (number of leaflets).
   c. Cirrhosely-pinnate (number of leaflets).
   d. Interruptedly-pinnate (number of leaflets).
   e. Lyrate (number of leaflets).
   f. Bipinnate.
   g. Tripinnate.
   h. Quadripinnate.
   i. Pinnately-decompound.

FORM FOR THE STUDY OF LEAVES (CONTINUED).

(3) Shape of leaflet.
- a. General outline.
  - Filiform.
  - Orbicular.
  - Linear.
  - Oblong.
  - Elliptical.
  - Ovate.
  - Obovate.
  - Lanceolate.
  - Cordate.
  - Obcordate.
  - Length.
- b. Base.
  - Acute or cuneate.
  - Obtuse or rounded.
  - Cordate.
  - Oblique.
- c. Apex.
  - Acute.
  - Acuminate.
  - Obtuse.
  - Retuse.
  - Obcordate.
  - Mucronate.
  - Cuspidate.
  - Aristate.
- d. Margin.
  - Entire.
  - Serrate.
  - Serrulate.
  - Biserrate.
  - Dentate.
  - Denticulate.
  - Bidentate.
  - Crenate.
  - Crenulate.
  - Bicrenate.
  - Repand.
  - Undulate.
  - Sinuate.
  - Spinose.
  - Crispate.
  - Incised.
  - Lobate.
  - Cleft.
  - Parted.
  - Divided.

3. *Venation.*
- (1) Furcate.
  - a. Palmi-furcate.
  - b. Pinni-furcate.
- (2) Nerved.
  - a. Basi-nerved.
  - b. Palmi-nerved.
  - c. Pinni-nerved.
- (3) Reticulate.
  - a. Palmi-reticulate.
  - b. Pinni-reticulate.
  - c. Costate-reticulate.

4. *Texture.*
- (1) Herbaceous.
- (2) Scarious.
- (3) Membranous.
- (4) Succulent.
- (5) Coriaceous.

5. *Surface.*
- (1) Glabrous.
- (2) Glaucous.
- (3) Punctate.
- (4) Glandular.
- (5) Rugose.
- (6) Scabrous.
- (7) Verrucose.
- (8) Pubescent.
- (9) Puberulent.
- (10) Sericeous.
- (11) Lanuginous.
- (12) Tomentose.
- (13) Villose.
- (14) Pilose.
- (15) Floccose.
- (16) Hispid.
- (17) Strigose.
- (18) Spinose.
- (19) Echinate.
- (20) Aculeate.

6. *Insertion.*
- (1) Sessile.
- (2) Clasping.
- (3) Sheathing.
- (4) Perfoliate.
- (5) Connate.
- (6) Decurrent.

VIII. PETIOLE.

1. Length as compared with lamina.
2. Flattened on ventral surface.
3. Channelled on ventral side.
4. Flattened vertically.
5. Wing-margined.
6. Phyllodium.

IX. STIPULES.

1. Foliaceous.
2. Scarious.
3. Caducous.
4. Adnate.
5. Half-sagittate.
6. Ochreate.
7. Forming spines.
8. Forming tendrils.
9. Forming glands.

X. TASTE.

1. Insipid
2. Bland.
3. Sweet.
4. Bitter.
5. Mucilaginous.
6. Pungent.
7. Acrid.
8. Warm.
9. Burning.
10. Cooling.
11. Astringent.
12. Nauseous.
13. Prickling.
14. Saline.
15. Alkaline.
16. Acidulous.

XI. ODOR.

1. Odorless.
2. Faint.
3. Agreeable.
4. Aromatic.
5. Mint-like.
6. Balsamic.
7. Camphoraceous.
8. Terebinthinous.
9. Pungent.
10. Musky.
11. Disagreeable.
12. Irritating.
13. Nauseous.
14. Narcotic.
15. Putrid.
16. Fetid.

EXERCISE XIII.

A TYPICAL FLOWER OF A DICOTYL.

In beginning the study of flowers it is well to have in mind a type or pattern flower with which all others may be compared. This is not merely a great convenience, but it is probable that all or nearly all of the flowers of the two higher groups of flowering plants, the monocotyls and the dicotyls, no matter how irregular, defective, or unsymmetrical they may now be, have been modified from one or a few simple structural types. The study and comparison of a large number of flowers have enabled botanists to determine with a good deal of certainty what these types are for monocotyls and dicotyls respectively.

Most existing flowers have in the course of time been considerably, sometimes profoundly, modified from the type, and these modifications exist in great variety among different species; but there are still a few which conform rather closely to the original plan. From some of these the selections for study will be made.

The plan will be, first, to take up a nearly typical flower from the dicotyls, and after its structure has been comprehended to study some others that show more or less considerable deviations from the type; then, finally, to proceed in a similar manner to the study of monocotyls.

The following dicotyls produce flowers that approach quite closely to the typical form: the Mossy Stonecrop (Sedum acre, *L.*), the Purple Stonecrop (Sedum pulchellum, *Michx.*), the Live-for-ever (Sedum Telephium, *L.*), the Common Flax (Linum usitatissimum, *L.*), the Perennial Flax (Linum perenne, *L.*), the Wild Cranesbill (Geranium maculatum, *L.*), the Common Wood-sorrel (Oxalis Acetosella, *L.*), the Yellow Wood-sorrel (Oxalis corniculata, *L.*).

The flower of the Common Flax shall serve the present purpose.

The plant is a rather slender, erect, somewhat branching, and ground plan on Plate XVII. (Fig. 4). Another noteworthy fact is the resemblance between the pieces of each whorl. These pieces are alike in size, shape, and coloring—a fact expressed by saying that they are *regular*.

Inferences can now easily be drawn as to the type or model on which the flower was originally constructed: (1) It was five-whorled; (2) It was symmetrical; that is to say, the whorls alternated with each other; (3) It was regular; (4) It was constructed on the numerical plan of five; (5) Its parts were all distinct or ununited and separately inserted on the receptacle.

To this plan or type the flower conforms in most respects, but deviates slightly, as has been seen, in some: in the partial disappearance of one whorl of stamens; in the growing together of the basal parts of the filaments; and in the partial union of the carpels of the gynœcium.

(2) *Deviations from the Type.*—Comparing the flowers of different dicotyls with the type, various kinds of deviations from it are found.

(*a*) *The numerical plan is often different.* By far the commonest number among dicotyls is the number five; but not infrequently the number four is met with, as in the Cruciferæ, the Oleaceæ, and many of the Rubiaceæ; sometimes the number two, as in the Papaveraceæ and the Fumariaceæ; and sometimes the number six, as in some of the Berberidaceæ.

In some instances there is such an excessive multiplication of parts, or, on the other hand, such an extreme reduction of them, that the original numerical plan is obscured. Instances of the former occur in the Water Lilies and Cactaceæ, and of the latter in the Willows.

It is probable that in some instances of deviation from the number five the deviation has come about by a reduction of the number of parts. For example, in the genus Sedum tetramerous flowers are often found in the same cluster with pentamerous ones, and there can be little doubt that the tetramerism has been brought about as a gradual modification from the pentamerous type.

It would be unsafe to conclude, however, that all flowers of dicotyls were originally constructed on the plan of five.

(*b*) *The whorls are often diminished in number.* The most commonly omitted whorl, perhaps, is the outer or inner whorl of the petals. Doubtless most deviations of the kind may be explained in this way, but sometimes they are due to the consolidation of two whorls into one, as is probably the case in some members of the Barberry family.

As a practical point of much importance to the beginner, it is to be noted that flowers constructed on the numerical plan of three are much the commonest among monocotyls and seldom occur among dicotyls.

The student should now study and make drawings of one of the other flowers mentioned at the beginning of this exercise.

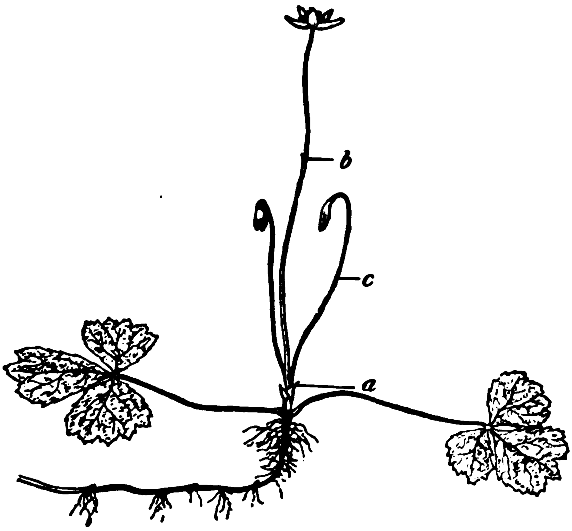
EXERCISE XIV.

STUDY OF THE FLOWER OF A RANUNCULACEOUS PLANT.

SELECTIONS may be made from any of the following: Goldthread (Coptis trifolia, *Salisb.*), any one of the Buttercups (as, for example, the Common Ranunculus septentrionalis, *Poir.*), the Marsh Marigold (Caltha palustris, *L.*), the Columbine (Aquilegia Canadensis, *L.*), the Larkspur (Delphinium consolida, *L.*), or the Monkshood (Aconitum Napellus, *L.*). The last two are cultivated in gardens, while the rest are all common native plants.

A selection is made of the Goldthread, a beautiful little plant exceedingly common in the bogs of our northern forests, where it grows among the moss. It is called Goldthread because its long, slender, creeping rhizomes, not more than a millimetre in diameter, are golden yellow in color. At intervals of about an inch these rhizomes bear minute scales occurring alternately, and from near these issue numerous very delicate adventitious roots, also golden yellow in color. In flowering-time, which occurs in May, two long-petiolate, exstipulate, radical leaves may be observed, which are ternately divided, with obovate-cuneate, serrate, and somewhat trilobate segments. These leaves have persisted over winter, and are smooth, deep glossy-green above, paler below, and lie spread out upon the moss. At this time two other leaves, upright and in the process of unfolding, are also to be seen, and from between these rises the slender scape, bracted above its middle and terminated by a single white flower.

(1) The flower is studied first *with reference to its parts.* Careful scrutiny shows that there are, as in the typical flower already studied, four kinds of floral organs: an outside whorl, imbricately arranged, and consisting usually of five distinct pieces (though the number varies sometimes to six or seven); a second whorl of club-shaped bodies, each hollow and with a small aperture at the top; a circle, or rather several circles, of distinct stamens, the number varying between fifteen and twenty-five; and in the



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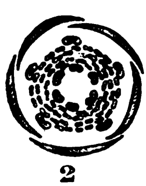

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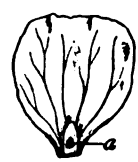

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PLATE XVIII., FIG. 1.—Plant of Coptis trifolia (⅔ natural size): *a*, scales at base of young leaves and scape; *b*, bract on scape; *c*, one of the young leaves.

FIG. 2.—Ground Plan of Flower.

FIG. 3.—A sepal, *a*; a petal, *b*; a stamen, *c*; a pistil, *d*; and the cross-section of the ovary, showing placentation, *e*.

FIG. 4.—Petal of Buttercup, showing nectary, *a*, at its base.

EXERCISE XV.

STUDY OF A DIMEROUS FLOWER.

Any of the following plants bear flowers that may be studied to advantage: the Bloodroot (Sanguinaria Canadensis, *L.*), the Celandine (Chelidonium majus, *L.*), the Poppy (Papaver somniferum, *L.*), the Prickly Poppy (Argemone Mexicana, *L.*), the Climbing Fumitory (Adlumia cirrhosa, *Raf.*), the Dutchman's Breeches (Dicentra cucullaria, *DC.*), or the Pale Corydalis (Corydalis glauca, *Pursh*).

For this study the first in the list is chosen. The Bloodroot is a very common herb found in rich woods throughout the Northeastern United States and Canada. Its conspicuous white or pinkish blossoms are among the most prized of our early spring flowers, and its short, thick rhizomes are useful in medicine. The whole plant contains a copious orange-red milk-juice which is very acrid to the taste, and the color of which has given origin both to the common and to the first part of the scientific name of the plant.

I. Subterranean Parts.—The rhizomes are reddish-tinged on the outside, from four to six centimetres in length and from ten to twelve millimetres thick, are nearly circular in cross-section, somewhat enlarged at intervals of about one centimetre, distinctly annulate, with rather faint stem-scars on the enlargements on the upper surface, and provided with rather numerous nearly simple adventitious roots that spring chiefly from the sides and lower surface, but occasionally also from the upper. The rootlets have the same color as the rhizome, and are from one to one and a half millimetres in thickness at their base.

The rhizome, when mature, sends out from lateral buds from one to several branches which are relatively thin at the point of attachment to the main body. Not infrequently an old rhizome may be found with five or six of these branches attached to it, each producing a leaf or leaves and a flower-stalk. Ultimately, in outline and a little more than half as long as the petals. The outer petals are lance-oval or lance-ovate, obtuse, and about three millimetres in length. The inner petals are much narrower than the outer ones.

The stamens are numerous, usually from sixteen to thirty-two, and are probably to be regarded as being arranged in successive whorls of two, though they are so crowded that the fact is not evident from inspection. The stamens are not of equal length, the inner being longer than the outer.

Each stamen consists of a white thread-like stalk or filament and an oblong, somewhat curved, two-lobed, adnate, and extrorse anther which dehisces longitudinally.

All the parts of the flower thus far considered are distinct from one another and separately inserted on the convex receptacle.

The pistil, however, consists of two leaf-elements or carpels united. This is shown not only by the distinctly two-lobed stigma and the more or less two-lobed ovary, but by the internal structure, presently to be studied.

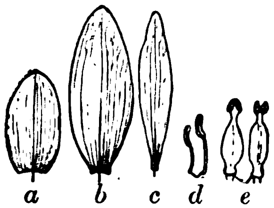
Except the papillose yellow stigma, the pistil is glaucous and green. The style is short and erect; the ovary is somewhat flattened, with two faint ridges running from base to stigma along its margins, and is inserted directly on the top of the receptacle.

A cross-section reveals the fact that the ovary is one-celled and that the numerous ovules are anatropous and arranged in two opposite vertical rows on the ovary-walls. That is to say, the placentation is marginal.

Although the fact that the ovules are anatropous might be made out with an ordinary magnifying glass, it can more easily be done later on, when the pistil has ripened, or nearly so, into a fruit.

It is clear from our study that the numerical plan of this flower is that of two; it is therefore *dimerous*. All the different organs of a flower are represented; it is therefore *complete*. All the petals are distinct or ununited; the flower is therefore *choripetalous*. And the stamens are not attached to any other floral organ, but are directly inserted upon the receptacle below the pistil; they are therefore *hypogynous*.

Drawings should now be made showing (1) the plant as a whole when in the blossoming stage, (2) the separated parts of the flower, and (3) a ground plan of the flower.



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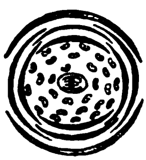

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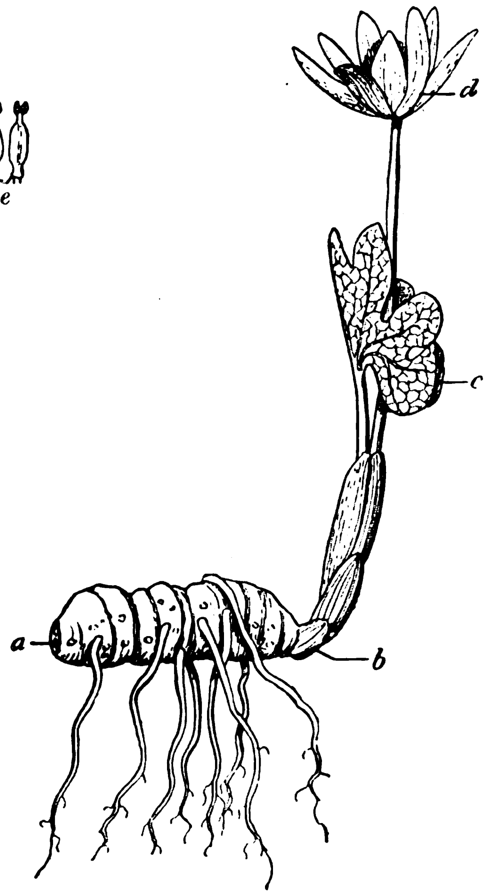

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PLATE XIX., FIG. 1.—Whole Plant of Bloodroot (natural size): *a*, rhizome with its ring-like scars and rootlets; *b*, one of the lower bud-scales; *c*, imperfectly-developed leaf-blade; *d*, the fully-expanded flower, the calyx having fallen away.

FIG. 2.—Different Parts of Flower (⅔ natural size): *a*, sepal; *b*, one of the outer petals; *c*, one of the inner petals; *d*, two of the stamens—the one to the left an outer one, and the one to the right an inner one; *e*, pistil viewed from different directions.

FIG. 3.—Ground Plan of Flower.

two outer and smaller stamens are inserted on the receptacle slightly lower down than the other four, and hence one may conclude that they are members of a different whorl. The four inner and larger stamens also occur in pairs, each pair occupying the interspace between two of the petals. It might be concluded from this, especially as in some species of the family the filaments of each pair are found united at the base, that each pair is formed by the division or branching of a single stamen. Is, then, the numerical plan of the flower that of two or that of four? This is one of the botanical questions which cannot be answered offhand, but which, if answered at all, can be safely done only by the most careful study of the floral structure. There is reason to believe, from a study of the arrangement of the woody bundles that pass from the stem into the respective floral organs, that the flower originally had at least five whorls—one of sepals, one of petals, two of stamens, and one of pistils—and that the number in each whorl was at least four, or even probably five. It is reasonable to suppose that changes in the original plan have been brought about by the visits of insects, the number of the parts of the flower having thus become modified and reduced to the present limits.

It is remarkable that throughout the family—which, by reason of the cross-shaped appearance of the flowers, is called the Cruciferæ—there should be such a close resemblance in the floral structure. Whenever one meets with a four-sepaled and four-petaled flower having tetradynamous (that is to say, two short and four long) stamens and a two-celled pistil, all separately inserted on the receptacle, one may be certain that the plant bearing it is a member of the natural order Cruciferæ.

(3) *Stamens and Pistil.*—Examining the stamens particularly, it will be found that the anthers are inserted by their bases directly on the ends of the filaments. The anthers are therefore called *innate*. They are also *introrse*, or face inward toward the pistil, and they dehisce longitudinally.

The pistil has a short thickish style, a slightly convex, capitate stigma, and a somewhat flattened ovary. Making a transverse section of the latter, it will be observed that it is two-celled, but the insertion of the ovules is different from that in most plurilocular ovaries—namely, the ovules are borne at the junction of the partition with the walls, and not in the centre or axis of the ovary. This also aids in distinguishing the Cruciferæ from other plants.

Let the student now study and make drawings of the flower of some other cruciferous plant.

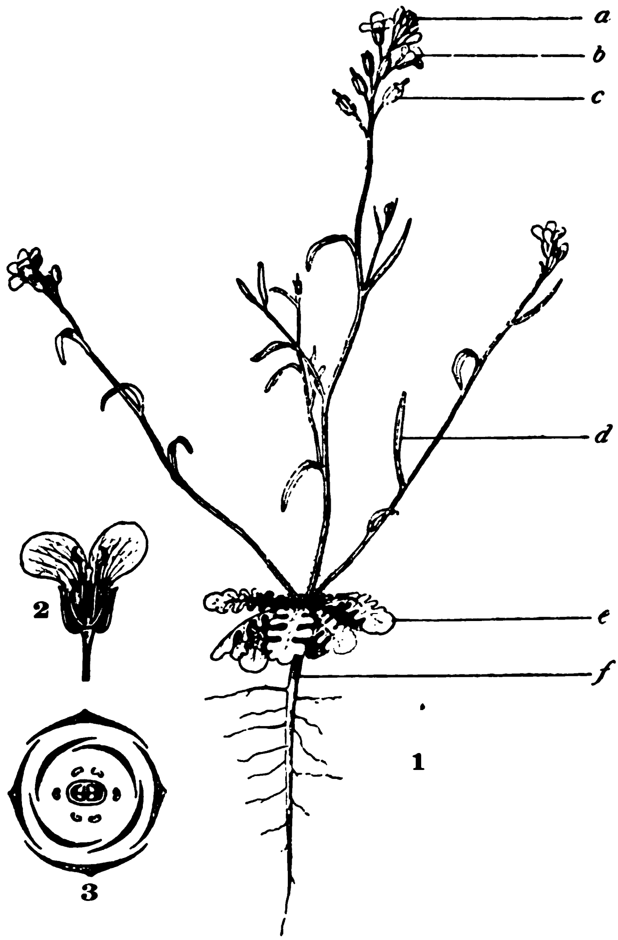

PLATE XX., FIG. 1.—Arabis lyrata, entire plant (⅔ natural size): *a*, upper flower-bud of one of the racemes; *b*, a fully-opened flower; *c*, an older flower from which the petals and stamens have fallen; *d*, one of the cauline leaves: *e*, one of the radical leaves; *f*, the tap-root.

FIG. 2.—Vertical Section of one of the Flowers (enlarged), showing insertion of parts.

FIG. 3.—Ground Plan of Flower.

EXERCISE XVII.

STUDY OF A ROSACEOUS FLOWER.

SELECTIONS may be made from the following common plants: the Strawberry (Fragaria Virginiana, *Mill.*), the Cinquefoil (Potentilla Canadensis, *L.*), the Prairie Rose (Rosa setigera, *Michx.*), the Smooth Rose (Rosa blanda, *Ait.*), the Dog Rose (Rosa canina, *L.*), the Wild Red Plum (Prunus Americana, *Marshall*), the Cultivated Cherry (Prunus avium, *L.*), the Blackberry (Rubus villosus, *Ait.*), and the Dewberry (Rubus Canadensis, *L.*).

For this study the commonly cultivated Bird Cherry (Prunus avium) is selected.

The flowers of this tree spring from axillary buds of the previous autumn, and occur either singly or in umbel-like clusters of from two to five, as shown on Plate XXI. (Fig. 1). On the same twig may be seen the leaf-buds with the conduplicately-folded leaves in the process of unfolding.

(1) *The flower as a whole* may be described as hermaphrodite, complete and regular, but not wholly symmetrical, the gynœcium, and frequently the andrœcium, deviating more or less from symmetry. The flower being showy and white, perfumed, and possessing adhesive pollen, the conclusion is reached that it is *entomophilous.*

(2) *The calyx* may be regarded as gamosepalous with a cup-shaped tube and a five-parted limb. It is so regarded by many botanists, but others view the cup not as the calyx-tube, but as a hollow receptacle from the margin of which spring the five distinct sepals. The calyx-lobes (or sepals) are oblong, obtuse, greenish, and valvately arranged in the bud.

(3) *The corolla* consists of five somewhat obcordate or nearly round, white, short-clawed, spreading petals, about fifteen millimetres long and inserted on the throat of the calyx (or, as some view it, on the margin of the receptacular tube). The preflora-

definite, and the flowers yellow with spreading corollas. But in the Potentilla the stamens and petals are perigynous, while in the Buttercup they are hypogynous.

This illustrates the fact, so often met with in natural history, that structural characters are vastly more important in determining relationship than are mere superficial resemblances. In fact, the latter are often very misleading.

EXERCISE XVIII.

STUDY OF A PAPILIONACEOUS FLOWER.

THE plants of the very numerous sub-order Papilionaceæ of the natural order Leguminosæ all have papilionaceous flowers. Good ones for study are the following: the Sweet Pea (Lathyrus odoratus, *L.*), the Scarlet Runner (Phaseolus multiflorus, *Willd.*), the Marsh Vetchling (Lathyrus palustris, *L.*), the Common Pea (Pisum sativum, *L.*), the Wistaria (Wistaria sinensis, *DC.*), the Locust (Robinia Pseudacacia, *L.*), the Lupine (Lupinus perennis, *L.*), and the Broom (Cytisus scoparius, *Link*).

The first of these is selected for the present study.

I. EXTERNAL CHARACTERISTICS.—(1) Observe, first, that the stem differs from the usual form of stems in being strongly flattened or wing-margined. Its surface, like that of the other parts, is pubescent and somewhat glandular. It is herbaceous, and the plant has the scandent habit, climbing by means of tendrils which are modified leaflets of the compound leaf.

(2) The leaves are alternate and stipulate, with ovate-lanceolate, acuminate, half-sagittate stipules; the petioles are wing-margined, and the blade consists of a single pair of ovate-lanceolate, entire, or slightly wavy-margined leaflets and of from three to five others developed into tendrils.

(3) The showy, sweet-scented flowers occur in long-peduncled, few-flowered racemes, with only two or three flowers in a cluster, or they are sometimes solitary. They occur in the axils of the upper leaves.

(4) Draw a portion of the plant, about six or eight inches of its upper end, and point out the stem, a stipule, a petiole, a tendril, an unopened flower-bud, and a fully-expanded flower.

II. STRUCTURE OF THE FLOWER.—(1) *Irregularity.*—One of the most striking things about the flower is the irregularity in its shape. From a fancied resemblance to a butterfly, it has been called *papilionaceous*. Like most irregular flowers, it faces later-are distinct at the base, though those forming the keel are united toward the apex. The stamens—forming as they do two groups by the union of the filaments of nine of them, while the other one remains distinct—are described as *diadelphous*.

Since the flower is on the numerical plan of five, one would naturally expect to find either five distinct pistils or else one compound pistil composed of five united carpels. Is the one pistil which is present one-carpeled or five-carpeled? This question can be answered only by studying the structure. Observing the stigma, it will be found to be entire, and not at all lobed or divided. This is evidence, so far as it goes, of a one-carpeled pistil. But there must be additional proof. Making a cross-section of the ovary, this is found to be only one-celled, and, what is more to the point, it is seen that the ovules form a double row along the upper or ventral side of the ovary only. Had there been two double rows on opposite sides, one would have been obliged to regard the pistil as two-carpeled, or, if three, three-carpeled, and so on; but, since there is only one, it must be concluded that it is but one-carpeled, or represents but a single modified leaf. The flower has become unsymmetrical, then, by the loss of four of its pistils.

(4) *Adhesion.*—Making a vertical section centrally through the flower from base to apex, it will be found that the different whorls of floral organs are successively inserted on the receptacle; there is no growing of one floral leaf to another of a different kind, and therefore no *adhesion* nor *adnation*.

(5) Make a drawing of the separated petals, so that their relative shapes and position may be seen at a glance. Point out the vexillum, one of the alæ, and one of the two petals forming the carina.

(6) Draw a vertical section of the flower, showing the succession and mode of insertion of the parts. Point out the calyx, the vexillum, one of the alæ, a petal of the carina, the staminal tube, and the pistil.

(7) Draw a diagram of the ground plan of the flower, and point out the following parts: a sepal, the vexillum, an ala, a petal of the carina, a stamen, and the pistil.

(8) *Significance of the Peculiarities of Structure.*—The showiness of the flower, its agreeable odor, and the fact that it secretes

country, however, and in England cross-fertilization by insect agency seems to be a rare occurrence, owing probably to the lack of perfect adaptation of the flowers and native insects to each other. The flowers, though, are self-fertilized and seed freely. It is evident that they are so constructed that in case of failure to receive other pollen they can utilize their own. That Nature did not form them, however, for habitual self-fertilization is clearly indicated not only by the structure of the flower as explained above, but also by the fact, observed by Mr. Darwin, that the seeds produced by cross-fertilization develop stronger and more vigorous plants than those produced by self-fertilization.

The student should now study, describe, and draw one of the other Papilionaceæ mentioned at the beginning of this exercise.

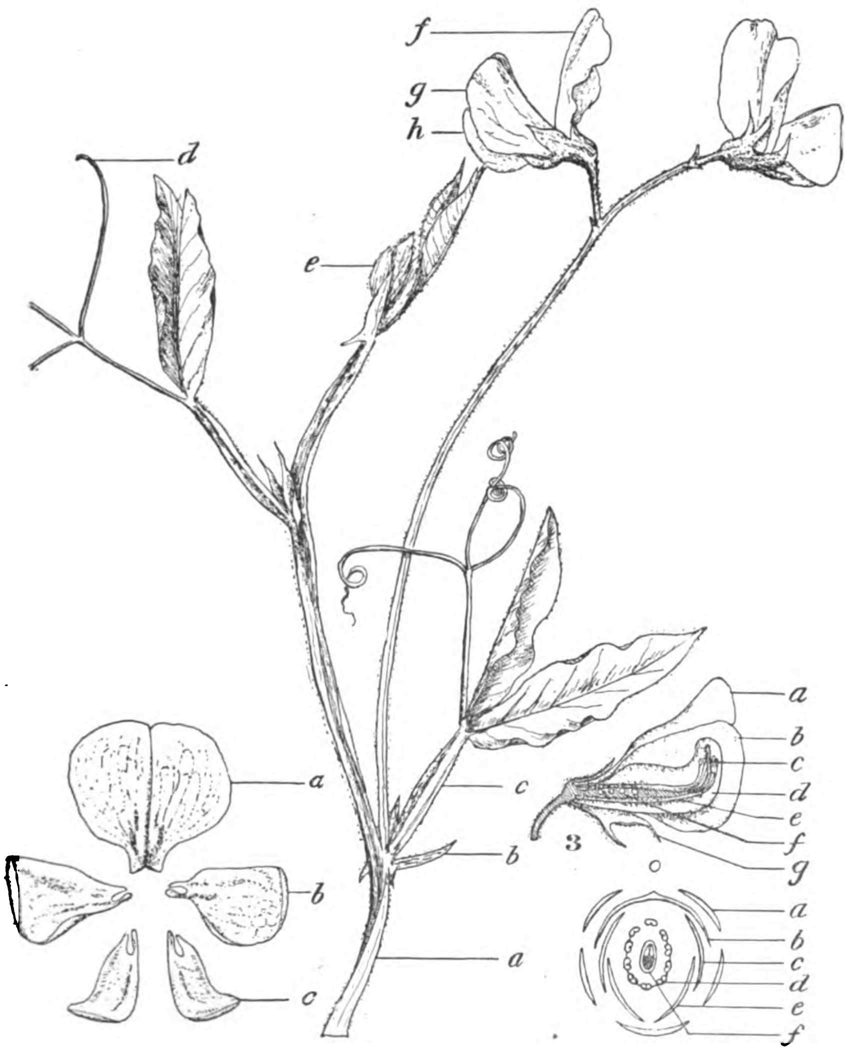

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PLATE XXII., FIG. 1.—Drawing of Upper Part of Plant of Lathyrus odoratus (2/3 natural size): *a*, winged stem; *b*, stipule; *c*, flattened or alate petiole; *d*, a leaflet-tendril; *e*, flower-bud, one of a cluster of three; *f*, vexillum, or large upper petal of corolla; *g*, one of the alæ or wings; *h*, carina or keel.

FIG. 2.—The Petals of the Corolla separated so as to show their shapes: *a*, vexillum; *b*, ala; *c*, one of the petals of the carina.

FIG. 3.—Vertical Section of one of the Flowers, showing insertion of parts: *a*, vexillum; *b*, ala; *c*, stamens; *d*, carina; *e*, staminal sheath; *f*, ovary; *g*, calyx-tooth.

FIG. 4.—Diagram of Ground Plan of Flower: *a*, sepal; *b*, vexillum; *c*, ala; *d*, stamen; *e*, petal of carina; *f*, pistil.

EXERCISE XIX.

FLOWER OF A GAMOPETALOUS DICOTYL.

SELECTIONS may be made from the following: the Jamestown Weed (Datura Stramonium, *L.*), the Common Potato (Solanum tuberosum, *L.*), the Ground Cherry (Physalis pubescens, *L.*), the Common Morning-glory (Ipomea purpurea, *Lam.*), the Hedge Bindweed (Convolvulus sepium, *L.*), the Lungwort (Mertensia Virginica, *DC.*), the Wild Phlox (Phlox divaricata, *L.*), the Fringed Gentian (Gentiana crinita, *Froel.*), the Harebell (Campanula rotundifolia, *L.*), the Partridge Berry (Mitchella repens, *L.*), and the Bluets (Houstonia cærulea, *L.*).

The last mentioned on this list is selected for the present study. The Houstonia is a beautiful little plant, abundant in open and moist ground in most parts of the Northern United States, where it blossoms in early spring. Humble and unpretentious as it is, it is a member of the same family of plants as that to which the Coffee and Cinchona trees belong—the natural order Rubiaceæ. The delicate stems are somewhat branching, more or less quadrangular, erect, and rise to the height of from three to five inches. They spring from slender, filiform rhizomes which give rise to even more slender fibrous rootlets. The small, spatulate-oblong radical leaves are petiolate and entire or somewhat toothed. The opposite stem-leaves are smaller and narrower, the upper ones being reduced to linear bracts, and the bases are connected by minute entire stipules. The flowers are solitary at the ends of the main stem and its branches.

(1) *The calyx* is gamosepalous, its tube adherent to the walls of the ovary, and its limb separated into four small, linear, at first erect or ascending, but afterward spreading lobes, which are green and persistent.

(2) *The corolla* is gamopetalous and hypocrateriform, with a tube from five to seven millimetres long, narrow below and larger above. The flowers are of two forms—one with the enlargement

Thus the flower attracts insects by its showy color, rewards them for their visits by the nectar it secretes, and, by the structure of its corolla-tube, together with the proper relative adjustment of the anthers and styles, makes use of them to convey the pollen from the stamens of one plant to the stigmas of another, and so secures cross-fertilization. It is more than probable, also, that the plant, like many other species with dimorphous flowers, prefers pollen from another flower to its own, and only makes use of the latter when that from a flower of the other form cannot be obtained.

The Bouvardia of our greenhouses, a related plant from Mexico, is often available for study when Houstonia is not in blossom. The flowers are also dimorphous, and have a structure quite similar to that of Houstonia. A twig with ground plan and vertical section of a flower is shown on Plate XXIII. (Figs. 4, 5, 6).

EXERCISE XX.

STUDY OF AN ERICACEOUS FLOWER.

SELECTIONS may be made from the following plants: the Common Blueberry (Vaccinium corymbosum, *L.*), the Stagger Bush (Andromeda mariana, *L.*), the Leucothöe (Leucothöe racemosa, *Gray*), the Leather Leaf (Cassandra calyculata, *Don*), the Mountain Laurel (Kalmia latifolia, *L.*), the Pinxter-flower (Rhododendron nudiflorum, *Torr.*), the Prince's Pine (Chimaphila umbellata, *Nutt.*), the Shin-leaf (Pyrola elliptica, *Nutt.*), the Wintergreen (Gaultheria procumbens, *L.*), the Bearberry (Arctostaphylos uva-ursi, *Spreng.*), and the Trailing Arbutus (Epigæa repens, *L.*).

From this list, for the present study, choice is made of the Trailing Arbutus. This exquisite little plant, everywhere a favorite with lovers of flowers, has a wide distribution over the eastern part of North America, being especially abundant, however, in the Alleghenies and in the rugged pine and fir-clad regions bordering the Great Lakes and the St. Lawrence River. It blooms among the earliest of our spring flowers, often sending up its fragrant white- or rose-colored blossoms in close proximity to the lingering snow-drifts in our northern woods. Its shrubby stems are slender, extensively trailing, and covered, as are the petioles and inferior leaf-surfaces, with rusty-brown hairs. The leaves are five or six centimetres long, alternate, evergreen, with slender and rather long-petiolate, elliptical, entire-margined, prominently reticulate blades which are rounded or cordate at the base and mucronate at the apex.

(1) *The flowers* occur in short, almost spike-like racemes at the ends of the stems, and are white or rose-tinged and attain a length of one and one-half, and sometimes even two, centimetres. The pedicels are short, two or three millimetres long, and brown-hairy, as are also the scaly bracts.

(2) *The calyx* is five-parted or with almost distinct sepals which

fer from those of most other Heaths in dehiscing by longitudinal slits rather than by pores at the apex of the lobes.

The pollen-grains also differ from those of most plants outside this natural order in being composed of a group of four cells, as shown on Plate XXIV. (Fig. 5, *a* and *b*).

(5) *The gynœcium* consists of a single pistil, but it is compound, and shows by its structure that it is composed of five carpels. It thus conforms to the numerical plan of the flower, which, except in those unusual specimens in which the stamens are completely aborted, is that of the typical dicotyl already described.

The ovary in its lower part is faintly ten-lobed, but these lobes are in pairs. The upper part is densely hairy. The erect, rather stout cylindrical style is crowned with a five-lobed stigma which in the pistillate flower is star-shaped when fully expanded, but in the staminate one never opens.

A cross-section of the ovary shows five loculi, an axile placentation, and numerous small anatropous ovules.

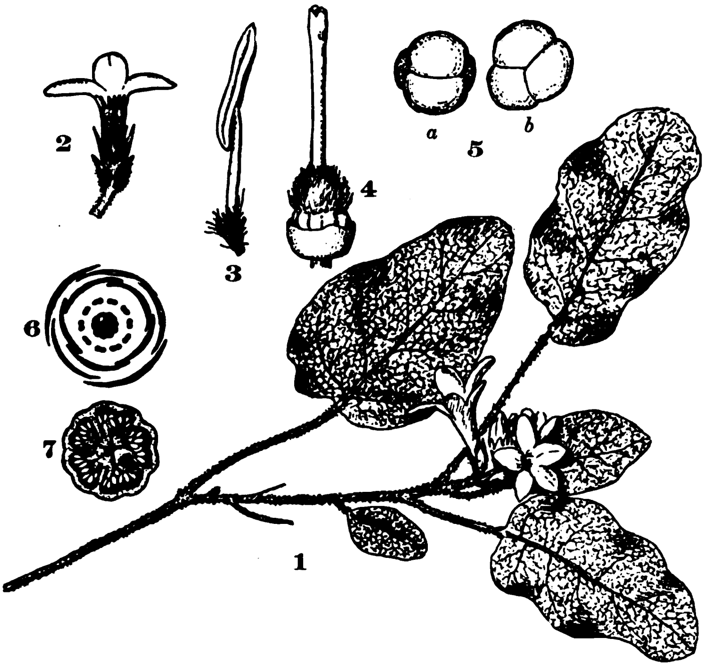


PLATE XXIV., FIG. 1.—A Branch of Trailing Arbutus (⅜ natural size).

FIG. 2.—One of the Staminate Flowers in longitudinal section (slightly enlarged).

FIG. 3.—One of the Stamens (magnified 8 diameters).

FIG. 4.—Pistil (magnified 4 diameters).

FIG. 5.—Pollen-grains in clusters of four (magnified 200 diameters).

FIG. 6.—Ground Plan of Flower, showing imbricate calyx and corolla.

FIG. 7.—Cross-section of Ovary, showing its ten lobes in five pairs, its five loculi, axile placentation, and numerous ovules. (Magnified 8 diameters.)

EXERCISE XXI.

STUDY OF A FLOWER OF THE COMPOSITÆ.

THE following species of this natural order are suitable ones for study by beginners: the Common Sunflower (Helianthus annuus, *L.*), the Jerusalem Artichoke (Helianthus tuberosus, *L.*), the Common Beggar-ticks (Bidens frondosa, *L.*), the Sneeze-weed (Helenium autumnale, *L.*), the Ox-eye Daisy (Chrysanthemum Leucanthemum, *L.*), the Burdock (Arctium Lappa, *L.*), the Rattlesnake Weed (Hieracium venosum, *L.*), the Dandelion (Taraxacum officinale, *Weber*), and Chicory (Cichorium Intybus, *L.*).

For the purpose of this exercise a selection is made of the Ox-eye Daisy, an introduced plant now become exceedingly common in most portions of the Eastern United States, where it is regarded by the farmers as a pernicious weed. Besides the common name above given, it is also called in different localities the Marguerite, White Daisy, and White Weed.

It is a perennial herb with ascending, often diffuse, somewhat striate and smooth, branching stems arising from short rhizomes. The lower leaves are rounded, oval, or spatulate, and taper into rather long petioles, and are coarsely toothed, incised, or lobed on their margins; the upper leaves are oblanceolate, lanceolate, or linear-lanceolate, and pinnatifid. They are smooth and deep-green both above and below.

(1) *The anthotaxy* in all the natural order Compositæ is indeterminate, and the flower clusters consist of heads. In many species, however, the heads are cymosely arranged. In this species the heads occur singly at the ends of long, few-bracted peduncles that terminate the main stem and branches.

(2) *The Involucre.*—In the Compositæ the heads are subtended by an involucre consisting of bracts, usually numerous and arranged in one or more circles. In this case the involucre is flattish or slightly convex below and composed of scales imbricated in several rows. The component scales are linear-lanceolate and

scarious on their margins and at their tips. They doubtless represent the bracts of what were in the remote ancestors of these plants a much looser inflorescence, but which in course of time became concentrated into a head.

(3) *The flowers* or florets are individually quite small, and, as in many other of the Compositæ, are of two kinds—marginal ones which are relatively large and showy and are called *ray-flowers,* and interior, smaller, and less showy ones which are called *disk-flowers.* The ray-flowers have ligulate and the disk-flowers tubular corollas. In some Compositæ, as the Dandelion and Chicory, the florets are all of one kind and ligulate, while in others, as in the Burdock and Boneset, they are all tubular.

(*a*) *The common receptacle* on which the florets are arranged is flat or slightly convex and naked; that is to say, no chaff or scales occur upon it among the flowers as they do in many other species of the order. It will be observed that the florets are regularly arranged on the receptacle in spirals.

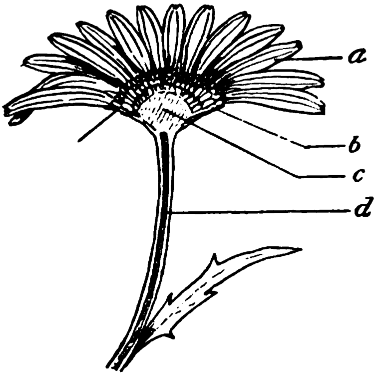
(*b*) *The ray-flowers* are white, the corolla two-nerved, obscurely two- or three-toothed at the apex, contracted and tubular below, near its insertion on the top of the ovary, and is from ten to eighteen millimetres in length. These flowers are usually in one or two circles, and there are from twenty to thirty of them in each head.

In all the Compositæ the corollas and stamens are epigynous and the tubular calyx (or receptacle) is adnate to the ovary. The calyx-limb, if present, is ring-like, chaffy, bristly or scaly, and is termed a *pappus.* In the present instance it is usually wanting altogether, though sometimes recognizable as a minute scale.

The two-lobed stigma and the upper part of the cylindrical style project from the tubular portion of the corolla as shown on Plate XXV. (Fig. 2), but the stamens are altogether wanting in the ray-flowers.

The ovary is obovoid in outline and longitudinally striate.

(*c*) *The disk-flowers* are very numerous—often four or five hundred in a single head; they are yellow, with a five-toothed limb the teeth of which are valvate in the bud, and have a tube which is somewhat inflated and bell-shaped above, contracted a little below the middle, and again slightly inflated a little above the ovary. The bottom part of the tube is filled with nectar. The



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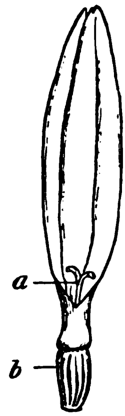

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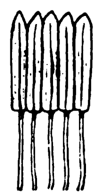

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PLATE XXV., FIG. 1.—Flower-head of Ox-eye Daisy (about natural size), cut longitudinally to show arrangement of parts: *a*, one of the ray-florets; *b*, a disk-floret; *c*, the common receptacle; *d*, the hollow peduncle.

FIG. 2.—One of the Ray-florets (considerably enlarged): *a*, two-lobed stigma; *b*, ovary surmounted by the corolla-tube.

FIG. 3.—One of the Tubular Disk-florets (much enlarged).

FIG. 4.—Pistil with fully-developed Style and Stigma. (Much enlarged.)

FIG. 5.—Staminal Tube laid open and exposing inner face of Anthers.

EXERCISE XXII.

STUDY OF A MONOCHLAMYDEOUS FLOWER.

THE following plants are favorable ones for study: Wild Ginger (Asarum Canadense, *L.*), Pipe Vine (Aristolochia Sipho, *L'Her.*), Buckwheat (Fagopyrum esculentum, *Moench*), Four-o'clock (Mirabilis Jalapa, *L.*), and Pokeweed (Phytolacca decandra, *L.*).

From the above-mentioned is selected for this study the Wild Ginger, a member of the Birthwort family, and a plant which is not uncommon in rich woods in the northern part of the United States, and which blossoms in May. It produces rhizomes which creep extensively near the surface of the ground and which branch frequently as in Podophyllum, giving rise to new plants. These rhizomes are nearly cylindrical or somewhat quadrangular, marked at intervals of about twelve millimetres with prominent, more or less oblique scale-scars, and on their under surface, mostly from the nodes, producing small clusters of slender, nearly simple rootlets averaging about sixty millimetres in length. A cross-section of a rhizome shows a thin circle of wood enclosing a large pith and composed of about twelve short wood-bundles. The iodine test shows it to contain abundance of starch. Besides some bitterness, it is pungently aromatic, reminding one of ginger, hence the popular name of the plant.

The end of the rhizome rises obliquely to form the very short above-ground stem, and this bears two long-petiolate, exstipulate leaves whose blades are broadly reniform, entire-margined, and slightly pointed at the apex. The blades are thin, have a transverse diameter of from ten to twelve centimetres, are deep-green and silky lustrous by reason of a minute pubescence on the upper surface, and are lighter colored and prominently veiny below.

From between the two leaf-bases issues a single pedunculate, nodding, dull-purple flower, which, together with the peduncle, is densely covered on the outside with a woolly pubescence.

(4) *Numerical Plan and Affinities.*—The peculiarities of structure thus far ascertained raise some questions as to the numerical plan and the affinities of the plant. Is the number plan three or six? The sepals, as has been observed, were three in number—or, rather, the calyx, being parted into three segments, indicates a construction on the numerical plan of three; but both stamens and pistils indicate a numerical plan of six. One might suppose the stamens to have been originally in four whorls of three each, which were afterward condensed into two of six each, and that a similar condensation took place in the case of the pistils. The numerical plan would then be that of three. But there is the alternative supposition that the calyx is the organ that has varied from the original plan, and that the numerical plan is to be regarded as that of six.

If the former supposition be accepted, is the plant a monocotyl or a dicotyl? Monocotyls, as has been noted, almost always have their flowers arranged on the numerical plan of three, while in dicotyls this plan is very rare. Observing the leaves, the venation is found to be netted; studying the stem, its vasal bundles are found arranged in a circle; there is a cambium zone, there are medullary rays and a pith,—facts all of which point to the affinities of the plant with dicotyls. If, further, the seed be dissected, there is found—though with difficulty, because it is minute—a dicotyledonous embryo, which is most conclusive proof that the plant is a dicotyl.

But the question remains, Is three or six the numerical plan of the flower? It seems, on the whole, more reasonable to conclude that six is the number, because this number is not rare among dicotyls, and because, moreover, it is more reasonable to suppose that one set of organs (the calyx) has deviated from the plan than that two sets (stamens and pistil) have done so.

Let the student now make a careful study and drawings of one of the other plants mentioned in the list at the beginning of this exercise.

EXERCISE XXIII.

STUDY OF A LILIACEOUS FLOWER: THE MONOCOTYL TYPE.

SELECTIONS may be made from the following common plants: the Tiger Lily (Lilium tigrinum, *Ker*), the Wild Orange Red Lily (Lilium Philadelphicum, *L.*), the Turk's-cap Lily (Lilium superbum, *L.*), the Indian Cucumber (Medeola Virginica, *L.*), the Large-flowered Trillium (Trillium grandiflorum, *Salisb.*), the Erect Trillium (Trillium erectum, *L.*), the American White Hellebore (Veratrum viride, *Ait.*), the Wild Onion (Allium cernuum, *Roth*), the Star of Bethlehem (Ornithogalum umbellatum, *L.*), the Wild Hyacinth (Camassia Frazeri, *Torr.*), the Bellwort (Uvularia perfoliata, *L.*), and the Yellow Adder's-tongue (Erythronium Americanum, *Ker*).

The last-named plant on this list shall serve the present purpose. The Yellow Adder's-tongue is a common plant in the northern and eastern portions of the United States and Canada, where it grows in rich woods, blossoming in early spring.

The underground parts consist of a deeply-buried tunicated bulb and numerous nearly simple, fibrous, adventitious roots which are emitted from its lower end. In the sterile plant this bulb usually sends up but a single leaf, but in the flowering one two apparently opposite, but really alternate, ones. These are each about four inches long, lanceolate, oblanceolate, or elliptic-lanceolate, entire, acute, thickish, with an indistinct basi-nerved venation, smooth and light-green, with darker green or purplish irregular spots on both surfaces. The leaves taper below into long petioles, the outer or lower of which ensheathes the next, and this in turn the long, naked, cylindrical scape. The latter rises to the height of five or six inches, and bears at its apex a single yellow, nodding flower.

(1) *The anthotaxy* is therefore solitary and determinate.

(2) *The prefloration*, if the perianth be studied carefully, is found to be valvate in the first whorl and imbricate in the second.

But even a superficial inspection shows that the single organ is probably formed by the coalescence of three, for the stigma, as has been seen, the upper part of the style, and the ovary are each three-lobed. Moreover, the lobes alternate with the inner set of stamens, as would be the case if the compound pistil were formed by the coalescence of three simple ones. But confirmatory evidence of the correctness of the view that the pistil is three-carpeled is obtained by studying the cross-section of the ovary. This section shows three loculi, each containing a double row of ovules arranged vertically along the inner side of the loculus —an axillary placentation, in fact, as in Asarum. This is the precise arrangement which would result if three carpellary leaves were folded inward until the edges touched at the centre and a row of ovules were borne on each infolded edge.

The flower, therefore, is really constructed throughout on the numerical plan of three; and, since there are five whorls of three each, all alternating with each other, it is wholly *symmetrical.* It is, in fact, a nearly typical or pattern flower, the only real deviation being a slight irregularity shown in the shape of the pistil. This is related to the nodding position of the flower, and both are doubtless adaptations to cross-fertilization by insect agency. In this flower the deviation is but slight. In many other monocotyls, as in some orchids, it has become extreme, so that there is not only great irregularity in the shape and coloring of parts, but great dissymmetry also, often obscuring even the numerical plan.

(6) *The Monocotyl Type of Flower.*—Except for its slight irregularity, the flower of the Adder's-tongue may be regarded as a flower typical of monocotyl plants, as the Flax and Sedum are of dicotyls. In all this vast group the flowers appear to have been constructed on the numerical plan of three and on the basis of five alternating whorls—one of sepals, one of petals, two of stamens, and one of pistils. In course of time many species have developed irregularities and dissymmetries, as has been seen among dicotyls, but seldom is the original plan completely obscured; and, since the flowers of dicotyls are rarely constructed on the numerical plan of three, the one group of plants may almost always easily be distinguished from the other by observing the numerical plan of the flowers.

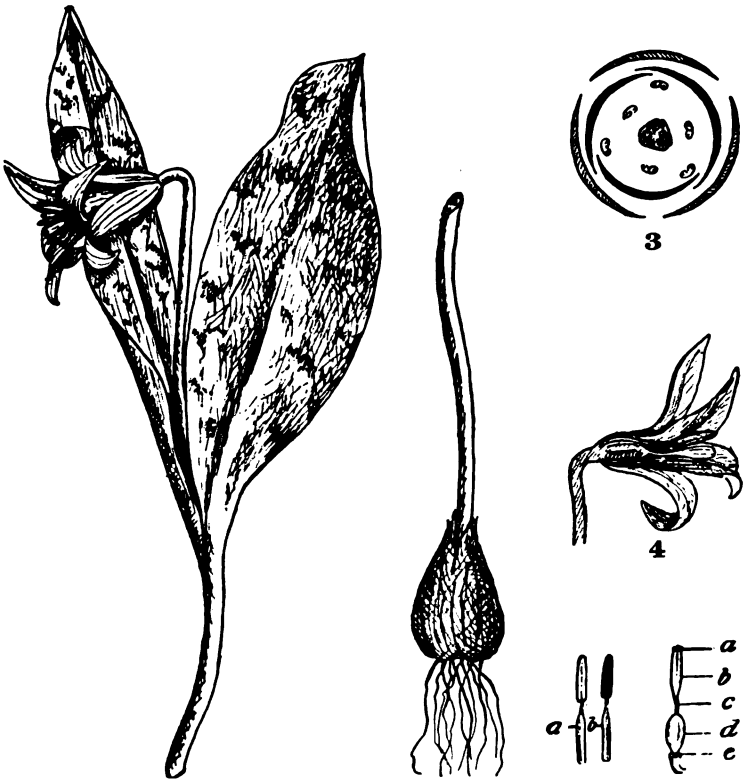


PLATE XXVII., FIGS. 1, 2.—Flowering Plant of Erythronium Americanum (⅔ natural size).

FIGS. 3, 4.—Ground Plan and Vertical Section respectively of the Flower.

FIG. 5.—One of the Stamens shown in dorsal (*a*) and in ventral (*b*) view.

FIG. 6.—Pistil: *a*, stigma; *b*, enlarged upper portion of style; *c*, contracted and somewhat bent lower part of style; *d*, ovary; *e*, torus.

EXERCISE XXIV.

FLOWERS OF MONOCOTYLS (CONTINUED).

IN connection with the study of a liliaceous flower, which has been taken as typical of the monocotyls, one may profitably study some of the flowers from related families in which the type has undergone modifications more or less important. Selections may be made from the Amaryllidaceæ and from the Orchidaceæ, as follows: *Amaryllidaceæ:* the Daffodil (Narcissus Pseudo-narcissus, *L.*), the Poet's Narcissus (Narcissus poeticus, *Salisb.*), the Jonquil (Narcissus Jonquilla, *Willd.*), the Polyanthus (Narcissus Tazetta, *Willd.*), or the Pancratium (Pancratium maritimum, *L.*). *Orchidaceæ:* the showy Orchis (Orchis spectabilis, *L.*), the Yellow Fringed Orchis (Habenaria ciliaris, *R. Br.*), the Fragrant Orchis (Habenaria leucophæa, *Gray*), the Arethusa (Arethusa bulbosa, *L.*), the Calopogon (Calopogon pulchellus, *R. Br.*), the Pogonia (Pogonia ophioglossoides, *Nutt.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Yellow Lady's Slipper (C. pubescens, *Willd.*), or the Stemless Lady's Slipper (C. acaule, *Ait.*).

PART I.—From these, for the first study, a selection is made of the commonly cultivated Narcissus poeticus. This is a spring-blooming plant with long, linear, parallel-veined, radical leaves which arise from a tunicated bulb. The flowers occur in a few-flowered umbel at the end of a scape, and the cluster is subtended at its base by a conspicuous, scale-like bract or spathe.

(1) *The perianth*, as in the Erythronium, is composed of six pieces, and these also are in two whorls of three each which alternate with each other, but the pieces have grown together at their base to form a long tube, so that the perianth is hypocrateriform. This growing together of parts, either of the same or of different whorls, constitutes one of the common ways in which many flowers have come to differ from the type. But the adhesion is car-

disk is sometimes hypogynous as in the Orange, sometimes perigynous as in Buckthorn, and sometimes epigynous as in the Umbelliferæ. In the latter case it may rise considerably above the level of the ovary, and form a crown-like ridge or elevation as in Peliosanthes. The reasons for believing that the crown of Narcissus may be of this character, despite its membranous texture and petaloid appearance, are derived from a study of its development. It begins later than do the other floral organs, as a slight ring-like elevation between the staminal whorls and those of the andrœcium, and wholly independent of both. By its growth perianth and andrœcium are carried up together, forming the common tube which both envelops the ovary and is carried much beyond it, the crown, according to this view, being only the free portion of this remarkably developed disk. This is the view of M. Baillon, and as such must command great respect. But it seems to the author that the facts Baillon states regarding the development of the disk are not inconsistent with the view that the corona represents the coalesced stipules of the perianth leaves. The stipules, as well as the other parts, may have been carried up by the development of the disk. Their texture and the fact that they are sometimes twelve-toothed seem more in accord with this view.

But, after all, it is of less importance what view be adopted than that the process of reasoning by which the view is arrived at be understood.

(3) *The andrœcium* here, as in Erythronium, consists of two whorls of three stamens each, but, instead of being borne on the receptacle beneath the ovary, they have become adnate by their filaments to the perianth-tube, one set of anthers appearing near its throat and the other near the middle of the tube. The free portions of the filaments are very short, but they may be traced along the line of their attachment to the tube clear to the base of the latter. The anthers are two-lobed, two-celled, introrse, and attached to the filaments near their middle.

(4) *The gynœcium* in most respects resembles that of Erythronium except for the adnate perianth-tube and the slender, straight style, the ovary being three-lobed, three-celled, many-ovuled, and with an axile placentation.

The flower, like that of Erythronium, is also nearly regular, but shows, by being bent on its peduncle and by being somewhat developed sac or moccasin-like body of a purple color, and totally different in appearance from the other two. This is called the *labellum*.

(3) *The column*, as it is called, is at its base a stout cylinder rising from the centre of the corolline whorl, and bearing on its upper side a thick, spade-shaped or somewhat rhomboidal body near the base of which, on either side, lie two gland-like bodies which, however, are really stamens. The spade-shaped body arches over a faintly and unequally three-lobed stigma which faces downward and terminates the column. In this organ, then, stamens and pistils have grown together or become adnate, and the arrangement is described as a *gynandrous* one.

(4) *The andrœcium* apparently consists of but the two gland-like stamens; but what has become of the other four? And do the two which are present belong to the inner or to the outer whorl? What is the nature of the spade-shaped body? Does it represent a petal or a stamen, or is it an outgrowth from the receptacle in the nature of a disk? These questions can be answered only by carefully studying the development of the flower, by comparing it with those of related plants, and by the study of those monstrosities which sometimes occur and indicate a return to an ancestral and more regular condition. It frequently happens both among animals and plants that an organ that has become rudimentary and tends to disappear suddenly appears fully developed; or that one which has become strongly irregular develops regularly; or that one which has disappeared entirely reappears. Thus, in some Scrophulariaceæ there is a rudimentary and functional fifth stamen which in rare instances develops into the ordinary form, or the petal of a Trillium or a Rose develops into an ordinary green leaf; and instances are on record where a Cypripedium has developed a perianth perfectly regular and symmetrical; and at least one instance of the kind is recorded where all the stamens but one have been restored and in their normal positions. From the study of such instances it may be concluded that the spade-shaped body of this flower is actually one of the outer whorl of stamens and really represents the hypertrophied connective of one of the anthers, and that the other two stamens belong to the second or inner whorl, the third having disappeared or perhaps coalesced with the lower petal to form the labellum.

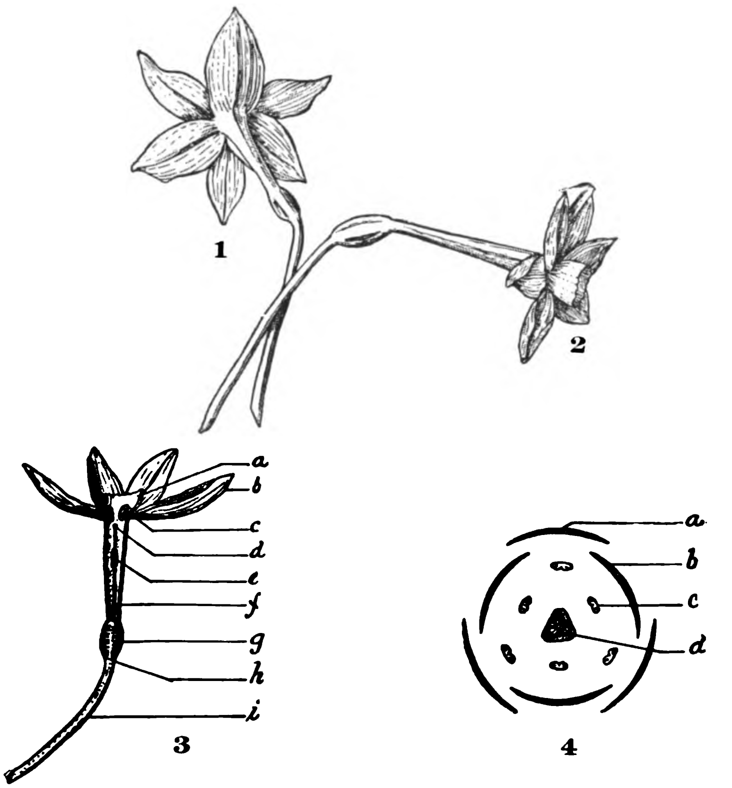


PLATE XXVIII., FIGS. 1, 2.—Flowers of Narcissus poeticus in different positions (⅗ natural size).

FIG. 3.—Vertical Section of one of the Flowers, showing, *a*, corona; *b*, one of the petals; *c*, one of the stamens; *d*, the stigma; *e*, an anther; *f*, the style; *g*, the ovary; *h*, the receptacle; and *i*, the peduncle.

FIG. 4.—Ground Plan of Narcissus Flower: *a*, sepal; *b*, petal; *c*, stamen; *d*, ovary.

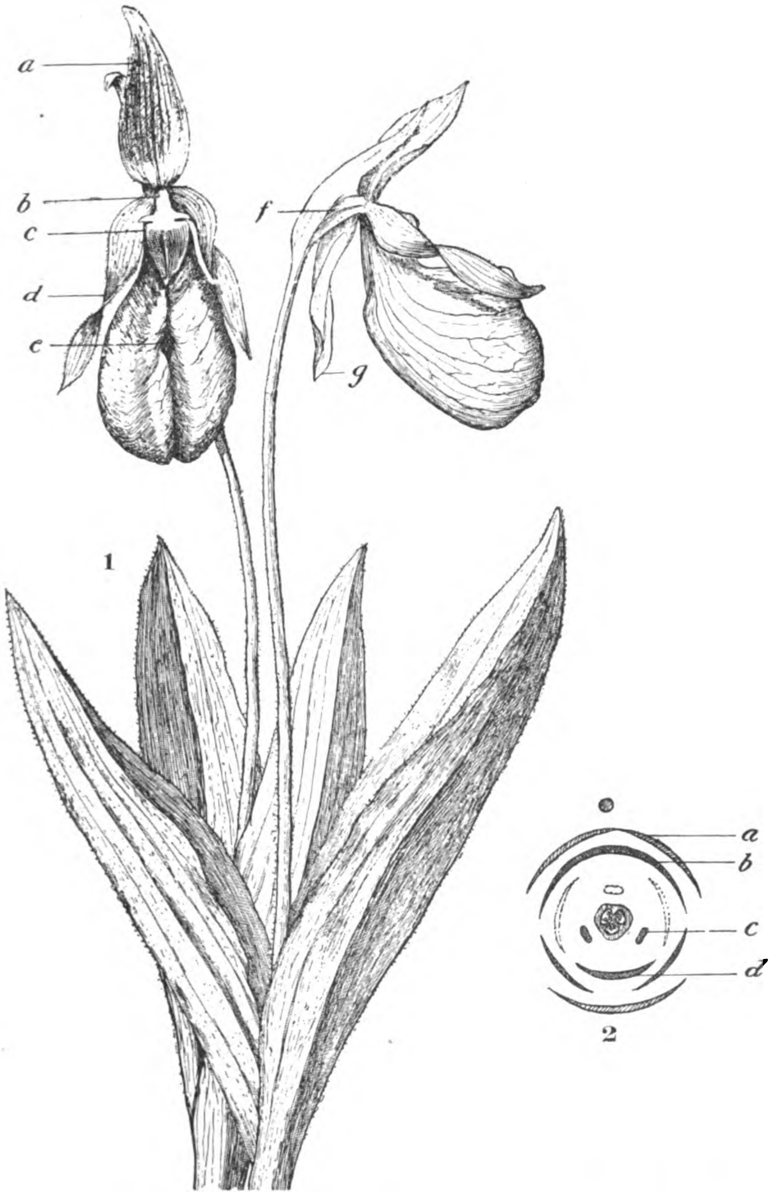


PLATE XXIX., FIG. 1.—Two Plants of Cypripedium acaule (2/3 natural size), showing flowers in different positions: *a*, sepal; *b*, base of column; *c*, opening from which insect emerges; *d*, lateral petal; *e*, slit through which insect enters; *f*, ovary; *g*, upper two sepals united into one.

FIG. 2.—Ground Plan of one of the Flowers: *a*, upper two sepals united into one; *b*, labellum; *c*, a stamen; *d*, spade-shaped body, an abortive stamen.

EXERCISE XXV.

STUDY OF THE INFLORESCENCE OF AN ABERRANT MONOCOTYL, ONE OF THE ARACEÆ.

THE following are species most of which are not difficult to procure in the proper season, and which are suitable for study: the Indian Turnip (Arisæma triphyllum, *Torr.*), the Green Dragon (Arisæma Dracontium, *Schott.*), the Arrow Arum (Peltandra Virginica, *Kunth*), the Water Arum or Calla (Calla palustris, *L.*), the Calla Lily (Richardia Æthiopica, *Kunth*), the Golden Club (Orontium aquaticum, *L.*), the Skunk Cabbage (Symplocarpus fœtidus, *Salisb.*), and the Sweet Flag (Acorus Calamus, *L.*).

For the purposes of this exercise selection is made of the first on the list, the Indian Turnip. The plant is very common in low, rich woods throughout the eastern portion of the United States and Canada, where it blossoms in early spring. It has a flattened, much wrinkled corm that may attain a transverse diameter of two inches and a vertical diameter half as great, and emits numerous nearly simple, adventitious roots from its upper margin. From near the centre of its upper surface rises, to the height of six inches or even a foot or more, the erect, rather stout, cylindrical scape. The lower part is enveloped in alternate sheathing scales and the sheathing base of the true leaf or leaves. The scales are large, particularly the upper ones, and conspicuously parallel-nerved. The true leaves, one or two in number, like the scales, have their origin in the corm. Besides the long sheath, which completely surrounds the flower-stem, the leaf consists of a rather long, cylindrical petiole and a ternately-divided blade. The leaf deviates in structure from that of the great majority of monocotyls in being reticulate instead of nerved. The segments are ovate, entire-margined, acuminate, and have a sub-marginal vein running from the base to the apex. The whole plant is smooth, and the watery juice is very acrid.

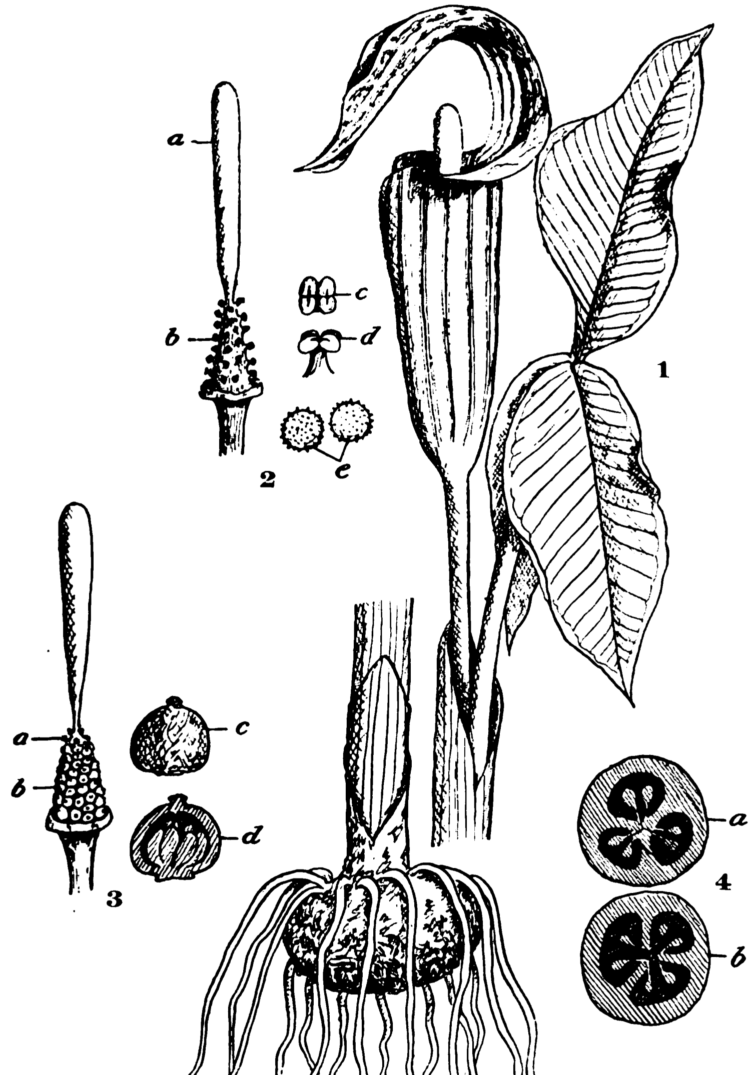


PLATE XXX., FIG. 1.—Plant of Arisæma triphyllum (about ⅔ natural size).

FIG. 2.—Staminate spadix with spathe cut away to show the flowers: *a*, naked portion of spadix; *b*, a staminate flower; *c*, an enlarged view of upper side of a stamen; *d*, a lateral view of the same: *e*, two pollen-grains strongly magnified.

FIG. 3.—Spadix of another flower of the same species in which only a few staminate flowers are present, but numerous pistillate ones: *a*, staminate flower; *b*, pistillate flower; *c*, one of the pistils enlarged; *d*, the same in longitudinal section, showing the six orthotropous ovules arising from a basal placenta.

FIG. 4.—Sections of Ovary of Calla Lily: *a*, of lower part, where three placentæ meet in the centre; and *b*, of the upper part, where the placentation is marginal.

FORM FOR THE STUDY OF FLOWERS.

I. ANTHOTAXY.

1. *Indeterminate.*
   - (1) Solitary.
   - (2) Raceme.
   - (3) Compound raceme or panicle.
   - (4) Corymb.
   - (5) Compound corymb.
   - (6) Umbel.
   - (7) Compound umbel.
   - (8) Spike.
   - (9) Compound spike.
   - (10) Head.
   - (11) Spadix.
   - (12) Catkin.
2. *Determinate.*
   - (1) Solitary.
   - (2) Cyme.
   - (3) Compound cyme.
   - (4) Fascicle.
   - (5) Glomerule.
   - (6) Scorpioid cyme.
   - (7) Helicoid cyme.
   - (8) Verticillaster.
3. *Mixed.*
   - (1) Mixed panicle.
   - (2) Thyrsus.
   - (3) Spiked verticillaster.
   - (4) Cymed heads.
   - (5) Corymbed cymes.

II. PREFLORATION.

1. *Individual piece.*
   - (1) Not bent or folded.
   - (2) Inflexed.
   - (3) Reflexed.
   - (4) Conduplicate.
   - (5) Convolute.
   - (6) Circinate.
   - (7) Plicate.
   - (8) Involute.
   - (9) Revolute.
2. *Relative position of pieces.*
   - (1) Valvate series.
     - *a.* Valvate.
     - *b.* Induplicate-valvate.
     - *c.* Reduplicate-valvate.
     - *d.* Involute-valvate.
     - *e.* Revolute-valvate.
   - (2) Imbricate series.
     - *a.* Imbricate.
     - *b.* Quincuncial.
     - *c.* Vexillary.
     - *d.* Equitant.
     - *e.* Half-equitant.
     - *f.* Triquetrous.
3. *Gamophyllous organs.*
   - (1) Contorted.
   - (2) Plicate.
   - (3) Supervolute.

III. KINDS OF ORGANS PRESENT.

1. Bracts.
2. Bracteoles.
3. Involucre.
4. Involucel.
5. Epicalyx.
6. Torus.
7. Calyx.
8. Corolla.
9. Nectaries.
10. Stamens.
11. Staminodes.
12. Pistils.

IV. NUMERICAL PLAN.

1. Monomerous.
2. Dimerous.
3. Trimerous.
4. Tetramerous.
5. Pentamerous.
6. Hexamerous.
7. Heptamerous.
8. Octamerous.
9. Polymerous.

V. SYMMETRY.

1. Symmetrical.
2. Unsymmetrical calyx.
3. " corolla.
4. " stamens.
5. " pistils.

VI. REGULARITY.

1. Regular.
2. Irregular calyx.
3. " corolla.
4. " stamens.

VII. FERTILIZATION.

1. *Autogamous.*
2. *Cleistogamous.*
3. *Allogamous.*
   - (1) Anemophilous.
     - *a.* Monœcious.
     - *b.* Diœcious.
     - *c.* Hermaphrodite.
       - (*a*) Protandrous.
       - (*b*) Protogynous.
   - (2) Entomophilous.
     - *a.* Monœcious.
     - *b.* Diœcious.
     - *c.* Hermaphrodite.
       - (*a*) Protandrous.
       - (*b*) Protogynous.
       - (*c*) Dimorphous.
       - (*d*) Trimorphous.
       - (*e*) Irregularity.
       - (*f*) Special adaptations.

VIII. BRACTS.

1. Herbaceous.
2. Scarious.
3. Petaloid.
4. Deciduous.
5. Persistent.

IX. INVOLUCRE.

1. Herbaceous.
2. Scarious.
3. Sacrious-tipped.
4. Scarious-margined.
5. One-rowed.
6. Two-rowed.
7. Imbricated in several rows.

X. TORUS.

1. Flat.
2. Convex.
3. Hemispherical.
4. Conical.
5. Concave.
6. Hollow.

XI. CALYX.

1. *Insertion.*
   - (1) Hypogynous.
   - (2) Perigynous.
   - (3) Epigynous.
2. *Chorisepalous.*
   - (1) Sepals:
     - Sessile.
     - Unguiculate.
     - Calcarate.
     - Filiform.
     - Linear.
     - Oblong.
     - Clavate.
     - Elliptical.
     - Lanceolate.
     - Oblanceolate.
     - Ovate.
     - Obovate.
     - Orbicular.
     - Emarginate.
     - Cordate.
     - Obcordate.
     - Saccate.
     - Entire.
     - Toothed.
     - Fringed.
     - Herbaceous.
     - Scarious.
     - Petaloid.
     - Length.
3. *Gamosepalous.*
   - (1) Tubular.
   - (2) Rotate.
   - (3) Campanulate.
   - (4) Infundibuliform.
   - (5) Hypocrateriform.
   - (6) Urceolate.
   - (7) Globose.
   - (8) Inflated.

FORM FOR THE STUDY OF FLOWERS (CONTINUED).

(9) Bilabiate.
(10) Saccate.
(11) Calcarate.
(12) Herbaceous.
(13) Petaloid.
(14) Length of tube.
(15) Limb.
  a. Entire.
  b. Toothed.
  c. Fringed.
  d. Crisped.
  e. Lobed.
  f. Parted.
  g. Divided.
(16) Number of component sepals.

4. *Duration.*
  (1) Caducous.
  (2) Deciduous.
  (3) Withering.
  (4) Persistent.
  (5) Accrescent.

XII. COROLLA.

1. *Insertion.*
  (1) Hypogynous.
  (2) Perigynous.
  (3) Epigynous.
2. *Choripetalous.*
  (1) Petals:
    Sessile.
    Unguiculate.
    Coronate.
    Calcarate.
    Filiform.
    Clavate.
    Linear.
    Oblong.
    Elliptical.
    Lanceolate.
    Oblanceolate.
    Ovate.
    Obovate.
    Orbicular.
    Emarginate.
    Obcordate.
    Cordate.
    Entire.
    Toothed.
    Fringed.
    Color.
    Length.
    Number.
3. *Gamopetalous.*
  (1) Tubular.
  (2) Rotate.
  (3) Campanulate.
  (4) Infundibuliform.
  (5) Hypocrateriform.
  (6) Urceolate.
  (7) Globose.
  (8) Inflated.
  (9) Bilabiate.
  (10) Personate.
  (11) Ringent.
  (12) Ligulate.
  (13) Saccate.
  (14) Calcarate.
  (15) Coronate.
  (16) Length of tube.
  (17) Limb.
    a. Entire.
    b. Toothed.
    c. Fringed.
    d. Crispate.
    e. Lobed.
    f. Parted.
    g. Divided.
  (18) Color.
  (19) Number of component petals.
4. *Duration.*
  (1) Caducous.
  (2) Deciduous.
  (3) Withering.
  (4) Persistent.

XIII. ANDRŒCIUM.

1. *Number of stamens.*
  (1) Monandrous.
  (2) Diandrous.
  (3) Triandrous.
  (4) Tetrandrous.
  (5) Pentandrous.
  (6) Hexandrous.
  (7) Heptandrous.
  (8) Octandrous.
  (9) Enneandrous.
  (10) Decandrous.
  (11) Endodecandrous.
  (12) Duodecandrous.
  (13) Polyandrous.
2. *Grouping of stamens.*
  (1) Distinct.
  (2) Monadelphous.
  (3) Diadelphous.
  (4) Triadelphous.
  (5) Polyadelphous.
  (6) Syngenesious.
  (7) Didynamous.
  (8) Tetradynamous.
3. *Insertion of stamens.*
  (1) Hypogynous.
  (2) Perigynous.
  (3) Epigynous.
  (4) Epipetalous.
  (5) Gynandrous.
  (6) Included.
  (7) Protruding.
  (8) Equal in length.
  (9) Unequal in length.
4. *Parts.*
  (1) Filament.
    a. Wanting.
    b. Filiform.
    c. Awl-shaped.
    d. Clavate.
    e. Bearded.
    f. Appendaged.
    g. Petaloid.
  (2) Anthers.
    a. Insertion.
      (*a*) Sessile.
      (*b*) Introrse.
      (*c*) Extrorse.
      (*d*) Adnate.
      (*e*) Innate.
      (*f*) Versatile.
    b. Dehiscence.
      (*a*) Longitudinal.
      (*b*) Transverse.
      (*c*) Valvular.
      (*d*) Porous.
      (*e*) Irregular.
    c. Structure.
      (*a*) Unilocular.
      (*b*) Bilocular.
      (*c*) Quadrilocular.
      (*d*) Dimidiate.
      (*e*) Appendaged.
    d. Connective.
      (*a*) Narrow.
      (*b*) Broad.
      (*c*) Caudate.
  (3) Pollen.
    a. Powdery.
    b. Adhesive.
    c. In masses or pollinia.

XIV. GYNŒCIUM.

1. *Kind.*
  (1) Gymnospermous.
  (2) Angiospermous.
  (3) Apocarpous.
  (4) Syncarpous.
2. *Apocarpous gynœcium.*
  (1) Number of carpels.
3. *Syncarpous gynœcium.*
  (1) Number of component carpels.
  (2) Degrees of union.
    a. Ovaries partly united.
    b. Ovaries wholly united.
    c. Ovaries and part of styles united.
    d. Ovaries and styles united.
    e. Stigmas only united.
4. *Parts.*
  1. Ovary.
  2. Style.
  3. Stigma.

FORM FOR THE STUDY OF FLOWERS (CONTINUED).

5. *Insertion.*
   1. Ovary superior.
   2. " half-superior.
   3. " inferior.
   4. " stipitate.
   5. " sessile.
6. *Ovary.*
   (1) Shape.
      a. Cylindrical.
      b. Oblong.
      c. Ovoid.
      d. Conical.
      e. Globose.
      f. Flattened.
         (*a*) In a vertical direction.
         (*b*) In a transverse direction.
      g. Lobate.
      h. Alate.
      i. Curved.
      j. Contorted.
   (2) Structure.
      a. Unilocular.
      b. Bilocular.
      c. Trilocular.
      d. Quadrilocular.
      e. Quinquelocular.
      f. Sexilocular.
      g. Septilocular.
      h. Multilocular.
   (3) Placentation.
      a. Marginal.
      b. Basilar.
      c. Axillary.
      d. Parietal.
7. *Styles.*
   (1) Number.
   (2) Distinct.
   (3) Partly united.
   (4) Position.
      a. Terminal.
      b. Lateral.
      c. Basal.
   (5) Form.
      a. Filiform.
      b. Clavate.
      c. Prismatic.
      d. Awl-shaped.
      e. Cylindrical.
      f. Short.
      g. Thick.
      h. Petaloid.
      i. Persistent.
      j. Deciduous.
8. *Stigmas.*
   (1) Number.
   (2) Sessile.
   (3) Capitate.
   (4) Convex.
   (5) Flat.
   (6) Conical.
   (7) Concave.
   (8) Beaked.
   (9) Filamentous.
   (10) Plumose.
   (11) Radiate.
   (12) Decurrent.
   (13) Lobed.
   (14) Parted.
   (15) Peltate.
   (16) Fringed.
9. *Ovules.*
   (1) Number.
      a. One in each cell.
      b. Two in each cell.
      c. Several in each cell.
      d. Many-ovuled.
   (2) Position.
      a. Erect.
      b. Ascending.
      c. Horizontal.
      d. Pendulous.
      e. Suspended.
   (3) Structure.
      a. Atropous.
      b. Campylotropous.
      c. Amphitropous.
      d. Anatropous.

XV. TASTE.

1. Insipid.
2. Bland.
3. Sweet.
4. Bitter.
5. Mucilaginous.
6. Pungent.
7. Acrid.
8. Warm.
9. Burning.
10. Cooling.
11. Astringent.
12. Nauseous.
13. Prickling.
14. Saline.
15. Alkaline.
16. Acidulous.

XVI. ODOR.

1. Odorless.
2. Faint.
3. Agreeable.
4. Aromatic.
5. Mint-like.
6. Balsamic.
7. Camphoraceous.
8. Terebinthinous.
9. Pungent.
10. Musky.
11. Disagreeable.
12. Irritating.
13. Nauseous.
14. Narcotic.
15. Putrid.
16. Fetid.

EXERCISE XXVI.

STUDY OF FRUITS: SOME APOCARPOUS FRUITS.

SELECTIONS may be made from fruits of the following plants: the Buttercup (Ranunculus bulbosus, *L.*), the Marsh Marigold (Caltha palustris, *L.*), the Goldthread (Coptis trifolia, *Salisb.*), the Moonseed (Menispermum Canadense, *L.*), the Common Pea (Pisum sativum, *L.*), the Scarlet Runner (Phaseolus multiflorus, *Willd.*), the Cultivated Cherry (Prunus avium, *L.*), the Peach (Prunus Persica, *L.*), the Common Plum (Prunus domestica, *L.*), and the Common Milkweed (Asclepias cornuti, *Decaisne*).

From these are taken for the present purpose two which differ from each other quite widely—the fruit of the Common Pea and that of the Cultivated Cherry.

A fruit may be defined as a ripened pistil. It is nothing more, in most cases, than a hollow vessel or pericarp containing in its interior a seed or seeds. This ripened pistil, like that of the immature one in the flower from which it is derived, may represent a single leaf or a cluster of united leaves; that is, it may be either *apocarpous* or *syncarpous*. It usually follows the structure of the pistil also in its placentation and in the number of its loculi, though rarely both undergo changes in development. The texture of the pericarp shows great variety in its structure in different fruits: it is sometimes thick and sometimes thin; sometimes hard and sometimes soft; sometimes hard exteriorly and soft interiorly, and sometimes the reverse; sometimes smooth exteriorly and sometimes roughened, hairy, spinose, alate, or papillose; and sometimes dehiscent and sometimes indehiscent. Most of the different forms the pericarp assumes have reference in some way to the modes of dispersion—by the wind, by animals, or by some other agency.

But fruits are often something more than single ripened pistils: they may consist of a cluster of distinct pistils which still remain attached to the common receptacle, as in the Blackberry, Anemone, and Mulberry, and these clusters may be the product of a single flower, as in the first two examples mentioned, or the product of a flower-cluster, as in the last and in the Pineapple. In the former case they are called *aggregated* fruits, in the latter *multiple* ones. Moreover, in another way a fruit is not always simply a ripened pistil. Take the Strawberry as an example. Here the fruits proper are the small, seed-like bodies (achenia) sprinkled over the conical, fleshy, scarlet pulp, which is really the greatly enlarged receptacle. The whole is called a fruit; it is an aggregated fruit with an accessory receptacle. So also there are fruits in which the persistent calyx constitutes a conspicuous part, or fruits with an accessory calyx.

With this preface, let us proceed to the study of—

I. THE FRUIT OF THE PEA.—This fruit is commonly called a pod, and in cookery it is treated as a vegetable, but in the botanical sense it is as much a fruit as is an apple or a grape. In making a study of it, it would be well to have before the student both ripe and fully-grown but unripe pods.

(1) *External Characteristics.*—Distinction must first be made between the base and the apex of the fruit. At the former there will be found, when the fruit is ripe, the withered remains of the calyx. It is therefore a *superior* fruit. At the apex will be seen the withered base or scar of the style, which, having performed its functions in the flower, has partially or wholly disappeared along with the stigma. In some kinds of fruits both persist and constitute a part of the ripe fruit.

The pericarp of the ripe Pea fruit is dry, rather thin—that is, of about the thickness of cardboard—and rather hard and elastic. If it has not yet dehisced, there may be observed on opposite edges, and running from base to apex, two sutures—one, usually that on the straighter edge, called the *ventral*, and the other the *dorsal* suture. When the pod is fully ripe slight pressure will cause its dehiscence along these sutures, and at the same time the two valves become somewhat twisted. These movements are the result of unequal drying, which produces a strain upon the pericarp, and it needs only a touch or a slight blow to cause the structure to yield along its weaker portions, which in this case are the sutures. As a result of the dehiscence the seeds are usually thrown

the ventral or the dorsal sutures or both, but the valves break away from the placentæ, leaving the latter in position, as in the capsules of Cardamom. This is the *septifragal* mode of dehiscence.

In all these types the dehiscence may be either partial or complete, and it may begin at the apex, the most common mode, or it may begin at the base. Now, the mode of dehiscence that occurs in the Poppy capsule, though technically called "porous" or "valvular," is really one of partial septicidal dehiscence, where the opening begins at the top. In the Campanula the dehiscence is valvular, but occurs at the base of the capsule.

Still another mode of dehiscence is seen in that modification of the capsule called the pyxis, where Nature wholly ignores the original sutures, and the opening is transverse or *circumscissile*, as in Portulacca, the Marcgravia, and the South American Lecythis. Moreover, the dehiscence in a few instances takes place without order or by irregular rupture through any part of the pericarp.

(4) *Provision for Dispersion.*—The seeds of the Poppy are very numerous; according to M. C. Cooke, a single capsule may contain as many as forty thousand of them. When ripe they become detached from the placentæ and fall to the bottom of the capsule. But the valves of dehiscence, as has been seen, are at the opposite end; how is it, then, that the seeds escape? It will be observed that the capsule when ripe is erect on the end of a dead but elastic stalk. In a stiff breeze this stalk is swayed to and fro, and when the motion is sufficiently rapid some of the seeds are thrown out of the openings near the apex, and, being small and light, are caught up by the wind and conveyed often to a considerable distance from the parent plant. During every wind-storm the process is repeated, until finally the capsules are emptied.

II. THE FRUIT OF COLCHICUM.—(1) *External Characteristics.*—The brownish capsule is an inch or more long, oblong, abruptly pointed, longitudinally ribbed and furrowed, and between the ribs and furrows somewhat rugose. By observing closely the ribs and furrows there will be obtained clear evidence that the fruit is a three-carpeled pistil. The dehiscence affords further evidence of the same thing. This dehiscence is clearly septicidal, for the seeds are found attached to the edges of the valves.

(2) *Internal Structure.*—Making a cross-section of the fruit

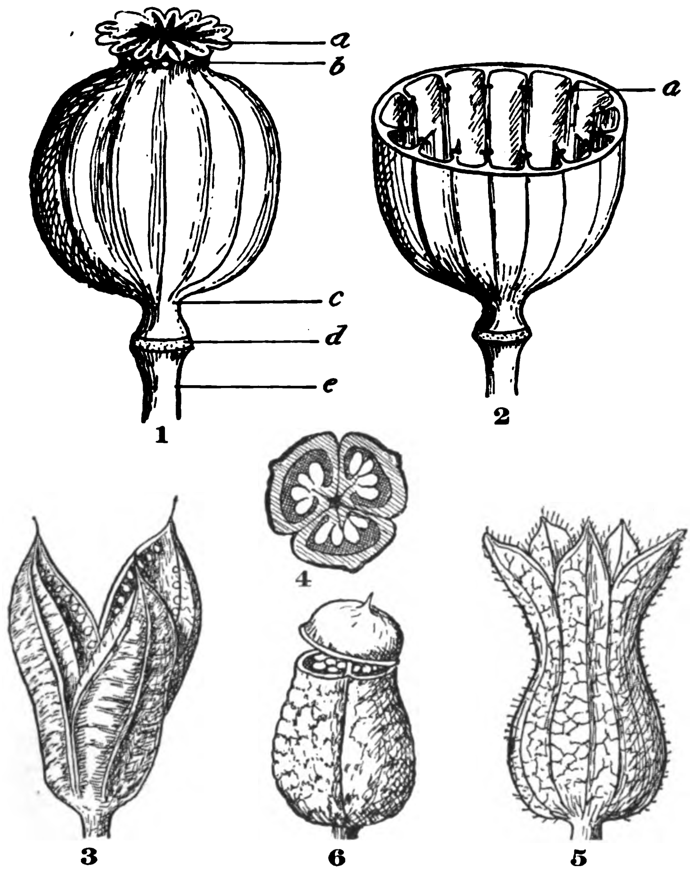


PLATE XXXII., FIG. 1.—Poppy-capsule (about natural size): *a*, stigma; *b*, one of the valves of dehiscence; *c*, stalk of capsule; *d*, portion of receptacle on which sepals, petals, and stamens were inserted; *e*, peduncle.

FIG. 2.—The same in transverse section, showing marginal placentation: *a*, one of the placentæ.

FIG. 3.—Capsule of Colchicum (somewhat enlarged), showing septicidal dehiscence.

FIG. 4.—Transverse section of unripe Fruit, showing axile placentation and three-carpeled structure.

FIG. 5.—Calyx of Hyoscyamus, enclosing pyxis. (Somewhat enlarged.)

FIG. 6.—Pyxis of Hyoscyamus, showing its two-celled and two-carpeled character and its mode of dehiscence.

EXERCISE XXVIII.

FURTHER STUDY OF SYNCARPOUS FRUITS.

FROM the list given at the beginning of the last exercise are selected the following for this exercise: the fruit of the Coriander and that of the Lemon.

I. THE FRUIT OF CORIANDER.—Coriander belongs to the natural order Umbelliferæ, the fruits of which have a close family resemblance and differ quite widely from those of most other plants in several important particulars. The fruits are called *cremocarps*, and a cremocarp may be defined as an inferior, two-carpeled dry fruit that is usually ten-ribbed longitudinally and is provided with oil-tubes or *vittæ*, has an epigynous disk, and, when ripe, splits readily, usually spontaneously, into two symmetrical, one-seeded half-fruits or *mericarps*. Between the primary ridges or *juga* there sometimes occur secondary or intermediate ones. The mericarps not infrequently remain suspended for a time after dehiscence from the top of a slender prolongation of the receptacle, called the *carpophore*. This may be either single or separated into two thread-like portions nearly to its base. The oil-tubes, when present, usually occur in the furrows between the primary ribs or on the commissural surfaces. The two styles are usually persistent and thickened at their bases into bodies called *stylopodia*. The seeds are albuminous, pendulous, and anatropous.

While it is an easy matter to distinguish members of this order from those of other orders by their fruits, the latter also afford the best means of distinguishing the species of the order from each other, since the cremocarps differ not only in shape and size, but also in the number and position of the oil-tubes, in the presence or absence of secondary ribs, in the surface appendages, etc.

The fruits of Coriander, as in most others of the order, occur in compound umbels. The individual fruits are nearly spherical and four or five millimètres long. At the apex of each are observed two stylopodia, each rising to a point, or sometimes still

(2) *The Internal Structure.*—Making a cross-section through the middle, it will be found that the thickish pericarp is differentiated into two portions—an outer, which is yellow and contains the secretion-vessels already mentioned, and an inner white and spongy portion destitute of glands.

Interior to the pericarp is the pulpy portion, divided by radial partitions into a varying number of compartments. In the inner angle of each compartment or loculus are usually one or two seeds, and these are attached to the axis. The placentation, therefore, is axile, and there are as many carpels in the fruit as there are loculi, which may be from five to fifteen or more.

The pulp which contains the acid juice is structurally altogether different from that of the Cherry, Peach, or, in fact, from that of any other fruits outside the family (Aurantiaceæ) to which the Lemon belongs. The juice is contained in numerous thin-walled sacs which are separate from each other and are borne on the walls of the loculus. By tracing their development they may easily be proved to be hairs which at first are like ordinary simple plant-hairs, but which, as the ovary develops into the fruit, become thick and succulent.

Citrus fruits resemble berries except for this peculiarity of their pulp, which justifies calling them by a different name, that of *hesperidia.*

The seeds have a leathery testa, are anatropous and exalbuminous, and the dicotyledonous embryo is frequently single, but sometimes, as in the orange, there are two or more embryos in each seed. The cotyledons are commonly somewhat unequal, and sometimes there are three or four instead of two. The plumule is usually well developed.

So far as the relation of the structure of this fruit to the dispersion of the plant is concerned, it may be remarked that the volatile oil in the pericarp is probably defensive against the attacks of insects and fungi, while not preventing the fruits from being eaten, when ripe, by larger animals. The seeds, while not specially protected by a hard enclosure, are nevertheless probably rejected, as a usual thing, by animals that feed upon the fruits, by reason of their bitter taste.

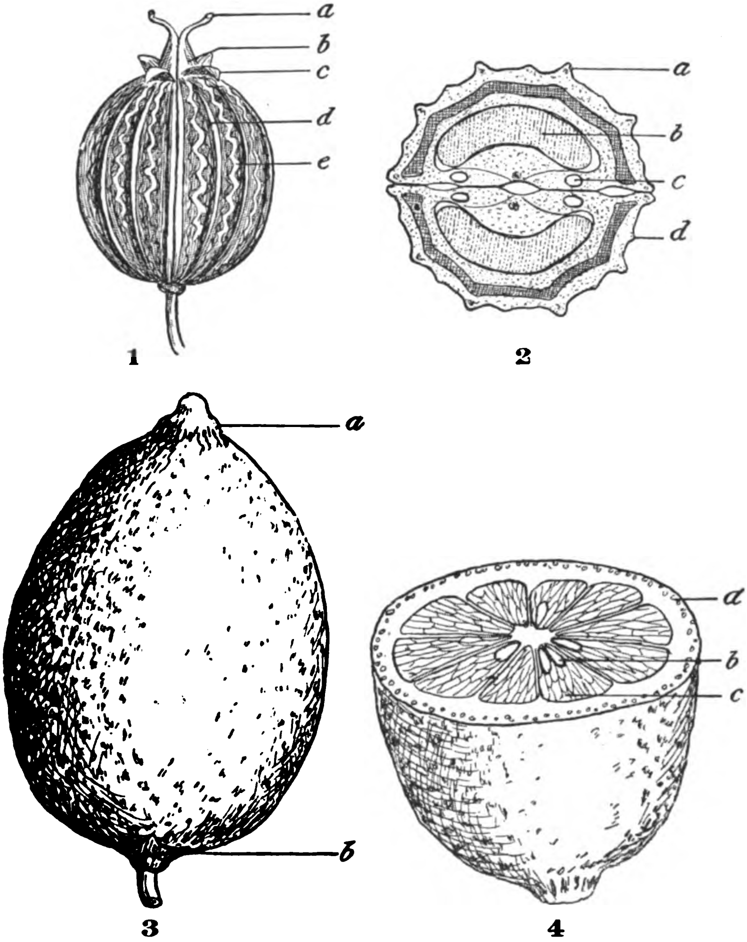


PLATE XXXIII., FIG. 1.—Fruit of Coriander (enlarged about 6 times): *a*, one of the stigmas sometimes persisting until the fruit is ripe; *b*, one of the stylopodia; *c*, one of the calyx-teeth; *d*, one of the primary ribs; *e*, one of the secondary ribs.

FIG. 2.—Transverse section through one of the Cremocarps (enlarged about 8 diameters): *a*, one of the primary ribs; *b*, seed; *c*, one of the villæ or oil-tubes; *d*, one of the secondary ribs.

FIG. 3.—Lemon (⅔ natural size): *a*, nipple-shaped apex; *b*, calyx at base.

FIG. 4.—Transverse section of the same, showing placentation: *a*, glandular portion of pericarp; *b*, a seed; *c*, one of the pulp-sacs, modified hairs.

EXERCISE XXIX.

STUDY OF ACCESSORY FRUITS.

THE following are convenient for study: the Strawberry (Fragaria Virginiana, *Mill.*, or F. vesca, *L.*), the Rose (the hips of any one of our common species, as Rosa setigera, *Michx.*, R. Carolina, *L.*, or R. rubiginosa, *L.*), the Mulberry (Morus rubra, *L.*), the Wintergreen (Gaultheria procumbens, *L.*), the Pineapple (Ananassa sativa, *Lind.*), and the Fig (Ficus Carica, *L.*).

From this list are selected for the present study the fruits of the Wintergreen and the Fig.

I. THE WINTERGREEN is an ericaceous plant very common in most portions of the Eastern United States, and it is particularly abundant in those portions of the country which abound in pines or other needle-leaved evergreens. From the thin, trailing stem or rhizome rise vertically, to the height of from three to six inches, slender, usually simple branches which bear a few crowded alternate or apparently whorled evergreen leaves.

The plant bears its white, nodding, urceolate blossoms singly in the axils of the leaves. The blossoming is in June and July, and the scarlet, berry-like fruits are matured in late summer or in early autumn, but persist on the plant until late in the succeeding spring.

(1) *External Characteristics.*—The so-called berries are nearly spherical, about a centimetre in diameter, somewhat depressed and bracteolate at the base, with five fleshy teeth at the apex, and with a simple persistent style.

The five teeth referred to are really the limb of the persistent gamosepalous calyx, which in fruit develops considerably, becomes succulent, acquires a scarlet color, and constitutes the really edible part of the fruit. This is clearly evidenced by a study of the

(2) *Internal Structure.*—On making a transverse section well toward the apex of the fruit there will be observed a five-celled,

close inspection are found not to be seeds, but small fruits (utricles), each with a single seed loosely enclosed in a thin, dry pericarp. Each fruitlet, as may easily be seen by studying its development, is the product of a single small flower.

In examining the Fig in blossom it would be difficult for the novice even to find the flowers, as he would scarcely think of looking for them concealed in the ends of twigs. These twigs, moreover, do not look very different from the ordinary ones, except that they are slightly thickened and pyriform at the apex, and bear just below this thickened portion a few scaly bracts instead of true leaves. The minute aperture at the apex, closed as it is by scales, might easily escape observation altogether.

If a longitudinal section of one of these branches be made, there will be found in the interior hollow a few minute staminate flowers located near the apical aperture, and very numerous small pistillate flowers occupying the remainder of the interior surface. The former consist of a gamosepalous, three-parted calyx and three introrse stamens; the latter also consist of a gamosepalous calyx (which, however, may be from three- to five-parted) and a single one-ovuled pistil which has a style, inserted more or less laterally, and a two-lobed stigma. The flowers are also stalked, and in development the stalks and calyx become fleshy, while the fruit proper becomes dry and utricle-like or achenium-like.

It will thus be seen that what is called the fig is not a single fruit, but a multiple or collective one; but it is also something more, for the greater portion of its bulk is composed of the succulent hollow receptacle. Such a multiple fruit with an accessory receptacle has been called by botanists a *syconium*.

(3) *Mode of Dispersion.*—Regarding this it may be remarked as significant that, besides being attractive and palatable when ripe, the seeds possess laxative properties which doubtless render them more likely to escape digestion, and at the same time ensure their dispersion by frugivorous birds and mammals.

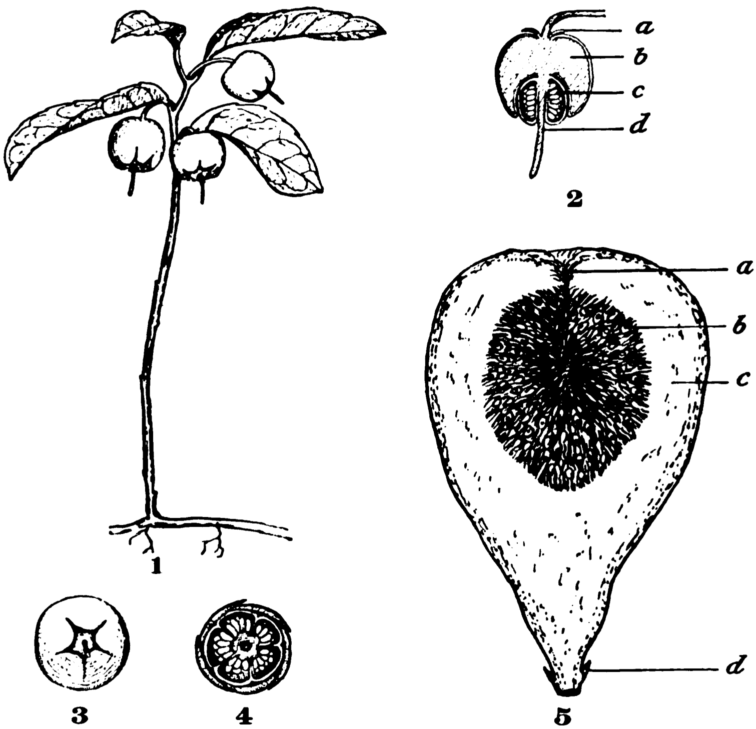


PLATE XXXIV., FIG. 1.—Whole Plant of Wintergreen in fruit (⅔ natural size).

FIG. 2.—Longitudinal section of one of the Fruits (enlarged): *a*, bract at the base; *b*, fleshy calyx; *c*, fruit proper; *d*, persistent style.

FIG. 3.—View of upper end of Fruit, showing the five calyx-teeth, the upper end of the capsule, and the style.

FIG. 4.—View of cross-section through the upper part of one of the Fruits, showing the five-celled, many-seeded capsule surrounded by the calyx.

FIG. 5.—Longitudinal section of a Fig (about natural size): *a*, apical aperture; *b*, one of the fruitlets; *c*, hollow receptacle; *d*, one of the bracts at the base.

FORM FOR THE STUDY OF FRUITS.

I. SIZE.
  1. Length.
  2. Breadth.
  3. Thickness.

II. COLOR.
  1. Exteriorly.
  2. Interiorly.

III. SHAPE.
  1. Globose.
  2. Depressed-globular.
  3. Oblong.
  4. Ovoid.
  5. Conical.
  6. Pyriform.
  7. Flattened.
  8. Winged.
  9. Ribbed.
  10. Lobed.
  11. Nodular.
  12. Irregular.

IV. SURFACE AND APPENDAGES.
  1. Glabrous.
  2. Polished.
  3. Glaucous.
  4. Punctate.
  5. Glandular-hairy.
  6. Rugose.
  7. Scabrous.
  8. Verrucose.
  9. Pubescent.
  10. Puberulent.
  11. Sericeous.
  12. Lanuginous.
  13. Tomentose.
  14. Villose.
  15. Pilose.
  16. Floccose.
  17. Hispid.
  18. Strigose.
  19. Spinose.
  20. Echinate.
  21. Aculeate.
  22. Pappiferous.

V. INTERNAL STRUCTURE.
  1. *Texture of pericarp.*
    (1) Succulent throughout.
    (2) Succulent exteriorly.
    (3) Succulent interiorly.
    (4) Farinaceous throughout.
    (5) Farinaceous exteriorly.
    (6) Farinaceous interiorly.
    (7) Oily throughout.
    (8) Oily exteriorly.
    (9) Oily interiorly.
    (10) Waxy exteriorly.
    (11) Coriaceous throughout.
    (12) Coriaceous exteriorly
    (13) Coriaceous interiorly
    (14) Ligneous throughout
    (15) Ligneous exteriorly.
    (16) Ligneous interiorly.
    (17) Fibrous exteriorly.
    (18) Corneousthroughout.
    (19) Corneous exteriorly.
    (20) Corneous interiorly.
    (21) Bony throughout.
    (22) Bony exteriorly.
    (23) Bony interiorly.
  2. *Number of loculi.*
    (1) Unilocular.
    (2) Bilocular.
    (3) Trilocular.
    (4) Quadrilocular.
    (5) Quinquelocular.
    (6) Sexilocular.
    (7) Multilocular.
  3. *Seeds in each loculus.*
    (1) One.
    (2) Two.
    (3) Several.
    (4) Many.

VI. KIND.
  1. *Inferior.*
  2. *Superior.*
  3. *With accessory organs.*
    (1) Accessory calyx.
    (2) Accessory involucre.
    (3) Accessory receptacle.
  4. *Without accessory organs.*
  5. *Product of single flower.*
    (1) Of one pistil.
      a. Indehiscent.
        Akene.
        Utricle.
        Caryopsis.
        Samara.
        Double samara.
        Glans.
        Cremocarp.
        Drupe.
        Tryma.
        Berry.
        Hesperidium.
        Pepo.
        Pome.
      b. Dehiscent forms.
        Follicle.
        Legume.
        Loment.
        Cochlea.
        Capsule.
          Septicidal dehiscence.
          Septifragal dehiscence.
          Loculicidal dehiscence.
          Porous dehiscence.
        Silique.
        Silicle.
        Pyxis.
    (2) More than one pistil.
      a. Etaerio.
      b. Strawberry.
      c. Hip or cynarrhodium.
  6. *Product of flower-cluster.*
    (1) Sorosis.
    (2) Syconium.
    (3) Strobile.
    (4) Galbulus.

VII. TASTE.
  1. Insipid.
  2. Bland.
  3. Sweet.
  4. Bitter.
  5. Mucilaginous.
  6. Pungent.
  7. Acrid.
  8. Warm.
  9. Burning.
  10. Cooling.
  11. Astringent.
  12. Nauseous.
  13. Prickling.
  14. Saline.
  15. Alkaline.
  16. Acidulous.

VIII. ODOR.
  1. Odorless.
  2. Faint.
  3. Agreeable.
  4. Aromatic.
  5. Mint-like.
  6. Balsamic.
  7. Camphoraceous.
  8. Terebinthinous.
  9. Pungent.
  10. Musky.
  11. Disagreeable.
  12. Irritating.
  13. Nauseous.
  14. Narcotic.
  15. Putrid.
  16. Fetid.

it should be noted that every seed possesses at least two, and usually only two, scars, that of the micropyle and that called the hilum, the latter marking the place where the seed has broken away from its funiculus or from the placenta. One may tell by the relative position of these scars whether the seed is atropous, anatropous, campylotropous, or amphitropous—always an important point to determine. If the seed is straight and the two scars are at opposite ends, the seed is *atropous;* if it is straight and the two scars are adjacent to each other at one end, it is *anatropous;* if straight and the chalaza is at one end, the micropyle at the opposite one, and the hilum intermediate between the two, it is *amphitropous;* and if the seed is bent or curved so that the opposite ends and the two scars are approximated, it is *campylotropous.*

In some seeds the nucellus consists wholly of embryo; that is, the seeds possess no extra food store, and are hence called *exalbuminous,* as was found to be the case with the Cherry; other seeds possess both the embryo and the extra food store: they are described as *albuminous.* In an albuminous seed the albumen or extra food store may be developed either wholly within the embryo-sac or outside of it. In the former case the albumen is called endosperm; in the latter, perisperm. In a few seeds both endosperm and perisperm are present.

I. The Almond Seed.—The fruit of the Almond is drupaceous like the peach and the cherry, only the sarcocarp is less succulent and is not employed for food. The almond of the markets corresponds to the pit of the peach; that is, the outer hard part is endocarp and contains the seed.

(1) *External Characteristics.*—Carefully removing the seed, so as to observe its attachments, it will be noticed that it has on one edge, near its smaller end, a narrow hilum-scar extending up along the edge of the seed from one-third to one-half of the length of the latter. At the small end of the seed, immediately adjoining one end of this scar, is the small but distinct micropyle-scar. These scars being adjacent and the body of the seed not being bent, the seed is known to be anatropous. At or near the large end may be seen a roundish spot, often darker than the rest of the surface, where the two coats still adhere to each other: this is the chalaza. From this point veins are seen to radiate and con-

verge toward the opposite end. On the hilum edge may also be traced a straight line and a slight ridge which connects the hilum and chalaza: this is the raphé.

The general outline of the seed is ovate; it is flattish, somewhat wrinkled from drying, and more or less longitudinally striate. The length is from two to two and one-half centimetres, the width from one to one and one-half centimetres, and the greatest thickness from one-half to three-fourths of a centimetre. The testa is thin and brown; it is also scurfy from large, bladdery, exterior cells.

(2) *Internal Structure.*—Soaking the seed in water for a few hours and removing the coats, the latter are found to be two in number and quite distinct except at the chalaza; the inner one is membranous and white, and covers the white nucellus. The latter is found to consist wholly of embryo; the seed, therefore, is exalbuminous.

The embryo is straight; that is, the radicle and the cotyledons point in opposite directions. The cotyledons are large and thick, constituting much the larger part of the whole embryo. As shown in the illustration (Pl. XXXV., Fig. 2), they are not always equal, but one may be considerably larger than the other. They are usually more or less cordate at the base. The radicle and caulicle, though relatively small, are distinctly recognizable by the naked eye, as is also the plumule, which is well developed.

(3) *Tests.*—Applying iodine solution to a freshly-cut surface, it will be observed that no blue color is developed, and therefore no starch is present. If the solution be strong, however, a brown color is produced, which indicates the presence of proteids. But the great bulk of the food material stored in the embryo consists of fixed oil. The presence of the latter may be proved by thoroughly warming the freshly-cut surface of a seed and rubbing it on a clean sheet of white paper, when a non-volatilizable greasy spot will be left.

II. The Pumpkin Seed.—(1) *External Characteristics.*—The seeds are smooth, white, oblong-ovate, strongly flattened, with a raised border extending from the smaller end around the edge to the same end. The hilum and micropyle-scars are located side by side at the smaller end of the seed, and, though not large, are distinct. The chalaza is at the opposite end, but the raphé in the fully-developed seed merges into the border above described, and is no longer recognizable. The length of the seed is about two centimetres, its greatest breadth about one centimetre, and its greatest thickness about two millimetres.

(2) *Internal Structure.*—The testa is coriaceous in texture and distinct from the thin, membranous, olive-green tegmen, which immediately envelops the embryo, there being no albumen.

The embryo consists of two oblong-ovate or elliptic, equal cotyledons, flat on their applied faces and convex on their exterior ones, each provided with about seven veins radiating from the base to the entire margin.

The caulicle and radicle together form a small, somewhat flattened cone, and the plumule exists only as the merest conical point between the bases of the cotyledons. It is, in fact, but an epicotyl, and not a plumule in the proper sense, no leaves being developed upon it until after germination begins.

Tests show that the seed possesses abundance of albuminous and oily matter, but no starch.

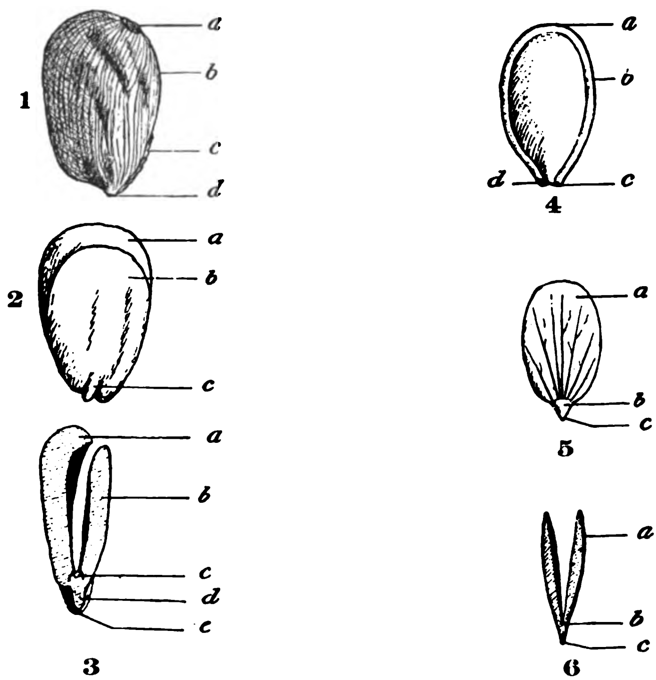


PLATE XXXV., FIG. 1.—Almond Seed (about natural size): *a*, chalaza; *b*, raphé; *c*, hilum; *d*, micropyle.

FIG. 2.—The same with the seed-coats removed, consisting wholly of embryo: *a*, the larger of the two cotyledons partly concealed behind the smaller one, *b*; *c*, the radicle.

FIG. 3.—The same cut lengthwise through the middle of the two cotyledons and the radicle: *a*, larger cotyledon; *b*, smaller cotyledon; *c*, plumule; *d*, caulicle; *e*, one of the projecting lower lobes of the larger cotyledon.

FIG. 4.—Seed of Pumpkin (about natural size): *a*, chalaza; *b*, raised border; *c*, hilum; *d*, micropyle.

FIG. 5.—Embryo of same, showing outer face of one of the cotyledons, *a*, the caulicle, *b*, and the radicle, *c*.

FIG. 6.—Embryo of same, cut vertically through the middle of the cotyledons: *a*, one of the cotyledons; *b*, the epicotyl, scarcely yet developed into a plumule; *c*, the radicle.

EXERCISE XXXI.

STUDY OF ALBUMINOUS SEEDS.

SEEDS of the following plants are not difficult to obtain and are good for study: the Common Morning-glory (Ipomæa purpurea, *Lam.*), Stavesacre (Delphinium Staphisagria, *L.*), the Yellow Pond-lily (Nuphar advena, *Ait.*), Sweet Cicely (Osmorrhiza longistylis, *DC.*), Nux Vomica (Strychnos Nux-vomica, *L.*), Datura Stramonium, *L.*), Castor Bean (Ricinus communis, *L.*), Croton-oil Plant (Croton Tiglium, *L.*), Yellow Dock (Rumex crispus, *L.*), and Black Pepper (Piper nigrum, *L.*).

For this exercise the Castor Bean and Black Pepper are selected.

I. THE CASTOR BEAN.—These seeds are easily obtainable from druggists or from dealers in agricultural seeds.

(1) *External Characteristics.*—They are ovate or elliptical in outline, convex on one side and on the other flattish, or rather with two flattish surfaces inclined at a very obtuse angle to each other. The two surfaces are shown respectively in Figures 1 and 2 (Pl. XXXVI.). The seeds measure from one to one and one-half centimetres in length, from six to nine millimetres in width, and from four to six millimetres in thickness. At one end is a rounded or more or less two-lobed strophiole or caruncle which partly conceals the hilum and micropyle, located side by side at the same end. The chalaza is usually evident to the eye as a somewhat elevated point near the opposite end. Between the hilum and the chalaza, on the flatter side of the seed, may be traced the straight raphé, which appears as a slight ridge.

The whole surface, except the brownish or yellowish strophiole, is maculate with irregular reddish-brown spots and lines on a light-brown or grayish background. The surface is also smooth and polished.

(2) *Internal Structure.*—It is usually best, as a preliminary to the dissection of a seed, to soak it for a few hours in water, but in this instance it is hardly necessary. Removing the outer coat

grains should be soaked for several hours in water, and then longitudinal sections should be made of them.

Internal Structure.—Interior to the thin seed-coats, which lie in close contact with the wall of the endocarp, is a large quantity of albumen and a relatively minute embryo. The seed is erect and orthotropous, and the embryo is straight, with its radicle close to the micropyle. But a point worthy of special note is the fact that the albumen is not all alike: it is divided into two distinct portions, separated from each other by a sharp line and differing from each other in texture and color. One of them is light-colored, even white, and occupies a small area at the apex of the seed; it is the part in which the embryo is imbedded. The other is darker, harder, freely besprinkled with secretion-cells, and occupies all the rest of the interior of the seed. These two portions of the albumen, though serving the same purpose, are really quite different in their origin: the former is the endosperm, so called because it is developed within the embryo-sac of the ovule while the embryo is developing; the latter is the perisperm: it is equally a food store, but is developed outside the embryo-sac in the nucellus.

In the great majority of seeds that possess an albumen the latter consists of endosperm only, the embryo-sac absorbing all the rest of the nucellus into itself in the process of its development; in a few instances, as in Pepper, both the embryo-sac with its contents and that portion of the nucellus exterior to the embryo-sac develop *pari passu*, and both endosperm and perisperm are found in the mature seed; and in a few other cases the albumen consists of perisperm only, the endosperm at first developed being absorbed by the embryo before the seed matures. This is the case with the Canna of our gardens.

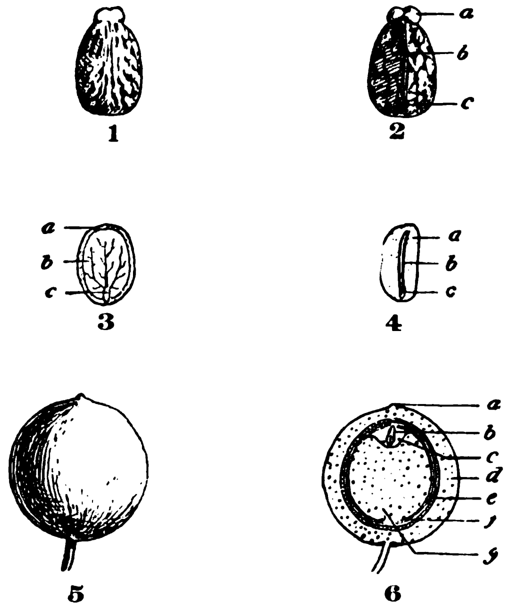


PLATE XXXVI., FIG. 1.—Castor Bean (about natural size): view of convex surface.

FIG. 2.—The same: view of fatter of the two sides: *a*, strophiole; *b*, raphé; *c*, chalaza.

FIG. 3.—Nucellus of Castor Bean, laid open so as to show embryo: *a*, albumen; *b*, one of the cotyledons; *c*, caulicle.

FIG. 4.—Nucellus of Castor Bean, cut vertically in such a manner that the section passes through the middle of both cotyledons: *a*, albumen; *b*, one of the cotyledons; *c*, caulicle.

FIG. 5.—Drupe of Black Pepper (magnified about 3 diameters).

FIG. 6.—The same in longitudinal section: *a*, apex of fruit, showing scar of style; *b*, embryo; *c*, endosperm; *d*, sarcocarp containing oil-cells; *e*, putamen or endocarp; *f*, seed-coats; *g*, perisperm.

EXERCISE XXXII.

STUDY OF SEEDS: MONOCOTYL AND DICOTYL EMBRYOS.

AMONG seeds having monocotyledonous embryos the following are suitable for study: the Indian Corn (Zea Mays, *L.*), the Wheat (Triticum vulgare, *Villars*), the Oat (Avena sativa, *L.*), the Barley (Hordeum distichon, *L.*), the Canna (Canna edulis, *Ker*), the Date Palm (Phœnix dactylifera, *L.*), the Cocoanut Palm (Cocos nucifera, *L.*), and the Water Plantain (Alisma Plantago, *L.*).

Among those with polycotyledonous embryos almost any species of the genus Pinus may be selected, but especially those with large seeds, such as Pinus monophylla, *Torr.*, Pinus flexilis, *James*, Pinus Torreyana, *Parry*, and Pinus ponderosa, *Douglass*.

I. A SEED HAVING A MONOCOTYLEDONOUS EMBRYO.—A selection is made of the seed of the Indian Corn. What is commonly called the seed, however, is really a one-seeded fruit whose pericarp-wall is thin and closely adherent to the coats of the seed. Such a fruit is called a *caryopsis*. That of the Corn is one of many similar fruits aggregated on a common receptacle popularly called the "cob." The so-called "tassels" of the Corn are the clusters of staminate flowers; the "silks" that protrude from the young "ear" are the styles and stigmas; the "kernels" (fruits) are the ripened ovaries; and the "husks" are bracts which subtend the pistillate inflorescence, and, persisting, form the covering of the fruits until they are ripe.

There are, as is well known, a great many different kinds of Maize, but all of them, from the most pigmy varieties of "popcorn" to the giant "dent corn," are probably but varieties of a single species.

(1) *External Characteristics.*—In the larger varieties of Field Corn—Yellow Dent, for example—the fruits may be twelve or fifteen millimetres long by ten or twelve millimetres wide and five or six millimetres thick. The sides are more or less flattened by the mutual pressure of the grains during growth. On one of

the flat faces is a shallow depression, oval or ovate in outline, beginning near the hilum and extending about two-thirds the length of the grain. It is usually lighter in color than the rest, and marks the position of the embryo. Thus the seed, aside from its coats, is composed of a large quantity of albumen against one side of which is lodged the relatively small embryo. The hilum- and micropyle-scars are located at one end, the narrower one, and near together, and since the body of the seed is not bent, it is anatropous.

Plate XXXVII. (Fig. 1) shows a kernel of Yellow Dent Corn about twice the natural size. *a* is the depression in which lies the embryo, and *b* and *c* are respectively the micropyle- and hilum-scars.

(2) *Internal Structure.*—If one of the grains be soaked for a few hours in tepid water to facilitate cutting, and a vertical section be made in such a manner that it passes medially through the embryo, the structure shown in Plate XXXVII. (Fig. 2) will be revealed. At the top is a depression, shown at *a* in the figure. The exterior membrane is the pericarp-wall, interior to which, without any intervening space, are seen the rudimentary seed-coats. At *c* is the dense horny albumen whose cells are closely packed with starch-grains, and at *b* a less dense and more farinaceous portion. At *d* is shown the large body often called the *scutellum*, much larger than all the rest of the embryo put together. It has by some been regarded as a part of the axis, but it is really an outgrowth from the base of the cotyledon, and should therefore be regarded as a part of it. It almost completely enwraps the rest of the embryo and supplies nutriment for its growth, absorbing the food materials from the endosperm, with which it is in contact. The cotyledon proper is shown at *m*, and it fits over the well-developed plumule like a candle-extinguisher. The plumule is shown at *e*, the caulicle or axis at *f*, the radicle at *g*, and the root-sheath or *coleorhiza*, an organ not occurring except in monocotyledonous embryos, at *i*.

If a grain be allowed to germinate until the radicle and plumule have emerged from their enclosure, the relation of parts will be understood better. Such a grain is shown in Figure 3 (Pl. XXXVII.). The root-sheath, pierced by the growing radicle, is shown at *d;* at *e* adventitious roots destined soon to replace the primary root, which early ceases to grow, are beginning to emerge from the scutellum; and at *a* is shown the plumule, fast developing into a leafy shoot.

Now, what are the most essential differences between dicotyledonous embryos, such as have already been studied, and monocotyledonous ones like that of Maize? (1) There are in the former two opposite and usually equal cotyledons, while in the latter, if more than one leaf be developed in the embryo, they are alternate, and the one lowest down on the axis is much larger and envelops the rest. (2) In the great majority of monocotyledonous embryos a root-sheath is present, but not in dicotyledonous ones. (3) In germination the portion of the caulicle below the cotyledon, called the *hypocotyl*, does not elongate, but remains short, the growth of the stem in length being due chiefly to the elongation of that portion above the cotyledon, called the *epicotyl*. This is expressed by saying that the germination is *endorhizal*. In dicotyledonous embryos, on the other hand, the hypocotyl usually elongates more or less, often very considerably, as well as the epicotyl. This is expressed by saying that the germination is *exorhizal*. (4) The germination of a monocotyledonous embryo gives rise to a stem which, near its base at least, is nearly always obconical in form; that is, the larger diameter is toward the apex rather than at the base, the reverse of what it is in the stem developed from a dicotyledonous embryo. (5) In nearly all monocotyledonous embryos the primary root stops growing at an early period after germination, and in some instances scarcely develops at all, being replaced functionally by the growth of lateral or adventitious roots. These sometimes may even be recognized in the embryo before germination. In dicotyledonous embryos, on the other hand, the primary root usually persists longer, frequently throughout the life of the plant, giving rise to huge tap-roots and an extensive root-system of which it is the axial portion.

These differences in the embryos form the basis of the division of angiospermous plants into two great sub-classes, the monocotyls and the dicotyls, which also differ from each other in many other particulars to which in previous Exercises attention has been called—namely, in the structure of their roots, in the structure and growth of their stems, in the venation of their leaves, and in the numerical plan of their flowers.

the radicular end of the embryo, and are also shown on Plate XXXVII. (Fig. 6, *b*). At *b* (Pl. XXXVII. Fig. 7) is the radicle; at *c*, the caulicle; at *d*, a small conical prominence representing the plumule, though it consists wholly of a portion of the axis (epicotyl), no leaves being as yet formed upon it; and at *e*, one of the several cotyledons. These, in this species, range in number from six to ten, and form a whorl.

In the cross-section of the seed, shown in Figure 8 (Pl. XXXVII.), the section passes through the cotyledons transversely. In this instance they are nine in number, arranged, it will be seen, in a circle. A minute dot is perceptible in each cotyledon, the beginning of the single vein that traverses it when mature.

Except for the number of cotyledons, this embryo is in all essential respects like the dicotyledonous ones already studied. In fact, in many of the Gymnospermæ the embryos do not even possess this difference, having but two cotyledons. The mode of germination is also essentially like that of dicotyledonous embryos.

Though the Gymnospermæ are on the whole lower in the life-scale than either monocotyls or dicotyls, judging by their embryos and by the structure of their stems, which are closely similar to those of dicotyls, one may conclude that they are more nearly allied to the latter group than to the former.

It should be noted that there are a few cases among plants that are really dicotyls where one of the cotyledons becomes aborted, as in Abronia; in some other rare instances—as in Cuscuta, for example—both cotyledons disappear; and in a few instances also the cotyledons become abnormally multiplied, or polycotyledonous. Embryos of the Lemon, for example, have been seen with as many as four cotyledons, though the normal number is two.

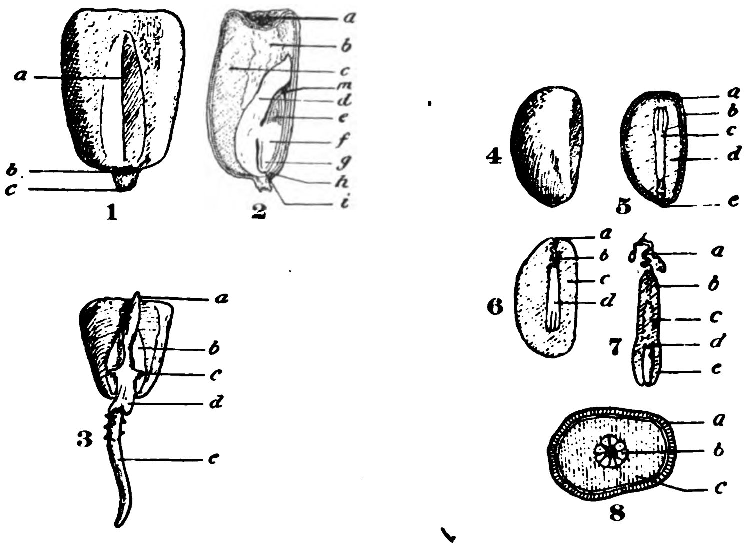


PLATE XXXVII., FIG. 1.—A Grain of Yellow Dent Corn (about twice natural size): *a*, depression on one side, in which lies the embryo; *b*, micropyle; *c*, hilum.

FIG. 2.—One of the grains in longitudinal section: *a*, depression at top of grain; *b*, lighter and less dense portion of endosperm; *c*, denser portion; *d* and *h*, portions of scutellum; *e*, plumule; *f*, axis or caulicle; *g*, radicle; *i*, root-sheath or coleorhiza; *m*, cotyledon.

FIG. 3.—A Grain of Maize in process of germination: *a*, plumule; *b*, portion of scutellum; *c*, an adventitious root; *d*, root-sheath through which the primary root, *e*, has burst.

FIG. 4.—Seed of Pinus monophylla (enlarged about 1½ diameters).

FIG. 5.—The same cut longitudinally, showing internal structure: *a*, outer seed-coat; *b*, inner coat; *c*, embryo; *d*, albumen; *e*, micropyle.

FIG. 6.—Nucellus of Seed separated from the seed-coats and laid open longitudinally: *a*, opening at micropylar end; *b*, remains of embryos that did not develop, and of suspensory filaments; *c*, albumen; *d*, embryo.

FIG. 7.—An Embryo removed from its cavity in the albumen (considerably magnified): *a*, suspensory filaments and rudimentary embryos; *b*, radicle with root-cap already formed; *c*, caulicle; *d*, conical apex of the stem; *e*, one of the several cotyledons.

FIG. 8.—Transverse section of one of the Seeds cutting through the Cotyledons: *a*, outer seed-coat; *b*, one of the cotyledons; *c*, albumen.

FORM FOR THE STUDY OF SEEDS.

I. SIZE.
  1. Length.
  2. Breadth.
  3. Thickness.

II. COLOR.
  1. Exterior.
  2. Interior.

III. SHAPE.
  1. Globose.
  2. Discoid.
  3. Lenticular.
  4. Cylindrical.
  5. Prismatic.
  6. Pyramidal.
  7. Three-sided.
  8. Conical.
  9. Ovoid.
  10. Crescentic.
  11. Reniform.
  12. Flattened.
  13. Polyhedral.
  14. Lobed.
  15. Nodular.
  16. Irregular.

IV. SURFACE AND APPENDAGES.
  1. Smooth.
  2. Polished.
  3. Rugose.
  4. Reticulate.
  5. Alveolate.
  6. Tuberculate.
  7. Scabrous.
  8. Verrucose.
  9. Pubescent.
  10. Puberulent.
  11. Sericeous.
  12. Lanuginous.
  13. Tomentose.
  14. Villose.
  15. Strigose.
  16. Spinose.

V. EXTERNAL STRUCTURE.
  1. *Comose.*
    (1) Coma at hilum only.
    (2) Coma at hilum and along raphé.
    (3) Coma covering most of surface.
  2. *Arillate.*
    (1) Color of aril.
    (2) Aril fleshy.
    (3) Aril fibrous.
    (4) Aril entire.
    (5) Aril branching.
    (6) Size of aril.
      a. Large.
      b. Small.
  3. *Caruncülate.*
    (1) Color of caruncle.
    (2) Caruncle large.
    (3) Caruncle small.
  4. *Atropous.*
  5. *Campylotropous.*
  6. *Amphitropous.*
  7. *Anatropous.*
  8. *Shape of hilum-scar.*
    (1) Circular.
    (2) Oblong.
    (3) Linear.
    (4) Curved.
    (5) Triangular.
    (6) Conspicuous.
    (7) Inconspicuous.
  9. *Micropyle-scar.*
    (1) Conspicuous.
    (2) Inconspicuous.
    (3) Adjacent to hilum.
    (4) At opposite end from hilum.
    (5) Midway between opposite end and hilum.

VI. INTERNAL STRUCTURE.
  1. *Testa.*
    (1) Homogeneous.
    (2) Differentiated into layers.
    (3) Texture.
      a. Membranous.
      b. Thick.
      c. Mucilaginous exteriorly.
      d. Fleshy.
      e. Leathery.
      f. Woody.
      g. Horny.
      h. Bony.
  2. *Tegmen.*
    (1) Membranous.
    (2) Distinct.
    (3) Coalescent with testa.
    (4) Wanting.
  3. *Nucellus.*
    (1) Composition.
      a. Exalbuminous.
      b. Albuminous.
    (2) Albumen.
      a. Composition.
        Endosperm.
        Perisperm.
      b. Quantity.
        Copious.
        Equal.
        Scanty.
      c. Position.
        Surrounding embryo.
        Surrounded by embryo.
        To one side of embryo.
      d. Texture.
        Mealy.
        Oily.
        Horny.
        Bony.
        Containing starch.
        Without starch.
    (3) Embryo.
      a. Kind.
        Monocotyl.
        Dicotyl.
        Polycotyl.
        Acotyl.
      b. Parts recognizable.
        Radicle.
        Caulicle.
        Cotyledons.
        Plumule.
      c. Position.
        Straight.
        Plicate.
        Curved.
        Coiled.
        Cotyledons.
          Accumbent.
          Incumbent.
          Number.
          Texture.
            Membranous.
            Thickish.
            Thick.
          Shape.
            Linear.
            Oblong.
            Elliptical.
            Ovate.
            Obovate.
            Lanceolate.
            Oblanceolate.
            Clavate.
            Cordate.
            Lenticular.
            Irregular.
            Entire.
            Lobate.
          Composition.
            Starchy.
            Without starch.
          Germination.
            Epigeal.
            Hypogeal.

PART II.

VEGETABLE HISTOLOGY.

INTRODUCTION.

THE MICROSCOPE AND ACCESSORY APPARATUS TO BE USED IN THIS COURSE.

THE MICROSCOPE.

THE essential parts of the compound microscope are the following:

(1) *The stand*, or that part of the instrument which holds in position the optical parts and the object to be examined. It may be quite simple or very complicated in its construction, according to the uses to be made of it or the fancy of the user, but for the purpose of these exercises a simply-constructed stand is preferable as being less expensive, more readily understood, and more easily manipulated. It should, however, be substantially and carefully made, so as to admit of the use of high powers and not be liable to be easily disarranged. A stand of small or moderate size, built after the so-called Continental model, is preferable for botanical work to one of larger size, both because more convenient to handle and because, on account of the frequent application of test-reagents to tissues undergoing investigation, the stage of the instrument must be horizontal, which necessitates an upright position of the stand. If, therefore, the stand were a large one, to work with it would be both inconvenient and tiresome. There are now many different instruments to be had, answering well the requirements, the product of both American and European factories.

The construction and the parts of the stand are best understood by reference to the accompanying illustration (Fig. 2). The tube or combination of tubes holding the optical parts is called the *body*, indicated at *A* in the figure. The interior tube (*B*), called the *draw-tube*, slides smoothly within the outer for the purpose of varying the distance between the eye-piece (*C*) and the objective (*G*), which distance varies within certain limits the magnifying power of the combination. The body is supported by an *arm* (*F*) rigidly connected with the *stage* (*H*). At *D*, where the body is connected with the arm, is a rack and pinion by means of which the body may be raised or lowered. This constitutes what is called the *coarse adjustment*, and it should be constructed with the greatest care that the movements be smooth and true, without liability to derangement. The coarse adjustment should also be so constructed as to compensate for wear, and the rack should be long enough to permit at least six centimetres working distance between the stage and the front of the objective. The oblique rack-work is no doubt preferable to the ordinary form, giving, when well constructed, greater steadiness of motion. At *E* is the head of a fine-threaded screw by means of which the whole body of the instrument may be raised or lowered very gradually through a short distance. This screw is used in focusing with high powers, and is hence called the *fine adjustment*. This part of the instrument also requires especial care in its construction, so that lost motion may be avoided and that the adjustment may not easily be impaired by use.

The stage should be commodious—not less than seven centimetres from front to back, and not less than eight centimetres from right to left. The upper surface, which should be faced with either vulcanite or glass, so that it may not be acted upon by corrosive reagents, should be very rigid and firm, and its plane should be exactly at right angles to the optical axis of the instrument. The central aperture, through which light is admitted from below for illuminating the object, should be not less than two centimetres in diameter. This aperture should be provided with diaphragms for regulating the light. The best form of diaphragm, because the most convenient in adjustment, is the iris diaphragm. On the upper surface of the stage are two spring-clips for holding the object-slide in position.

To an extension of the arm below the stage is attached the *illuminating mirror* (*I*). This should have a diameter of about five centimetres, and one of its faces should be plane, the other

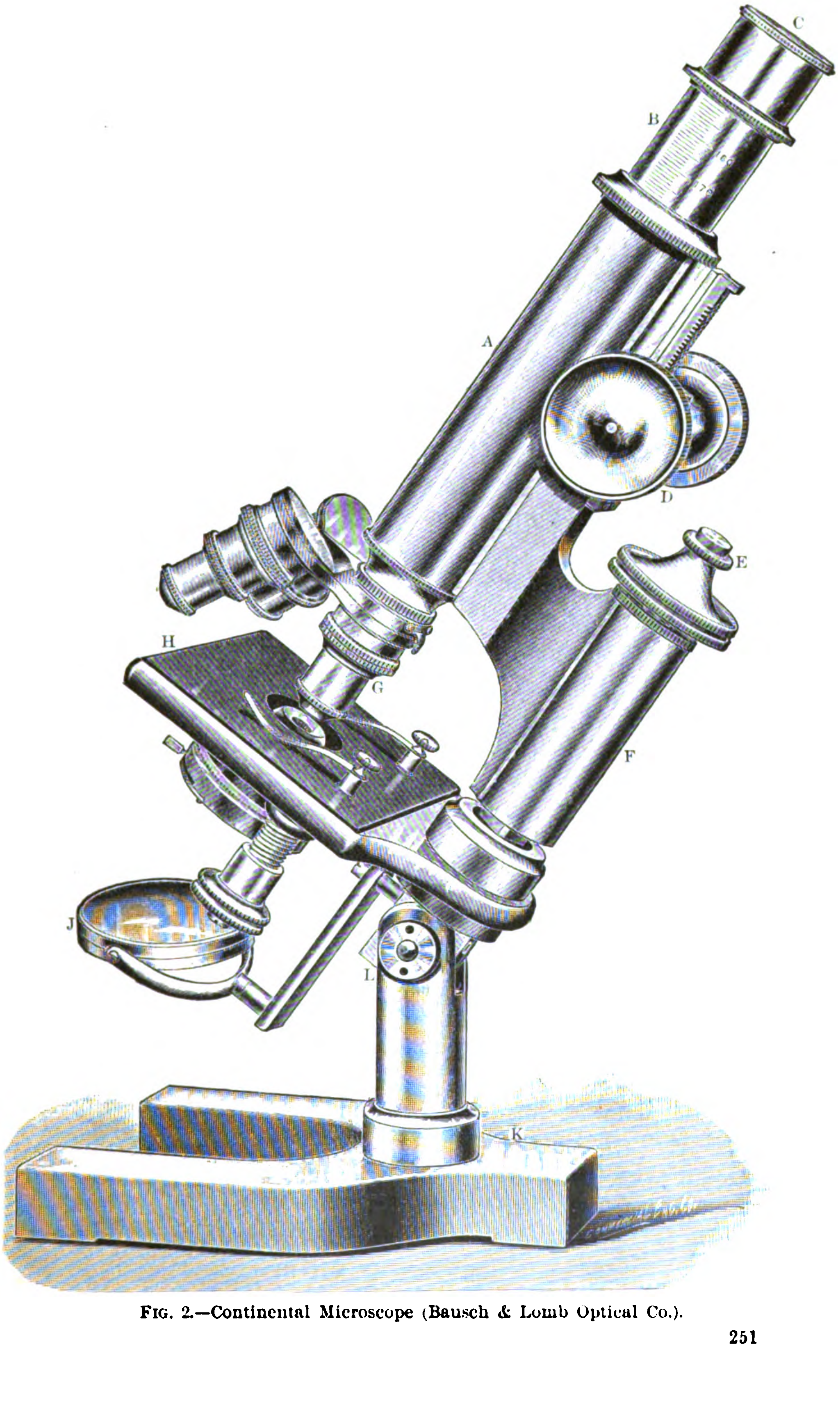


FIG. 2.—Continental Microscope (Bausch & Lomb Optical Co.).

different ones may be used, giving different magnifying powers. The common mode of rating them is by their focal length. The most serviceable are the two-inch, the one-and-a-half-inch, and the one-inch, or, if German or French microscopes are employed, the Nos. i., ii., and iii. eye-pieces.

The objectives are the lenses or combinations of lenses which screw into the front end of the tube, or next the object, whence the name *objective.* One is shown at *G* in the illustration. As a matter of fact, the objectives of all really serviceable microscopes are combinations of two or more lenses and of two or more different kinds of glass, very carefully ground and polished and with their curvatures very accurately adjusted each to the other, so as to give a clear and faithful image of the object—a result which could not be accomplished by means of a single lens. Objectives require, therefore, great skill in their manufacture, and constitute the most expensive parts of the microscope. This is especially true of the high powers, where the combinations must be very complex in order to give the most perfect results.

Objectives of many different powers are manufactured, and these too are rated according to their equivalent focal length. The most serviceable for botanical purposes are a one-inch or a two-third-inch for a low power and a one-sixth-inch or a one-eighth-inch for a high power. These, with the eye-pieces mentioned, will permit of a range of powers from about forty or fifty diameters to six hundred or eight hundred diameters—amply sufficient, if the objectives are of good quality, for most of the work that needs to be done by the student of vegetable histology.

(3) *Estimation of Magnifying Power.*—The magnifying power of a compound microscope may be roughly calculated as follows: Suppose the tube to be of such a length that the distance in a straight line from the object when in focus to the distal end of the eye-piece is ten inches, and that the two-inch eye-piece and the one-inch objective are in position. Ten inches being the normal length of distinct vision, an objective that focuses an object at one-inch distance practically brings it ten times nearer, and therefore magnifies it ten diameters. The same reasoning applies to the eye-piece, which magnifies the image produced by the objective, and, as the eye-piece in this case magnifies five diameters, the magni-

as the micrometer and parallel to its scale, the foot-rule, preferably one having a white surface ruled with black lines, and then look with one eye through the microscope at the scale on the stage, at the same time keeping the other eye open. Both scales will be seen simultaneously, and may be directly compared.

Suppose, for example, that the lines on the micrometer scale, which are known to be, say, one-one-thousandth of an inch apart, appear through the microscope to be precisely one inch apart as measured by the foot-rule: the magnifying power used must therefore be one thousand diameters.

Accessory Apparatus.

The following may be regarded as necessities:

(1) *A stage micrometer*, preferably one ruled according to the metric scale. One millimetre ruled into one hundred equal parts is a very convenient scale for most purposes.

(2) *A section knife* for making thin sections of tissues. The most convenient for ordinary work is a good razor ground flat on one side and slightly concave on the other, but not too thin, and with a straight edge. It should be kept well sharpened, and the student would do well to provide himself also with a good hone and strop.

(3) *A graduated ruler* such as the one described above, or preferably one with the English scale on one edge and the metric scale on the other. Such a ruler is highly useful not only for the purpose above mentioned, but also in drawing.

(4) *A pair of dissecting-needles.* These may easily be made from two cedar-wood pen-holders by sawing them off through the metallic portion so that the remaining metal will form a ferule, and then, by means of pincers, forcing the heads of sewing-needles into the feruled ends. These needles are very useful for teasing apart tissues that have been treated with Schulze's maceration fluid.

(5) *A pair of sharp-pointed scissors* for dividing sections, membranous tissues, etc. Bent ones, such as those shown in Figure 3, are to be preferred.

(6) *A pair of delicate forceps or pincettes* for handling cover-glasses and small objects. A very good form for laboratory purposes is shown in the illustration (Fig. 3).

also to have a few of larger size, seven-eighths of an inch in diameter.

The following pieces of apparatus, though useful, are not really indispensable for such a course as here laid down :

(*a*) *A camera lucida* for drawing. The most useful form is that devised by Professor Abbé, and now manufactured under various modifications by most of the principal makers of microscopes. The principle of its construction is explained and illustrated in the author's *College Botany*, pp. 206, 207. There are several cheaper kinds, but this is altogether the most desirable.

(*b*) *A polariscope* is a useful adjunct to the microscope in the investigation of certain structures, as starches, crystals, thickened cell-walls, etc. It consists of two Nicol prisms, one usually screwed into the nose-piece just above the objective, and the other arranged to rotate beneath the stage.

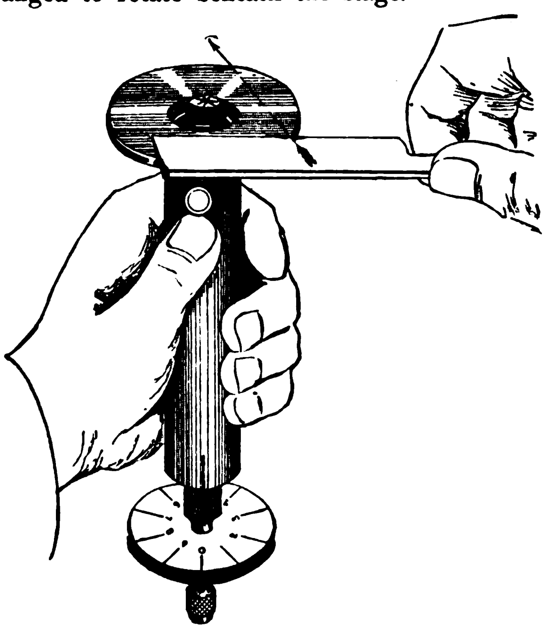


FIG. 5.—Student's Microtome (Queen & Co.).

(*c*) *A pair of draughtsman's dividers* is a useful implement as an aid in drawing microscopic objects.

(*d*) *A microtome* for cutting thin and even sections of plant structures is useful, and for some of the more difficult investigations where serial sections are required it is indispensable. For the latter purpose one of the numerous forms of the sledge microtome is probably on the whole the most desirable; but for the ordinary work of sectioning stems, roots, leaves, etc. the simple and inexpensive sectioner shown. in Figure 5, and devised in accordance with the author's suggestions, is very convenient and efficient. It is a modification of the well microtome, the novel feature in which consists in the manner in which the object is clamped in the well so as to prevent it from bending or yielding before the knife. It is made of such a form as to be conveniently held in one hand while the knife is manipulated with the other. The accompanying illustration will give an idea of its appearance and the method of using it.

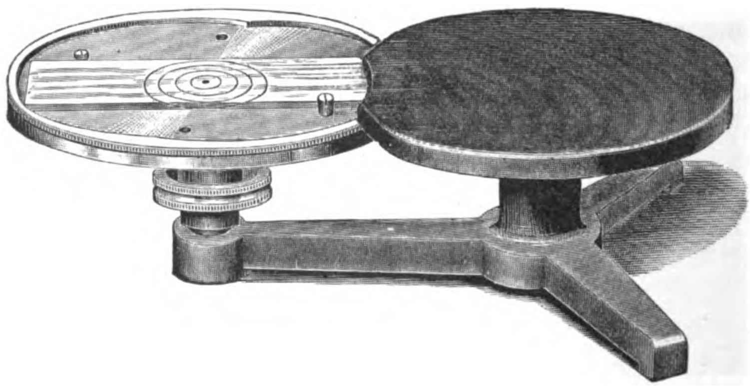


FIG. 6.—Centring Turn-table (Zentmayer).

(e) *A turn-table* is a very useful bit of apparatus for the permanent mounting, particularly the finishing, of slides. Some of the self-centring kinds are particularly convenient. One of these is shown in the accompanying illustration.

MICRO-REAGENTS.

Sulphuric Acid.—The strong acid dissolves starch and cellulose, causing them first to swell and then to disappear. It also produces chemical change in them, converting the former into dextrin and the latter into amyloid, a substance which, like starch, acquires a blue color with iodine. It dissolves protoplasm and other albuminous substances much more slowly, and hence may be used for demonstrating the continuity of protoplasm from cell to cell in certain tissues. For this purpose it is used either strong or diluted with one-fourth its bulk of water. After acting for a few moments the acid is washed out thoroughly and the sections are stained.

Cuticularized and lignified tissues, if first treated with iodine solution and then with sulphuric acid to which one-fourth its bulk of water has been added, turn brown, but the former are not dissolved, and the latter are dissolved much more slowly than are cellulose tissues.

Cells containing protoplasm, if first treated with a solution of cane-sugar and then with dilute sulphuric acid, acquire a rose-red color.

In the dilute form sulphuric acid is also used as an aid to the identification of certain crystalline deposits in cells, crystals of calcium oxalate, calcium carbonate, calcium phosphate, and calcium malate being changed to needle-like crystals of calcium sulphate in the cells. Sphere crystals of inulin may also readily be distinguished from those of calcium phosphate by the fact that the former readily dissolve in sulphuric acid without residue.

Sulphurous Acid.—Certain objects when hardened in alcohol turn black, and sections become too opaque for study. To prevent this, Overton adds to the alcohol sulphurous acid and prepares the hardening solution as follows: He adds to half a gram of sodium sulphite a few cubic centimetres of 80 per cent. sulphuric acid, and conducts the fumes of sulphurous acid which are generated directly into 100 grams of alcohol. Sulphurous acid may be employed in the same manner in picric-acid hardening solutions.

A weak aqueous solution of sulphurous acid also greatly expedites the washing of tissues which have been hardened in chromic-acid solutions.

Hydrochloric Acid.—Besides its use in connection with phloroglucin, phenol, thymol, α-naphthol, and anilin chloride as a reagent for lignified tissue, hydrochloric acid is more or less useful as a clearing agent. It is also serviceable in distinguishing between calcium carbonate and calcium oxalate in cells, both being soluble in this reagent, but the former with effervescence, the latter more slowly and without effervescence.

A $\frac{1}{2}$ per cent. solution of hydrochloric acid in 70 per cent. alcohol is also serviceable in reducing the color of sections which have been over-stained in hæmatoxylin, carmine, and some aniline solutions.

Nitric Acid.—The strong acid immediately kills, but does not dissolve, protoplasm, and causes it to shrink away from the cell-wall. If a solution of ammonium or potassium hydrate be afterward added, the proteid cell-contents will assume a yellow color. This is called the xantho-proteid reaction for proteids.

If a section containing thick-walled tissues be treated first with hot nitric acid and then with ammonia, the middle lamella will be stained yellow.

A solution of 3 parts of strong nitric acid in 97 parts of water is sometimes employed for fixing protoplasm where it is desired to study the microsomes and other granular contents.

A 30 per cent. solution of nitric acid is used for the detection of amyloid, which at once swells strongly when the reagent is applied, and after a time completely dissolves.

Chromic acid is employed in .5 per cent. to 1 per cent. solutions for fixing the cell-contents of tissues. Tissues are soaked in it for twenty-four hours or more, and must then be washed thoroughly before staining, as the presence even of traces of the acid interferes with most stains.

A concentrated aqueous solution of chromic acid is often employed for the separation of cells, especially those of thick-walled tissues, since the middle lamella is more readily soluble in it than is the rest of the cell-wall. All cell-wall structures are, however, finally dissolved by it. Suberized and cutinized tissues, though, yield to its action only after a long time. Fungus cellulose also dissolves very slowly in it.

Acetic Acid (Glacial).—This acid in 1 or 2 per cent. aqueous solution is serviceable for defining the nucleus. It is also used for the same purpose in connection with certain stains, especially gentian-violet and methyl-green. In strong solution it is a valuable clearing agent, rendering the cell-contents more transparent and the cell-walls therefore more distinct.

A mixture of acetic acid 1 part and absolute alcohol 3 parts forms an excellent reagent for fixing cell-contents with the view to subsequent staining and study of the nuclear figures. This mixture is also useful in distinguishing between crystals of calcium oxalate and those of calcium carbonate, the former being insoluble in it, while the latter dissolve with effervescence.

Formic acid is employed in much the same way as is acetic acid for the study of the nucleus and for clearing, and has about the same value.

Picric Acid.—Strong solutions, either aqueous or alcoholic, are employed for fixing the cell-contents. Objects should remain in the solution from twelve to twenty-four hours, and should then be washed thoroughly in alcohol before staining.

Picric acid is also used for the same purpose in association with sulphuric acid: 2 parts of the latter are mixed with 100 parts of water, and the mixture saturated with picric acid; the whole is then mixed with three times its volume of water. This solution has the advantage of being more readily washed out of the tissues by alcohol than that of picric acid alone.

By reason of its staining as well as its fixing properties picric acid is used also in association with carmine, nigrosin, and aniline-blue in the preparation of various structures for study.

Osmic Acid.—This poisonous substance owes its chief value in microscopy to the fact that it very rapidly penetrates tissues and instantly kills and fixes protoplasm. It is quite useful, therefore, in the study of nuclear figures. It is often employed for the purpose in 1 per cent. solution in distilled water. The treatment of the tissues with this reagent must be carried on in the dark, and the acid must be washed out thoroughly before exposing the tissues to the light, otherwise reduction to the metallic form will take place and the tissues will be blackened. This reduction always occurs when the acid, in contact with organic matter, is exposed to light. Tannins and fats also reduce osmic acid without the aid of light, and the acid may therefore aid in the detection of these substances.

Sections which have been blackened by osmic acid may be bleached, without injury to the structure, by means of hydrogen peroxide, which may be used in the proportion of 1 part to 10 or 15 of 75 per cent. alcohol. The sections may then be washed and stained.

Osmic acid is usually sold in sealed glass tubes containing 1 gram of the crystals. To prepare the solution the distilled water is measured out and poured into a suitable vessel, and then, by means of

Tannin may also be recognized by a strong solution of the reagent, the cell-contents of cells containing tannin turning yellowish or brownish. In dilute form potassium hydrate may also be used as a means of distinguishing between protein-crystals or crystalloids and crystals of inorganic matters. The former immediately swell and lose their angles, while the latter are mostly unaffected.

Very hard tissues, such as the shells of many nuts and the exterior coats of many seeds, may be softened for sectioning by soaking them for some time in solutions of this reagent. (For softening tissues by means of potassium hydrate, see Introduction to Part I.).

Potassium-iodide Iodine.—This is one of the most useful of the solutions employed in vegetable histology. It stains starch blue, proteid matters yellowish-brown, and lignified cell-walls a deep-brown. Along with sulphuric acid it may also be used as a test for cellulose, as follows: The sections are first treated with a few drops of the iodine solution, and then, after a few minutes, with a mixture of 2 parts of strong sulphuric acid and 1 part of water. After treatment with the acid the cellulose membranes, which are scarcely stained at all by the iodine alone, rapidly acquire a blue color, while the lignified cell-walls are stained a deep-brown. The iodine solution used for this purpose should consist of iodine 1 part, potassium iodide 4 parts, and distilled water 195 parts.

As a test for protoplasm it is better to use a stronger solution, in order that the staining effects may be decided, but as a test for starch the solution should be much weaker, otherwise the grains will be so deeply stained as to appear black. Iodine solution also rapidly kills protoplasm without dissolving it, and is therefore useful as a fixing agent. Vapor of iodine is sometimes employed for the same purpose.

All iodine solutions should be kept in amber-colored bottles to prevent the formation of iodic acid.

Chloriodide-of-zinc Iodine Solution.—According to Behrens, this solution may be prepared conveniently by dissolving 25 parts of pure zinc chloride and 8 parts of potassium iodide in 8.5 parts of distilled water and then adding as much iodine as will dissolve.

Solid chloriodide of zinc is, however, now an article of commerce, and a still simpler way of making the solution, according to Zimmermann, is to dissolve the salt in somewhat less than its own weight of water, and then add a quantity of metallic iodine sufficient to give the solution a deep sherry-brown color.

This reagent is highly useful. It constitutes one of the best direct tests for cellulose, coloring it blue, while lignified and cutinized tissues are colored brown. Starch-grains are also stained blue by it, and, besides, are caused to swell and finally to disappear. It is useful in the study of sieve-tubes, since it stains callose a deep-reddish or reddish-brown color. It has, moreover, been employed with success in studying the continuity of protoplasm from cell to cell, since it swells the cell-walls and stains the protoplasmic threads brown.

Chloral-hydrate Iodine.—This consists of 5 parts of chloral hydrate dissolved in 2 parts of water to which a little iodine solution has been added. It is employed for dissolving chlorophyll bodies and to demonstrate the presence in them of minute starch-grains by causing the latter to swell and by staining them blue.

The solution without the iodine is also a useful clearing agent, especially for rendering leaves transparent after the chlorophyll has been dissolved out by alcohol.

Alcohol has many important uses in vegetable histology. One of the most important is for the preservation of tissues. For this purpose 70 per cent. alcohol is strong enough. But it is often desirable at the same time to harden the tissues preparatory to section-cutting. For this purpose strong alcohol, 95 to 98 per cent., is often necessary. If, however, the tissues are very delicate, they must not be placed immediately in alcohol of this strength, but must gradually be transferred through the medium of solutions of increasing strength, otherwise osmotic action will contract the tissues and render them unfit for study.

Alcohol dissolves chlorophyll and other coloring matters, together with resinous substances and some oils, and so acts as a bleaching agent.

Since it coagulates and kills protoplasm without seriously impairing its structure, alcohol is useful in preparing cells for the study of the cell-contents. Living protoplasm is so transparent as to be nearly invisible, and it is also very difficult to stain ; but by treatment with alcohol protoplasm is rendered more opaque, and, besides, may then readily be stained with most of the usual staining fluids.

Labarraque's Solution (Solution of Chlorinated Soda).—This and the corresponding potash solution, called Javelle water, are useful clearing and bleaching agents where it is desired to study the cell-walls without the interference of the cell-contents. Sections placed in either solution should be watched carefully lest the destructive effects of the reagent extend to the cell-walls. If the sections are to be afterward stained, they must first be washed thoroughly to get rid of the last traces of the bleaching agent. The solutions, which are readily obtainable at most pharmacies, should be kept in a dark place and in tightly-stopped bottles. They require also to be frequently renewed.

Javelle Water (Solution of Chlorinated Potash).—Used for the same purposes as Labarraque's Solution (see above).

Chloral-hydrate Solution.—Used as a clearing agent. (See *Chloral-hydrate Iodine*, p. 264).

Diphenylamin Solution.—A good formula for the preparation of this reagent is that of Strasburger: Dissolve 0.5 grain of the crystals in 10 cubic centimetres of pure sulphuric acid. The solution is employed as a test for nitrates, tissues containing them turning blue on applying the reagent, from the formation of anilin-blue. The nitrites show the same reaction, but are very seldom found in plants.

Anilin or Anilin Oil.—This liquid is sometimes used as an intermedium between water and balsam, to obviate the necessity of complete anhydration by alcohol. Since anilin dissolves about four per cent. of water, the sections may immediately be transferred from aqueous liquids to anilin, and then from this to balsam. The anilin may be kept free from water by placing solid potassium hydrate in the containing vessel, the alkali possessing a strong affinity for water and being wholly insoluble in the anilin.

Potassium Bichromate.—A saturated solution of the salt in distilled water is often employed as a test for tannic matters, most tannins forming with it a yellowish-brown or dark-brown precipitate. Structures containing tannin may be placed *en masse* in the solution for twenty-four hours or more, and then be washed, sectioned, and examined. The masses, however, must not be of very large size, as the solution penetrates rather slowly. This reagent is not wholly satisfactory as a tannin test, since some other compounds besides the tannins form brownish precipitates with it.

have been bleached by means of Labarraque's solution. The process is as follows: Thoroughly wash the sections after removing them from the bleaching solution, then soak them for a few minutes in the tannin solution, then, after quickly draining off as much as possible of the liquid, transfer them to the solution of ferric chloride. Even very thin membranes may then be seen readily, because stained a deep-black color. Tannin is also used in connection with osmic acid to stain crystalloids.

Sodium Phosphate.—A concentrated solution of the salt in distilled water is employed in the study of the crystalloids which are contained in protein-granules, as, for example, those in the endosperm-cells of the castor bean. The reagent dissolves all the rest of the grain, but leaves the crystalloid unchanged.

Cuprammonia.—This is prepared by adding to a strong aqueous solution of copper sulphate an aqueous solution of sodium hydrate, collecting the resulting precipitate by allowing it to settle, and then decanting the supernatant liquid. The precipitate is then dissolved in strong ammonia-water. This is the only known reagent capable of dissolving cellulose without producing chemical change in it. The reagent should be used in the undiluted form, and it is better when freshly prepared. It does not dissolve lignified cell-walls. The dissolved cellulose may be precipitated from solution by adding water.

Schulze's Maceration Mixture.—This consists of strong nitric acid in which chlorate of potash has been dissolved; it is chiefly used for the isolation of cells. Sections are placed in this mixture and gently heated until gases are evolved and the reddish color which first appears in the tissues has disappeared. The contents of the dish are then immediately poured into a large quantity of water to stop further action. The sections are now gently washed and stained with methyl-green. The cells may easily be separated by teasing or by mounting them in a drop of water on a slide and gently tapping the cover-glass with a needle-point.

The sections should never be transferred from alcohol directly to this mixture, but always from water; otherwise too violent, or even explosive, effects may be produced. It is better also to let the sections stand for a few minutes in the cold solution before applying heat, and then great care should be observed to stop the action at just the right point, otherwise either the middle lamella than from lignified and cutinized ones, it may be used to differentiate these tissues. If, after anhydrating the washed specimens, they be passed through oil of cloves in which eosin has been dissolved, beautiful double stains will be obtained.

By means of Gram's method most beautiful and instructive nuclear double stains are produced. The method is as follows: The sections are first soaked for about half an hour in the violet solution, and are then washed first with alcohol, then in a solution of potassium-iodide iodine (consisting of iodine 1 part, potassium iodide 2 parts, and water 300 parts), then again in alcohol until nearly all the color has been removed from the cell-walls; the sections are then passed through absolute alcohol and into eosin oil of cloves, and then, after a few minutes, they may be mounted in balsam. The chromatic nuclear figures will be stained violet, and the rest of the nucleus red.

Another solution of gentian-violet, particularly good for nuclear stains, consists of gentian-violet dissolved in 1 per cent. solution of acetic acid in distilled water until the liquid has acquired a deep-violet color.

Corallin Solution.—This useful stain is prepared as follows: Dissolve 3 grains of sodium carbonate in 2 ounces of distilled water, and in the solution thus obtained dissolve 10 grains of corallin, and filter. In order to preserve the liquid, place in the bottle containing it a few grains of camphor. Corallin thus prepared stains cellulose and lignified membranes different shades of red, sieve-callose a very brilliant red, and starch-grains red. The colors, however, are not permanent.

Picric-nigrosin Solution.—A good preparation is the following: To a saturated solution of picric acid in distilled water is added enough of a strong aqueous solution of nigrosin to give to the liquid a deep olive-green color. This solution fixes and at the same time stains the nucleus, and for this purpose is especially useful in the study of the filamentous algæ. Specimens usually require to be soaked in the solution for fully twenty-four hours in order to obtain satisfactory results.

Picric-nigrosin solution is also serviceable as a double stain for sections of roots, stems, etc., the nigrosin going to the cellulose and the picric acid to the lignified tissues. The preparations are permanent either in balsam or in glycerin jelly.

Cyanin Solution.—A solution of cyanin in equal parts of alcohol and distilled water is employed for the study of fats, which are colored a beautiful blue after soaking for half an hour or more in the solution. Glycerin or a strong solution of potassium hydrate may be employed for washing out the superfluous stain. The color is not permanent.

Alcannin Solution.—This stain is prepared by adding to the strong solution in absolute alcohol distilled water until a precipitate begins to be formed, and then filtering. It is used for the detection of fats, resins, and volatile oils, which after a little time it colors a deep-red.

The same solution may be employed for the identification of cutinized and suberized tissues, which after a few hours are colored decidedly by it, though not of so deep a red as are oily or resinous substances.

Great care should be exercised in the selection of the colors for staining, especially the coal-tar colors. Many of the safranins in the market, for example, are worthless for the purposes of vegetable histology. Only those colors should be purchased which are certified to by reliable dealers as suitable for microscopic use.

Permanent Mounting or Enclosing Media.

The most valuable are the following:

Canada Balsam, or Balsam of Fir.—This should be nearly colorless and entirely free from solid impurities. It may be kept in a capped bottle; but a better way is to obtain it in collapsible tubes of tin, which are now commonly sold by dealers in microscopical supplies. The ordinary or natural balsam, which consists of resin in solution in oil of turpentine, may be employed, or, as the writer prefers, the solution of the hardened resin in xylol.

Balsam mounts, though somewhat troublesome to make, are very durable and satisfactory.

Glycerin gelatin of good quality may be prepared as follows: Soak for an hour or more 1 ounce of the best French or German gelatin in 3 ounces of distilled water, and then raise the temperature nearly, but not quite, to the boiling-point, until the gelatin is completely dissolved; add 4 ounces of pure glycerin and as many drops of 95 per cent. carbolic acid, very gently stirring the mixture with a glass rod, so as to mix thoroughly and at the same time to avoid air-bubbles, and then allow the mixture to cool. It soon sets and forms a clear, transparent jelly. If the gelatin used is of the finest quality and perfectly free from superficial dust (which may be ensured by rinsing rapidly in cold distilled water before using), filtering or straining will be unnecessary.

Carmine-stained preparations are unsuited to this medium, as the carmine is soluble in it. The same is true of several of the anilin stains (see Table). Hæmatoxylin-stained specimens keep well in glycerin gelatin, providing it contains no trace of acid.

Glycerin alone is often employed as a mounting medium, but is troublesome on account of the difficulty of enclosing it. For nearly all purposes glycerin gelatin answers as well, and it is far more convenient.

Processes of Mounting.

The process of enclosing in balsam may be outlined briefly as follows: First, the sections, if they have been stained in any aqueous medium, must be anhydrated, and this, especially if they be delicate, must be done gradually by transferring them first to weak alcohol, then to stronger, and so on through solutions of gradually increasing strength to absolute or at least 98 per cent. alcohol. The sections are then usually passed through a clearing medium such as oil of turpentine, oil of cloves, xylol, or oil of bergamot, and are then placed on the centre of the slide and immediately covered with a drop of balsam, on which is placed the cover-glass, care being taken to put it on in such a manner as not to entrap air-bubbles and to get it in the centre of the slide. If just the right quantity of balsam has been used, and none has oozed out around the edges of the cover-glass, nothing further is really necessary except to let the balsam harden; but some prefer to "finish" the slides, for appearance' sake, by ringing them. This is done by running a circle of cement around the edge of the cover-glass by means of a fine pointed brush and a turn-table. Of course, no colored or opaque cement that is soluble in balsam should be employed for this purpose, because sooner or later the cement would run under the cover-glass and spoil the specimen.

In cases where, for some reason, it is not desirable to pass the sections through alcohol, and yet it is of importance to mount them in balsam, anhydration may be avoided by transferring them from the aqueous medium gradually to a concentrated solution of carbolic acid, and then immediately to balsam.

Instead of carbolic acid, anilin may be employed in the same way.

The process of mounting in glycerin gelatin is quite simple, but here also the effects of osmosis must be borne in mind. If the specimens are delicate, it will not do to transfer them at once from water or dilute alcohol to the enclosing medium. They must gradually be brought through weak into strong glycerin, and then be transferred to the glycerin gelatin. A very good way to accomplish the gradual transition is first to place the sections in 10 or 15 per cent. glycerin, and let this solution gradually concentrate by evaporation in a dry place protected from dust. The sections may then be transferred directly to the slide, the superfluous glycerin be taken up by blotting-paper, and a drop of the liquefied gelatin be placed upon them. The gelatin may readily be liquefied as occasion requires by placing the containing vessel in a dish partly filled with water and gradually applying heat.

It is advisable to use just enough of the medium to fill the space between the cover-glass and the slide. After the gelatin has set, it is desirable to protect the mount from injury by running a ring of some resinous cement—balsam, for example—around the edge of the cover-glass. After a long time the balsam is liable to crack. To prevent this the ring of balsam, after a few days, may be covered with one of gold-size. The mount is then almost as permanent as one in balsam.

DRAWING MICROSCOPIC OBJECTS.

What was said in the General Introduction about the importance of drawing is here repeated with emphasis. Every student who undertakes the work of the microscopical laboratory should by all means practise it. For this purpose he should, at the outset, provide himself with a suitable pencil and a drawing-book. Of course, drawings made by the aid of a good camera lucida, such as that described in the Appendix to Part II., *College Botany*, are likely to be somewhat more accurate than those made without its use, but the advantages of such an instrument are likely to be over-estimated. In fact, dependence upon it tends to foster slavish copying, to the detriment not only of artistic skill, but to that of the observing faculties of the student. The student's first efforts at drawing should be undertaken without the aid of the camera, and he should begin with simple structures, such as single cells, starch-grains, etc., and after he has acquired some degree of skill proceed to more complex ones. The apparent dimensions of the object may readily be transferred to paper, either by means of a pair of dividers or by means of a graduated scale as suggested on page 254.

In using the camera lucida it is of importance that the drawing-paper and the field of the microscope should be nearly equally illuminated, otherwise the pencil-point and the object to be delineated cannot be seen with equal distinctness, and the outlines of the structure, therefore, cannot be followed with accuracy. The outlines should be traced with a fine-pointed, hard pencil such as Faber's or Hardtmuth's HHH. The tracing should be made on smooth-finished white paper or cardboard. The camera will seldom be used except to draw outlines and locate important points; to fill in the minute details by means of it is usually impracticable.

Drawings designed merely as a record of observations or for the wood-engraver may be left in lead-pencil, but those that are to be reproduced by photographic process should be drawn in the blackest of black ink.

General Directions for Work.

(1) The student should at the very outset thoroughly acquaint himself with the mechanism of the microscope and the accessory apparatus with which he has to work, that he may use them intelligently.

(2) He should observe great care in the removal and putting on of objectives, so as not to drop them. Eye-pieces and micrometer should also be handled with especial care.

(3) He should observe care in focusing, particularly with high powers, so as not to run the objective down against the slide, and thus endanger breaking either the cover-glass or the objective. He should take care also that the object is in accurate focus, otherwise it cannot be seen distinctly.

(4) He should give due attention to the adjustment of the reflecting mirror, so as to secure the most perfect illumination of the object. Much of his success in seeing will depend upon the care with which this is done.

(5) He should bear in mind that many of the reagents employed are corrosive, and be correspondingly careful in the use of them. Some of the acids are volatile, which is a reason for keeping the containing bottles stopped when not in actual use; all the acids and iodine will act on brass-work; potassium hydrate will corrode glass; Schulze's maceration fluid evolves very corrosive fumes, which should not be permitted to escape into the room; and even alcohol and alcoholic solutions will remove the lacquer from the brass-work of the microscope.

(6) Nearly all objects to be examined will be studied as transparent objects—that is, they will be studied by transmitted light—and they will therefore be mounted in liquid of some kind, and should always be covered with a cover-glass, not only to avoid the distortion of the image which a curved or uneven liquid surface inevitably produces, but to protect the objective. Before placing the mounted object on the stand all liquid that oozes from under the edges of the cover-glass should be wiped away.

(7) Cleanliness should characterize all the work of the microscopical laboratory. All apparatus, slides, cover-glasses, etc. should be kept scrupulously free from dirt. The glasses of the objectives and the eye-pieces should never be touched with the fingers, for that would soil them and impair their optical performance. Whenever they need cleaning, which should not be often, the glasses should be breathed upon and be wiped gently either with a piece of perfectly clean and soft linen cloth or with a piece of the thin, soft paper that is sold at dental supply stores under the name of "Japanese filter-paper." A convenient way is to keep always at hand, in a place secure from dust, a quantity of this paper cut into suitable sizes. It is useful also for cleaning cover-glasses, slides, etc. If a fresh piece be used each time, there will be little danger that the glass of an objective or an eye-piece will be scratched or marred or its polish dimmed. All bottles containing reagents and stains should be kept stopped to prevent evaporation and the entrance of dust when not in actual use; the glass tubes used in applying the tests should always be returned imme-

diately to the proper bottles. Care ought also to be exercised not to put the caps on the wrong bottles.

(8) It is very important that the razor or section knife for cutting sections be always keen-edged, and the student should provide himself with the necessary appliances for sharpening. For most purposes sections require to be cut quite thin. The knife should be given an oblique or sliding motion in cutting, and should be pushed rather than drawn through the object. The motion should be steady and even, and never a to-and-fro or sawing motion. The forefinger of the hand holding the object should be extended slightly, so as to form a rest for the razor-blade as well as to assist in starting the section of the right thickness. Quite hard tissues may be cut successfully if only very thin sections of them are attempted, but if the knife-edge is allowed to run deep it is liable to be notched. Portions of thin structures, such as leaves, petals, and stamens, may readily be sectioned by placing them between pieces of elder or sunflower pith and cutting through pith and all. In case the tissue to be cut is quite hard, cork may often advantageously be substituted for the pith. Longitudinal sections of such small objects as ovules may often successfully be made by putting them between flat pieces of cork or pith and running the knife-blade vertically through them between the pieces of supporting material.

The knife should always be cleaned carefully after using it, and pieces of tissue should never be allowed to dry upon it, otherwise its surface will soon become tarnished by the acids and tannins in the tissues, and sections will not so readily slide up on the blade, but will fold or crumple.

In most instances it is best in cutting to keep the knife-blade wet with alcohol or with a mixture of equal parts of alcohol and glycerin. Sections of fresh tissues or of those that have been kept in any of the preservative fluids should, immediately after cutting, be transferred—best by means of a camel's-hair brush—to liquid, otherwise air will get into the cells and seriously impair the value of the section for study.

(9) The student should, in all his work with the microscope, proceed understandingly, endeavoring to know the reason for every test he is directed to apply, and carefully interpreting the results of each test.

EXERCISE I.

THE TYPICAL VEGETABLE CELL.

SELECTIONS for study may be made from among the following objects: the colorless epidermis of one of the fleshy scales of an Onion, Lily, Hyacinth, or Amaryllis bulb; the leaves of some of the mosses and liverworts, as, for example, those of Bryum roseum, *Schreb.*, Mnium cuspidatum, *Hedw.*, Jubula Hutchinsiæ, *Dumort.*, and Jungermannia Schraderi, *Martius;* or the filaments of some of the filamentous algæ, as Cladophora glomerata, *Kützing*, Œdogonium princeps, *Wittr.*, Spirogyra crassa, *Kützing*, or Zygnema insigne, *Kützing*.

For the present study selection is made of the epidermis of one of the fleshy scales of the Onion (Allium Cepa, *L.*), preferably that from the dorsal or convex surface of the scale.

(1) With the razor cut through the epidermis, but as little as possible into the sublying tissues, and, seizing the epidermis between the thumb and the razor-edge, strip it off and immediately transfer it to a slide previously wet with a drop of water; flatten it out with a camel's-hair brush, by means of the scissors or a knife-blade trim away those portions of it which have some of the sublying tissue attached, and cover the remainder with a cover-glass. In doing this be sure there is enough water on the specimen completely to fill the space between the cover-glass and the slide. The cover-glass—which, to prevent soiling, should be handled with the pincettes, and not with the fingers—should be brought down on the specimen one edge first or at a considerable angle with the slide, and then should gradually be pressed down into position. This is for the purpose of driving out the air. Air-bubbles seriously interfere with the view of the structure, and in all mounting, whether temporary or permanent, must carefully be avoided. Care should be taken also to place the object and the cover-glass as near the centre of the slide as possible.

iodine and sulphuric acid, called *cellulose*; a part that readily dissolves, but does not stain—the middle lamella, composed chiefly of insoluble pectates; and the cuticle, which is chiefly composed of a substance different from either, called cutin.

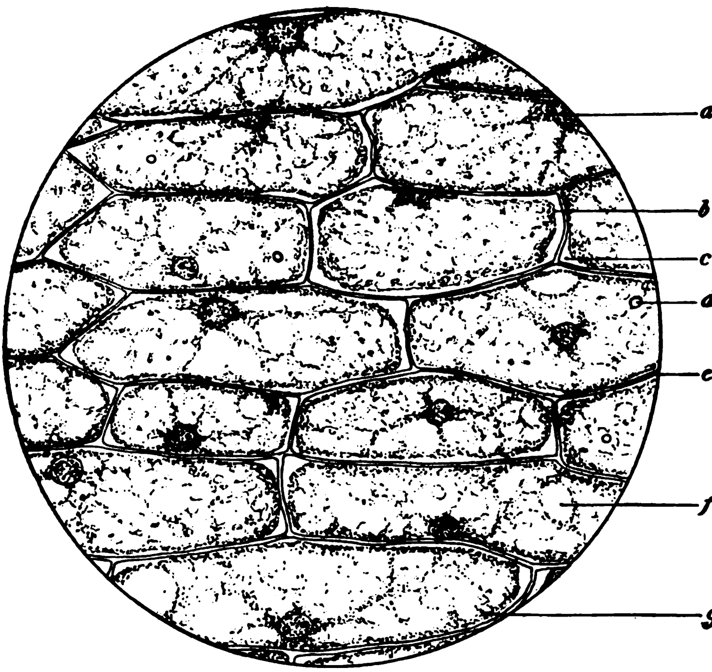
Another fact observed is that the protoplasm has been stained even a deeper brown than before, and that it is still recognizable, though disorganized, after the cellulose has disappeared.

Another reagent, even better for the recognition of cellulose and for distinguishing between it and cutin, is chloriodide-of-zinc iodine. Let there be mounted a fresh portion of the epidermis of the Onion scale in a few drops of this liquid, taking care not to dilute the latter, and permitting a few minutes to elapse before putting on the cover-glass, so as to give the reagent opportunity thoroughly to penetrate the cells. As before, it is found that the walls are stained blue, but less intensely, and, though swollen, they are not dissolved. The cutinized portion of the cell-wall is also turned brown, but this is best seen by studying a transverse section.

Sections may best be made by cutting through two or three scales at once. Placing one or two of these sections on the slide, treating them with a few drops of the reagent, and examining them with the high power, it will be found that the cells appear in a shape very different from that observed in the other view. They are oblong or nearly rectangular, with the longest diameter parallel to the surface of the scale; the inner and radial walls are thin, but the outer wall is thickened, and it is the exterior part of this wall that has acquired the brown color; it is the cutinized part, or cuticle.

(6) Beautiful and instructive permanent mounts may be obtained by the following method: First, let there be stripped off portions of the epidermis, and, to prevent them from curling, let them be spread out rapidly on slides and afterward treated with alcohol to kill and fix the protoplasm. They are then thoroughly washed in water and placed in Grenacher's alum-carmine, in which they are allowed to remain for twenty-four hours. They are then removed from the staining fluid, rinsed, and passed through weak, strong, and finally through absolute alcohol, then placed for a few moments in oil of cloves, and from this transferred to the centre of a slide, a drop of xylol balsam placed on them, and the cover put on,

care being taken in doing so not to entrap air-bubbles. The cell-walls will be stained red, but will be sufficiently transparent to allow the nucleus and the protoplasm, also stained red, to be seen distinctly. It is from specimens thus treated that the accompanying drawings (Pl. XXXVIII.) have been made.



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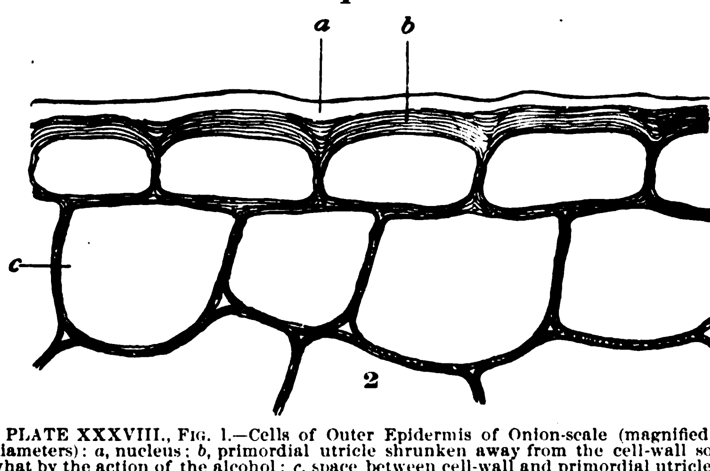

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PLATE XXXVIII., FIG. 1.—Cells of Outer Epidermis of Onion-scale (magnified 200 diameters): *a*, nucleus; *b*, primordial utricle shrunken away from the cell-wall somewhat by the action of the alcohol; *c*, space between cell-wall and primordial utricle; *d*, an oil-globule, which may best be seen in an iodine-stained section; *e*, cell-wall; *f*, vacuole; g, granular protoplasm.

FIG. 2.—Transverse Section of Epidermis of Onion-scale, showing thickening of exterior wall and cutinization of its outside portion. The unshaded part, *a*, represents cuticle; the shaded parts, *b*, the cellulose portion of the wall; *c*, one of the parenchyma-cells beneath the epidermis. The walls are considerably swollen, the drawing having been made from a section that had been treated with zinc-chloriodide iodine. The cell-contents are omitted from the drawing. (Magnification, 285 diameters.)

Of the above tissues, all of the prosenchymatous series are at maturity destitute of living protoplasm, and are therefore mechanical in their function; so also are sclerotic and suberous tissues; and collenchyma and endodermal tissues are partly so. The stems, leaves, and roots of almost any of the higher plants contain several of these tissues, sometimes nearly all of them, but a few are of rare occurrence.

For the purpose of getting a general idea of the commonest and most important, let sections, transverse and longitudinal, of the stem of the common Geranium (Pelargonium zonale, *Willd.*) be studied.

I. TRANSVERSE SECTION.—Having made a section, as thin as possible, extending from the outside to and into the central pith, it is placed on a slide and treated with a few drops of the zinc-chloriodide iodine, and after a few minutes examined under the low power.

It is observed, first, that there are tissues whose cell-walls have stained blue, and others whose cell-walls have stained a deep-brown. It is observed also that there are great differences of size and shape among the cells, differences in the compactness of their arrangement, and differences in the thickness of their walls, as well as great differences in their contents.

(1) On the very outside may be found a single tier of closely-laid and similar cells interspersed with hairs and having their outer walls thickened. This is the epidermis. Beneath it, if the stem is not too young, are several tiers of tabular or brick-shaped cells arranged in radial rows. The members of the outer tiers are empty, or at least contain no protoplasm, and their walls are stained brown. The inner members of the series, which are younger, may still contain protoplasm, and the walls may show some blue color. This whole series of tabular cells constitutes the cork-tissue which has formed underneath the epidermis, and which sooner or later, by the continuous multiplication of its cells, will push the epidermis off, and afterward the cork-cells themselves will peel off at the surface. It is this peeling off which gives the rough appearance to the exterior of the stem when it is old. Destruction of the epidermal and exterior cork-cells had in fact begun in the specimen from which the drawing (Pl. XXXIX.) was made. Figure 1, *a* represents the corky tissue.

(2) Underneath the cork is seen a tissue composed of cells quite different in shape and arrangement from the cork-cells. They are rounded or somewhat polygonal in outline; their walls are not cutinized, but are of cellulose, and therefore stain blue instead of brown with the zinc-chloriodide iodine reagent; they are not arranged in radial rows; they have more or less conspicuous thickenings at the angles where they join other cells; and they are rich in proteid contents. This is collenchyma-tissue, represented at *b* in Figure 1 (Pl. XXXIX.).

(3) Still further interior is found a much greater thickness of cells, different from the rest. They are larger than the collenchyma-cells; they are not thickened at the angles, but have small angular interspaces instead; their walls are thin and composed of cellulose; and they are rich in proteid and starchy contents. This is parenchyma-tissue, represented at *c* in Figure 1 (Pl. XXXIX.).

(4) Interior to this again is a zone of much smaller, angular, and very thick-walled cells whose walls have stained a deep-brown. The cells of this tissue are destitute of proteid and starchy contents; they are also very compactly arranged, so that there are either no intercellular spaces or only very minute ones. These thick-walled cells are bast-fibres constituting a variety of the mechanical tissues, and their walls, like those of most other mechanical tissues, are lignified. With the reagent that has been employed they have been stained the same color as the cork-cells, but their chemical constitution is not the same, as may readily be proved by means of another test: Let a fresh section of the same stem be treated first with two or three drops of the phloroglucin solution, and after a few moments with a similar quantity of hydrochloric acid; the section is then covered and examined: the bast-fibres are now found to be stained red, while the cork-cells remain unchanged in color. The bast-fibres are shown at *d* in Figure 1 (Pl. XXXIX.).

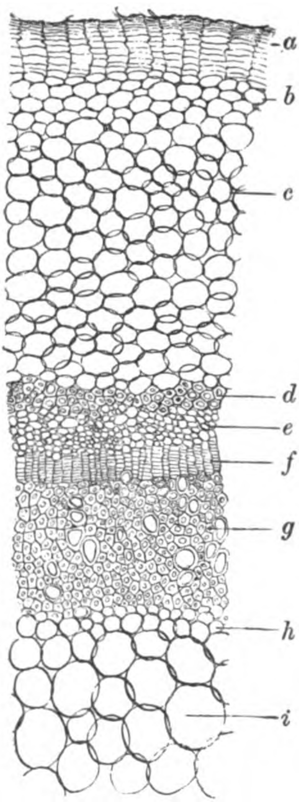
(5) Next the bast-fibres, on the side toward the pith, is a not very broad area or zone of small-celled tissue whose walls have stained blue with the chloriodide. By turning on a higher magnifying power there can easily be distinguished in it two layers: the outer layer, composed of somewhat larger cells which in this view appear more rounded, of unequal size, and which are not arranged in any apparent order, constitutes the soft bast, made up chiefly

of two kinds of thin-walled tissues—sieve-tissue and a variety of parenchyma; the inner of the two layers is composed of very minute and very thin-walled cells, rich in protoplasm, but destitute of intercellular spaces, and the cells have a more or less evident arrangement in radial rows. This is called meristem-tissue, and the zone of it which occurs here at the junction of the wood and the bark constitutes what is called the cambium zone of the stem. Meristem-tissue is, however, not really a separate tissue, but consists of very young cells, some destined to develop into one kind of tissue, others into another. In the illustration *e* and *f* (Fig. 1, Pl. XXXIX.) are respectively the soft bast and the meristem-tissues.

(6) Next interior to the cambium zone is a tissue-layer, more or less broad according to the age of the stem, composed of cells the majority of which, in this view, look like bast-fibres and have stained the same color. Sprinkled among these cells are others of larger calibre, but whose walls are thickened and likewise stained brown. The former is wood or libriform tissue, and the latter vasiform tissue, consisting of ducts or tracheids of various kinds. Both, like the bast-fibres, are mechanical tissues, their functions in the stem being chiefly those of strengthening and conveying nutriment.

(7) Interior to this zone of wood, as it is called, is a large-celled parenchyma substantially like that between the zone of cork and that of bast-fibres except that the cells are mostly larger: this is the pith-parenchyma. The outer layers of it consist of smaller cells more compactly arranged, while the inner part is composed of relatively large cells with rather conspicuous intercellular spaces. The pith-cells are rich in starchy contents, but often contain but little protoplasm, and in very old cells there is none at all. Usually from these the starch also has disappeared.

II. Longitudinal Section.—By making a thin section that runs lengthwise of the stem near its middle, and treating it as the last was treated, there will be discovered other important differences between the different tissues. But first the method of making good longitudinal sections with the razor should be learned. Let first a piece of the stem from three to five centimetres long be taken. By means of a sharp pocket-knife the stem is cut transversely about six millimetres back of one end to a trifle beyond its centre; then the knife-blade is withdrawn, and



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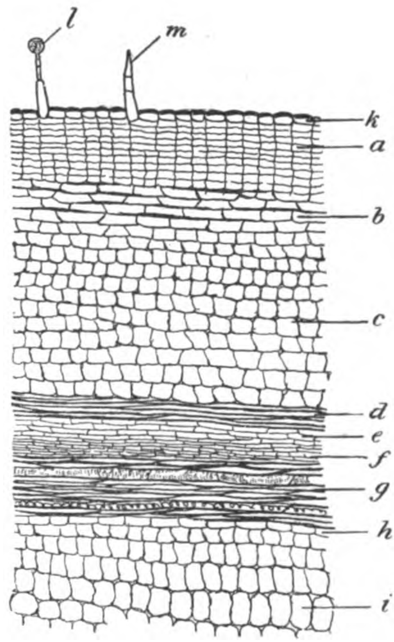

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PLATE XXXIX., FIG. 1.—Portion of Cross-section of Stem of Pelargonium zonale, extending from the exterior to the pith, and showing all the different kinds of tissues: *a*, cork-tissue exfoliating at the surface; *b*, collenchyma; *c*, cortical parenchyma; *d*, bast-fibres; *e*, soft bast; *f*, cambium zone; *g*, zone of wood consisting of wood-cells and ducts of various kinds; *h*, small parenchyma-cells at outer border of pith; *i*, large parenchyma-cells forming main portion of pith.

FIG. 2.—Portion of Longitudinal Section of another and somewhat younger Stem of the same species: the letters *a* to *i*, inclusive, refer to the same parts as in the previous figure; *k*, the epidermis, in this specimen not yet displaced by the cork-cells forming beneath; *l*, a glandular hair; *m*, an ordinary hair. (Both figures magnified about 50 diameters.)

EXERCISE III.

STUDY OF PARENCHYMA.

ORDINARY parenchyma is a very abundant tissue, and may be studied to advantage in the roots, stems, and leaves of almost any flowering plant or fern. In herbs and aquatics it constitutes by far the largest proportion of the plant; in woody plants, though much less abundant, it still exists in considerable quantity.

Besides the ordinary form there are several varieties or modifications, such as stellate parenchyma, where the cells are star-shaped; folded parenchyma, where the walls have internal folds; spongy parenchyma, where the cells are very loosely arranged; palisade parenchyma, where the cells are elongated and arranged somewhat like the posts of a palisade; and pitted parenchyma, where the walls are pitted or marked by thin places of various dimensions and shapes in different cells. Ordinary and pitted parenchyma will be studied in this exercise; the rest, farther along in the course.

I. ORDINARY PARENCHYMA OF PUMPKIN STEM.—Making a thin transverse section, mounting it in a few drops of potassium-iodide iodine, and examining it under a low power, it is observed—

(1) Parenchyma is the most abundant tissue of the stem; it consists of thin-walled, rounded or polygonal cells having small angular intercellular spaces, the cells being rich in protoplasm. These facts agree with what has already been observed in the parenchyma of the Geranium stem; they agree also with the structure of ordinary parenchyma-tissue in general. If a longitudinal section be made and the tissue be examined, it will be found that in this view it does not appear markedly different from that in the transverse section; the cells, that is, are not much longer than broad, and are blunt-ended, as is usually the case with par-

enchyma-cells. Ordinary parenchyma-cells may sometimes be found that are two, three, or in rare instances even several times as long as broad, but even then they are blunt or square-ended, not acute, oblique, or taper-pointed.

(2) As the walls have not been stained by the reagent used, it may be inferred that they are composed of cellulose, and therefore would probably stain blue with the chloriodide-of-zinc iodine. Since this reagent will aid to further knowledge of the structure of the tissue, a new section should be prepared and be treated with the chloriodide on another slide. After the blue color characteristic of cellulose has been developed in the walls, it will readily be seen, if the high power be turned on, that the walls are not uniformly colored, but appear punctate with nearly colorless dots. These dots are not apertures, as might at first be supposed, but are thin places in the wall, consisting really of little more than middle lamella. It is learned from the test that, thin as the walls of the cells are, they are not of even thickness. This is true of the walls of all cells which have reached maturity, but the inequality is usually greatest in the walls that have become considerably thickened, and it is by reason of this fact that some thickened cell-walls have very conspicuous markings, such as pits, bars, spirals, and so on.

(3) Returning now to the section that was treated with the potassium-iodide iodine, let the cell-contents be studied. It will be found, as was done in the cells of the Onion scale, that the cells contain protoplasm and a nucleus, and in these may be distinguished nearly the same structure. On the outside is the primordial utricle, which in places has been shrunken away from the cell-wall by osmosis; in the centre, or sometimes in contact with the wall of the cell, is the rounded, distinctly outlined nucleus, containing two or more nucleoli; there are the plates and bands of protoplasm connecting the nucleus with the primordial utricle; and between the plates and bands are sap-spaces or vacuoles. Here, as in all protoplasm, are found very minute granules, the *microsomes.*

Besides the microsomes there are other granules, rounded or oblong in form, of much larger size, and stained brown like the protoplasm and nucleus, only deeper, because they are denser. They are the *chloroplasts,* or chlorophyll-bodies; in the fresh stem they are green in color by reason of the chlorophyll they contain. It is the coloring matter in these chloroplasts which gives the green color to the leaves and other green portions of the plant.

There are other granules, dense, rounded, and stained so deeply as to appear black with the strong iodine solution used: these are of an entirely different nature, not proteid at all, but starch-grains, as may readily be proved by using on a fresh section a little of the iodine solution much diluted with water, when they will show their proper blue color. Or the same object may be compassed even better by the use of a few drops of the chloral-hydrate iodine, which dissolves the proteids and causes the starch-grains to swell slowly, at the same time staining them the characteristic blue color.

If the parenchyma examined is from near the outside of the section, it will be found that the chlorophyll bodies are numerous; if from farther interior, few or none will be seen, while here the starch-grains are usually more abundant.

II. Pitted Parenchyma from the Stem of the Sago Palm (*Cycas revoluta*).—This modification of parenchyma, though much less common than that just described, is still easy to observe, being found in the pith of many woody plants, as in that of Pilocarpus selloanus, *Engler*, P. Jaborandi, *Holmes*, Asimina triloba, *Dunal*, Magnolia grandiflora, *L.*, and Magnolia glauca, *L.*, in the parenchyma between the bundles in the stems of most woody monocotyls, and in the medullary rays of a large proportion of the woody dicotyls.

(1) If a transverse section of the petiole of the Sago Palm be made, and merely mounted in water without staining, it will be seen that the rather thick-walled parenchyma shows many transparent, rounded or oblong areas, that, being colorless, look like perforations. They are not perforations, however, but are merely thin places perfectly analogous to those already observed in the thin-walled parenchyma of the pumpkin stem; only here, owing to the much greater thickening of the rest of the wall, they are more conspicuous. They even give to the edges of the cell a distinctly beaded appearance.

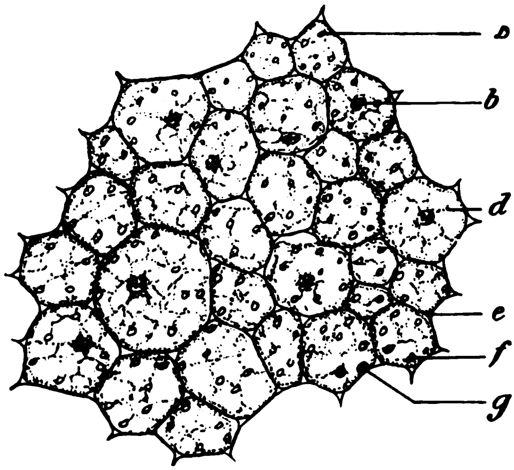
(2) If the cover-glass be taken off and the phloroglucin or aniline-chloride test be applied, it will probably be found that the thickened walls of the parenchyma-cells are also somewhat ligni-

fied, though not nearly so strongly as the wood-cells and ducts which may be seen in the same section.

(3) A still better idea of the structure of these cells will be obtained, however, if some new sections, both longitudinal and transverse, are made and are treated as follows: If the sections are cut from fresh tissues, they should be plunged into alcohol or acetic alcohol for a few moments to fix the protoplasm and to facilitate staining; they are then washed in water and placed for about fifteen minutes in a dish containing a little of the gentian-violet solution; they are again washed, this time in alcohol, to remove the excess of stain, in the last washing causing them to pass through absolute alcohol so that they become anhydrated, and are then laid for fifteen or twenty minutes in eosin oil of cloves, which both clears the section and removes most of the gentian-violet that is left in the cellulose tissues, while at the same time it communicates its own color to them. The thicker portions of the wall are now found to have retained the violet color, while the thin portions are unstained by it, but are distinctly colored by the eosin, thus proving that they are not perforations.

The staining also reveals the fact that the cells contain protoplasm and a nucleus.

Between this rather thick-walled and distinctly pitted parenchyma and the ordinary kind there are found in different plants, or often even in the same plant, every gradation; and, on the other hand, there may also occur every gradation between it and sclerotic tissue, soon to be studied.



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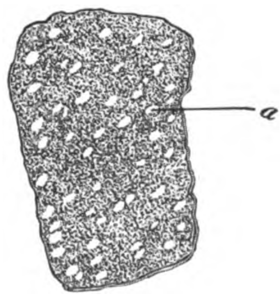

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PLATE XL., FIG. 1.—A small portion of the Parenchyma as seen in a transverse section of the stem of the Pumpkin (magnification about 60 diameters): *a* and *f*, chloroplasts; *b*, the nucleus; *d*, ordinary protoplasm; *e*, small, angular intercellular space; *g*, a starch-grain.

FIG. 2.—A small portion of the Cell-membrane of one of the Parenchyma-cells (magnified 500 diameters), showing the small pits. The drawing was made from a section which had been stained by means of zinc-chloriodide iodine. *a*, one of the pits.

EXERCISE IV.

STUDY OF COLLENCHYMA.

THE following objects are easily obtainable, and afford convenient examples for study: the petioles of almost any species of the cultivated Begonias; those of almost any species of Grape, of the Sumach, of Burdock, of Pie-plant, and of Plantain; the stems of the Yellow Dock, the Pumpkin, the Ohio Buckeye, of Joe-Pye Weed (Eupatorium purpureum, *L.*); and the stems and petioles of Spikenard (Aralia racemosa, *L.*).

I. THE PETIOLE OF BEGONIA DISCOLOR (*H. K.*), a common greenhouse plant, will be the subject of the present study. Let a transverse section first be made, as thin a one as possible, and mounted, without exerting pressure on the cover-glass, in a few drops of the strong potassium-iodide iodine solution. Care should always be taken, especially in the study of fresh or unhardened sections of delicate tissues, not to put on the cover-glass in such a way as to exert more than the minimum of pressure on the section, otherwise the cells will be crushed or inclined to one side, making it difficult to understand the structure. Having obtained a successful mount, let it be examined first with the low power and afterward with the high one.

(1) At the very periphery of the section is seen the epidermis, consisting of a single tier of cells, and immediately beneath or interior to this is the tissue to be studied—the thick-angled tissue, or collenchyma. It consists usually in this species of about five or six layers of cells of varying sizes, but averaging considerably larger than those of the epidermis exterior to them, and smaller than those of the parenchyma interior to them.

It is in this position—namely, just interior to the epidermis or to the cork that may be formed from it—that collenchyma, when present at all, is usually found. It very rarely occurs elsewhere in the plant. It is pre-eminently a strengthening tissue to the epidermis, and sometimes, as in the present instance, forms a continuous band or zone about the sublying tissues; at others it is interrupted at intervals, and forms long bands or strings running lengthwise of the organ, as in the stem of Yellow Dock and in the stems and petioles of many Umbelliferæ.

(2) The most distinguishing characteristic of collenchyma is readily seen—namely, the thickened angles of the cells. These thickenings in most cases are great enough to obliterate completely the intercellular space, though sometimes a portion of this still remains, as may often be seen in the petioles of Pie-plant. In some plants these thickenings are excessive, so as strongly to encroach upon the lumen of the cell; in other instances they are but slight. In some species the thickening is confined to the angles, while in others it may extend, to a less degree, to the entire wall.

It is easily determined, by aid of the sulphuric-acid-and-iodine or by the chloriodide-of-zinc iodine test, that the thickenings in the present instance are of cellulose, and not of lignin; and this is usually the case with this tissue, though in a few instances, where the thickenings are excessive, there is more or less of lignification.

Under a high power delicate stratification-lines may be observed in the more prominent thickenings. These are common in thickened walls generally, and are due to differences in the amount of water contained in different layers, making some more transparent than others. That this is the case may be demonstrated by removing the water completely by treatment with a considerable quantity of absolute alcohol, when the lines disappear. There are also other ways of proving the same thing, as will be demonstrated in a future exercise.

(3) The iodine test shows that these cells, like the parenchyma-cells farther interior, contain protoplasm, a nucleus, and chlorophyll-bodies. They are therefore not merely mechanical tissues, but take an active part in the vital processes of the plant.

Occasional cells, usually larger than the rest, are seen to contain stellate masses of crystals. If to a fresh section there be applied two or three drops of strong acetic acid, it will be found that even after some time the crystals remain unaffected; but if to a similar section a few drops of strong hydrochloric acid be applied, the crystals slowly dissolve without effervescence. Had they been composed of calcium carbonate, they would have effervesced and passed into solution in both acids; had they been composed of silica, they would not have been affected by either. Since, therefore, it is known that calcium oxalate is soluble without effervescence in hydrochloric acid, but not in acetic acid, the conclusion is that the crystals are of this substance—the commonest by far of all the crystalline substances in plant-cells.

II. LONGITUDINAL VIEW OF COLLENCHYMA.—Let there now be made a longitudinal section of the petiole nearly through its centre, in the same manner as directed in Exercise II. Care must be observed to cut the sections very thin, otherwise the structure cannot well be seen, owing to the overlapping of the cells. The sections should now be treated with chloriodide-of-zinc iodine, so that the cell-walls may easily be traced. The longitudinal view of the tissue appears quite different from the transverse view, partly because of the thickenings—which are now seen lengthwise, appearing as long, narrow bands—and partly because the cells themselves are considerably elongated in the direction of the section. As to their length, however, they differ much among themselves. Some are no more than twice as long as broad, while others may have a length five or six times the thickness. It will be observed that the narrower cells are usually the longer, as though what had been gained in length had been sacrificed in thickness. The cells containing crystals, being of great transverse diameter, are also short. It will be observed, furthermore, that the cells are blunt-ended, never taper-pointed, agreeing in this respect with parenchyma-cells. In fact, the tissue as it occurs in this plant is not very greatly modified from ordinary parenchyma. In some other plants, however, it is found tending strongly toward fibrous tissue. Its cells are greatly elongated, the walls much thicker, the ends more inclined to oblique or tapering forms, and in some instances the walls even somewhat lignified, forming a tough and strong tissue more exclusively devoted to mechanical functions.

EXERCISE V.

STUDY OF SCLEROTIC PARENCHYMA.

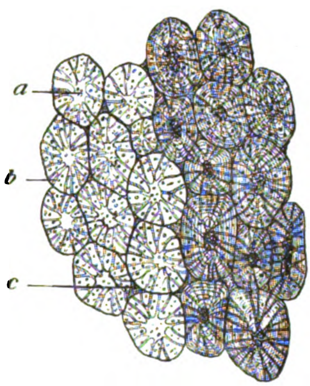
GOOD examples for study occur in most of the nuts, particularly the Hickory-nut, Pecan, Hazel-nut, English Walnut, and Cocoanut; in the flesh of the Pear, the gritty particles in which consist of this tissue; in the pith of the stem of Menispermum canadense, *L.*, and in that of the Apple twig; in the leaves of Tea and Camellia; in the stem-barks of Ceylon cinnamon (Cinnamomum Zeylanicum, *Breyne*), the Sweet Bay (Magnolia glauca, *L.*), the Umbrella Tree (Magnolia Umbrella, *Lam.*), the Flowering Dogwood (Cornus florida, *L.*), and the Custard Apple (Asimina triloba, *Dunal*); and in the root-barks of the Dogbane (Apocynum androsæmifolium, *L.*), the Butterfly Weed (Asclepias tuberosa, *L.*), the Yellow Dock (Rumex crispus, *L.*), and the Hop tree (Ptelea trifoliata, *L.*).

Sclerotic tissue, often from its hardness called "stony tissue," is, as found in the shells of nuts, for example, very difficult to cut without resorting to some softening process. Softening may be accomplished by soaking the tissues for a week or more in a 5 or 10 per cent. aqueous solution of potassium hydrate, and then washing out the alkali by means of clean water or water which has been slightly acidulated with acetic acid. Good sections may now be cut with a razor, even of such hard structures as the shells of the Hickory-nut or Cocoanut, without much danger of notching the blade, providing it be not allowed to run too deep. The darkening of the tissue, which is often one of the results of the process, may be corrected either by treating the sections with the sulphurous-acid alcohol described in the Introduction, or by bleaching them with Labarraque's solution, taking care to carry the bleaching process only so far as to get rid of the coloring matters. The sections may then be washed thoroughly, stained with safranin solution or with a solution of iodine-green, anhydrated by means of absolute alcohol, and permanently mounted in balsam.

But for the laboratory a method which is less time-consuming is more desirable, hence the following may be adopted: With a thoroughly sharpened pocket-knife cut a number of thin sections parallel to the surface of the shell, and place these sections by themselves in a dish of water. It does not matter that they are of small size or fragmentary if they are cut thin. After soaking for a few minutes in the water, particularly if it be heated to near the boiling-point, the sections, which usually roll up in cutting, may be flattened out by means of dissecting-needles or by means of a needle and a brush, and then be mounted in a drop of water or glycerin, and examined. The edges at least will be transparent enough to permit of the cells being seen distinctly.

(1) For this study the shell of the Cocoanut is selected, and by means of the process last described a dozen or more sections are cut parallel to the surface of the nut, and as many from the edge of a broken piece, or perpendicular to the surface. One or two sections of each kind are now mounted on different slides.

The section made parallel to the surface is first examined. Focusing with the low power upon the thinnest part, there is seen a mass of cells which are rounded, somewhat polyhedral, or slightly elongated in form, pressed so close together that no intercellular spaces are visible, and having excessively thick walls. On or in the walls are seen minute dots or punctulations, as well as radial lines connecting the very small cavity or lumen of the cell with the middle lamella. Many of the lines are simple, while others branch before reaching the exterior. With the high power and under favorable illumination one may readily convince one's self that the lines are really minute tubes beginning at the lumen and terminating at the middle lamella. The dots, too, are of the same nature, as may be learned by focusing up and down; they are small tubes looked at endwise, and therefore appearing round or dot-like. The tubes may be rendered more distinct by flattening out one of the sections on a slide, drying it over an alcohol lamp so as to expel the water from the tubes and lumen, putting on a drop of balsam, and covering with a cover-glass. The tubes are now easily traceable because



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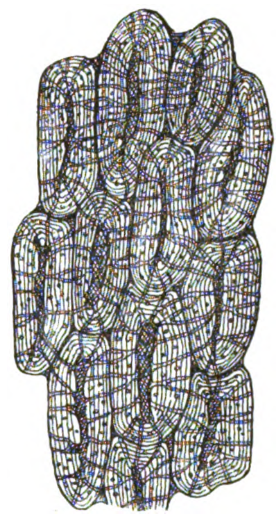

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PLATE XLIII., FIG. 1.—A group of Sclerotic Parenchyma-cells from a section of the Cocoanut shell (magnification about 330 diameters). The section was tangential, or made parallel to the surface of the nut. The cells to the right show both the pore-canals and the stratification-lines, while from those to the left the latter have been omitted to show the former more distinctly. *a*, lumen of a cell; *b*, a branching pore-canal; *c*, middle-lamella.

FIG. 2.—A portion of the same kind of Tissue from a Radial Section (magnified about 400 diameters).

EXERCISE VI.

STUDY OF EPIDERMAL TISSUE.

THE epidermis may readily be stripped off from the leaves of any of the following plants, which therefore afford convenient objects for study: most of the Cultivated Lilies; the Garden Hyacinth; the Tulip; most of the cultivated species of Amaryllis, Agapanthus, and Narcissus; Tradescantia Virginica, *L.*; some species of Sedum, as, for example, the Common Live-for-ever (Sedum Telephium, *L.*); the Gentians, as Gentiana alba, *Muhl.*; and some of the cultivated species of Begonia, as Begonia discolor, *H. K.*

In other instances, where the epidermis is too fragile or too closely adherent to sublying tissues to separate readily, good preparations of it in the fresh condition may still be made by carefully scraping away with a knife-blade the tissues next to the epidermis until the chlorophyll-bearing cells are removed.

For the present exercise is selected the epidermis from the leaf of the Tulip. This may be obtained, in pieces of sufficient size, in the manner described in the case of the Onion scale. Let the epidermis from the under or dorsal surface of the leaf first be studied.

(1) After transferring a piece of the epidermis to the centre of a slide and treating it for a few minutes with the strong solution of potassium-iodide iodine, it is covered, and examined first with the low and then with the high power.

It will be seen that the ordinary epidermal cells are arranged very much as in the Onion. They are considerably elongated in the direction of the length of the leaf, the ends are blunt, and the cells are so arranged as to leave no intercellular spaces. This is true of ordinary epidermal cells generally, and in this respect they differ markedly from those of parenchyma-tissue.

The cells are rich in protoplasm. The primordial utricle, the nucleus, the nucleoli, and the threads and bands of protoplasm are all as distinctly recognizable as in the cells of the Onion epidermis already studied, and are very similar in appearance to the cells of the latter. The vacuoles are also abundant, and many of them form transparent globules of various sizes.

But a conspicuous difference is the presence of *stomata*, or so-called breathing-pores—small apertures between a pair of crescent-shaped cells called *guard-cells*. These pores were not found in the epidermis of the Onion scale, because this was not exposed to the light. The epidermis of the colorless scales of parasites, of the scales of ordinary plants where not exposed to light, and of roots and subterranean stems, ordinarily does not possess stomata, but that of all green parts of plants above the mosses in the scale of life usually possesses them in abundance, except that they are often absent from the epidermis of the upper surface of leaves. The stomata are the openings through which the plant gets rid of the superfluous water it takes up chiefly through its roots, through which it exhales that portion of the disengaged oxygen which it does not require, and through which it takes in the carbon dioxide which it needs for food. They are apertures which also automatically dilate or contract, or even completely close, according to the condition of the atmosphere and the necessities of the plant. If the air is dry and there is need for the plant to conserve its moisture, the stomata contract; if the air is moist and the plant has more water in its tissues than is needed, they expand. The mechanism by which these movements are accomplished will presently be discussed.

The guard-cells are much smaller than the ordinary epidermal cells and are much richer in proteid matters, containing, besides a crescent-shaped nucleus and ordinary protoplasm, numerous chloroplasts and occasional oil-globules. The chloroplasts, it will be observed, are not present in the ordinary epidermal cells. This is true of the epidermis in most plants—a fact which accounts for its transparency.

(2) Let now a transverse section of the epidermis be made—that is, a section through it which is perpendicular to the longest diameter of the leaf; for in order to understand the structure of a stem it is necessary to have a section which crosses the two guard-cells near their middle, and, since the stomata all point in the same direction—namely, lengthwise of the leaf—this is the only section which will serve the purpose. It is necessary, more-

over, to have the section quite thin. It is readily made as follows: Cut out of the leaf a piece about half an inch square, and orient it properly between the flat surfaces of two pieces of elder pith. Holding the combination rather firmly between the thumb and the fingers, very thin sections may be cut through pith and all, and those of the leaf may be picked out by means of the pincettes.

The pith for this purpose is best prepared as follows: Take a piece about four centimetres long and halve it lengthwise, not by placing the edge of the razor across one end and forcing it through toward the other, but by placing it parallel to the length of the cylinder and cutting it as nearly as possible through the middle. The danger of breaking it into small fragments is thus avoided. Between the flat surfaces of the two semi-cylinders thus produced is placed the leaf to be sectioned.

The sections, as soon as cut, should be transferred to water to prevent the entrance of air; but care must be taken to keep the pith dry during the process of sectioning, for if moistened it does not cut well.

Having prepared thus several good sections, one is selected, and by means of a camel's-hair brush is transferred to a slide and mounted in a drop of water. Since the weight of the cover-glass is sufficient to crush and spoil a section so delicate, it is best that the slide used should have a ring of cement or of sheet wax in its centre, a little smaller in diameter than the cover, and of sufficient thickness to relieve the section of the pressure.

On placing the preparation under the microscope now, it will be found that the epidermis consists of a single layer of cells, which in this view are squarish in outline, quite thick-walled exteriorly and only a little less so interiorly, but with the radial walls rather thin. At intervals occur cells in pairs, smaller, of different shape, and with more granular contents. These are the guard-cells. If the section happen to run squarely through their middle, it will be possible to see the stoma or opening itself.

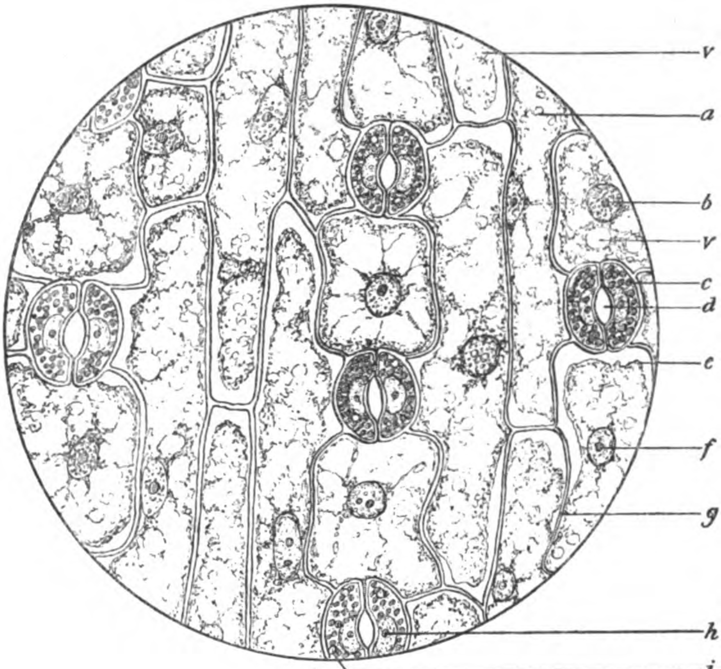
Underneath the epidermis are found relatively large, rounded, thin-walled parenchyma-cells having between them conspicuous intercellular spaces and containing numerous chloroplasts. The stomata, it will be observed, always open into a large intercellular space. Owing to this arrangement the outside air, when the stomata are open, is in free communication with the whole interior of the leaf, since air can circulate freely through the intercellular spaces. The importance of this fact to the functions already mentioned will readily be understood.

But while there is this free communication between the interior and the exterior through the stomata, the walls of the epidermal cells are all highly impermeable to water, for the epidermis, as would be found by testing it, is strongly cutinized, and cutin is of all vegetable substances one of the least permeable to water. The function of cutinized epidermis in preventing excessive evaporation is strikingly shown in the case of the leaf of the common Live-for-ever and in that of Bryophyllum. If a leaf of either be plucked and exposed to the sun and dry air even for a considerable time, it scarcely shows signs of withering; but if the epidermis first be stripped off, the leaf will shrivel and dry in the course of a few minutes.

(3) *Mechanism of the Opening and Closing of the Stomata.*— The movements of the guard-cells by means of which the aperture between them is enlarged or contracted are effected by means of their hygroscopism—that is, by their power to take up moisture from the air about them and to part with it. When the air is moist the guard-cells imbibe moisture and swell, but they are so placed as respects the other epidermal cells, and the thickenings of their walls are so adjusted, that in swelling the cells must bow out in the middle, thus increasing the size of the aperture; and when, on the other hand, the air is dry and they part with moisture, the cells become flatter, less convex on the outer or more remote surfaces, and less concave on the inner ones, or those next the aperture, thus either diminishing the latter or closing it completely. The cross-section shows that the more remote walls remain quite thin, thus permitting a movement in a direction parallel to the surface of the epidermis and perpendicular to the length of the guard-cells, while movements in other directions are not possible. Careful tests, moreover, show that while the outer part of the cell-walls, and even the inner part, is cutinized, the radial walls are not only not cutinized, but are quite thin throughout a considerable portion of their extent, so that they can readily take up moisture and as readily part with it. When the stoma is closed, however, only cutinized surfaces are presented to the outer air, and evaporation is thus shut off.

stomata. Very commonly the guard-cells are on the same level as that of the other epidermal cells; in some species they rise above that level, and in some other species they are depressed more or less below it.

(*k*) The stomata differ also in different species as respects their relation to adjacent cells. Sometimes they are scattered among ordinary epidermal cells, but not infrequently the cells immediately surrounding them are more or less modified in form and structure, so as evidently to be subsidiary to them. Such cells are called "accessory cells." In one instance—that of Aneimia fraxinifolia—according to Strasburger, the guard-cells are placed within an ordinary epidermal cell very much as a picture within its frame.



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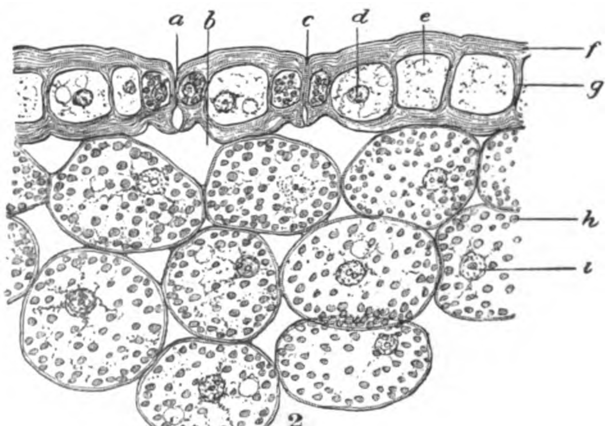

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PLATE XLIV., FIG. 1.—Lower Epidermis of the Tulip, view of the exterior surface. The drawing was made from a portion of the tissue which had been treated with potassium-iodide iodine (magnification, 285 diameters): *v*, *v*, vacuoles; *a*, protoplasm; *b*, nucleus; *c*, chloroplast in one of the guard-cells; *e*, primordial utricle shrunken away from the cell-wall by the action of the iodine solution; *f*, nucleolus; *g*, cell-wall; *h*, nucleus and nucleolus of guard-cell; *i*, oil-globule in guard-cell.

FIG. 2.—Small part of Transverse Section of the Leaf, showing a portion of the lower epidermis and a few of the adjacent parenchyma-cells: stomata are indicated at *a* and *c*; *b*, the air-chamber adjacent to a stoma; *d*, nucleus of an ordinary epidermal cell; *e*, a vacuole; *f*, cutinized exterior wall; *g*, thin radial wall; *h*, a chloroplast in one of the parenchyma-cells; *i*, nucleus of one of the parenchyma-cells. (Magnification the same as in Figure 1.)

EXERCISE VII.

STUDY OF EPIDERMAL APPENDAGES.

THE following will afford interesting studies: young stems and leaves of the Sycamore (Platanus occidentalis, *L.*); those of the Hickory (Carya alba, *Nutt.*); those of the Nettle (Urtica dioica, *L.*); those of Shepherdia (Shepherdia Canadensis, *Nutt.*); those of tobacco (Nicotiana Tabacum, *L.*); those of the Mullein (Verbascum Thapsus, *L.*); those of Mentzelia (Mentzelia oligosperma, *Nutt.*, or M. ornata, *Torr.* and *Gray*); those of the Horseshoe Geranium (Pelargonium zonale, *Willd.*); and the hairs on the filaments of the Spiderwort (Tradescantia Virginica, *L.*).

(1) For the first study is selected a stem of the Horseshoe Geranium which is not yet old enough for cork to have begun to form. Of this a half dozen or more thin transverse sections are made. Let one of these sections be placed on a slide, covered with several drops of the alcannin solution, and set aside under a bell-glass for half an hour or more to permit of satisfactory staining. Another of the sections may be treated with the chloriodide-of-zinc iodine and be put away in the same manner. A third is mounted in a drop of water and focused upon with the low power.

On exploring the margin of the section there will be found attached to the epidermis numerous hairs. These hairs are not all of the same kind, for some have a large rounded cell at the apex, while others are without such a cell. The former are the glandular hairs, the latter are ordinary simple ones.

Let first one of the simple hairs be examined. It will be observed to be long-conical in shape, and to be composed of a varying number of cells, usually three or four, placed end to end. The basal cell, more rounded and thicker than the rest, fits in among the other epidermal cells, and the apical cell is longer than the rest and terminates usually in a sharp point. The contents are transparent, though with care there may be discerned, even without staining, a nucleus and a small amount of granular protoplasm.

The glandular hairs are of three different varieties. One variety is much longer than the rest, and consists usually of from five to seven cells arranged in a single series, the apical cell constituting the gland, the rest the stalk. The latter has its basal cell set in the epidermis the same as the simple hair just described. The cells above it taper gradually in size until the fourth or fifth cell is reached, when there is an abrupt contraction, the succeeding one or two cells being considerably narrower and thinner-walled.

The gland-cell is nearly globular, and is so densely granular that its structure can only with difficulty be made out without the employment of clearing solutions. On the upper surface, however, there is usually a transparent, highly refractive portion, the nature of which will presently be investigated more closely.

Another kind of hair is much shorter, the stalk consisting of only two or three rather short cells, and the gland consisting of a very granular cell which is usually oblong or ovate instead of spherical, and which is often unsymmetrically inserted on the stalk. The third kind of hair, the most abundant of all, is also short, but with its stalk composed of four or five very short cells. The gland is spherical like the one first described.

It is these glandular hairs which cause the clamminess of the leaves and branches, and it is they also which emit the volatile essence that communicates to the plant its peculiar odor.

Treating a fresh section with potassium-iodide iodine, it is found that the cells of both the simple and the glandular hairs contain abundant protoplasm in which may be recognized the usual structure belonging to living cells—the nucleus and nucleolus, the primordial utricle, and the threads and bands of protoplasm. Even in the densely granular gland-cells there may in some instances be recognized the nucleus, showing that they also, in this stage of growth at least, are living cells.

Besides the protoplasm proper there will also be found a few rounded or oval granules colored brown like the protoplasm. These are leucoplasts, like chlorophyll bodies except that they contain no chlorophyll.

To another section are applied a few drops of the chloral-hydrate solution for the purpose of clearing the gland-cells, that their structure may the better be examined. The section should be examined immediately, before the liquid has had time completely to disorganize the protoplasm. In a few moments the gland-cell will be sufficiently clear to permit of the nucleus being recognized easily. Afterward the nucleus swells, and finally, like all the other proteids, is rendered nearly invisible. This clearing makes the cell-walls stand out with beautiful distinctness, and one becomes satisfied for the first time that the gland consists of a single cell.

Let now examination be made of the section which was treated with the chloriodide-of-zinc iodine, for the purpose of finding out whether or not the walls of the hair-cells are cutinized. It will be found that they are stained the same color as the rest of the epidermis. The interior of the walls may show a bluish tinge, indicating that cutinization is not complete, but the exterior is strongly cutinized.

Careful comparison of this with the previous section will render it evident that in those gland-cells which show at the top a transparent area the epidermal wall is divided into two parts, the exterior cutinized, the interior not cutinized or but slightly so, and that the refractive liquid lies between these two portions.

Sometimes it will be found, especially in older glands, that the cutinized portion is ruptured, the wall therefore more or less collapsed, and the refractive liquid accumulated in droplets on the outside. Some of the liquid seems, in fact, to be forced out by internal pressure before the wall becomes ruptured, as shown in Figure 2 (Pl. XLIV.). The conclusion naturally is reached that the refractive liquid, whatever it may be, is secreted by the granular protoplasm in the gland, and is forced out and accumulates between the non-cuticularized and the cuticularized portion of the wall, where, by reason of the impermeability of the latter, it accumulates until the pressure becomes so great as to force it through or finally to rupture the wall.

Let now an effort be made to ascertain the nature of the refractive liquid secreted by the glands. On soaking one of the sections for twenty minutes in absolute alcohol, evidence will be found that the secretion has passed into solution. The same result will also be reached if another section be treated for a few minutes with sulphuric ether. The secretion is, then, probably resinous or down the other, or passing off into the threads and bands that connect the primordial utricle with the nucleus. In some of the threads is observed a single current moving steadily in one direction, while in others may be seen two currents, side by side, running in opposite directions. The currents, however, are more or less shifting, as are the bands themselves.

This phenomenon is not exceptional. It not only occurs in the hairs of many other plants, as those of the Nettle and Glaucium luteum, but in the internodal cells and so-called leaves of the species of Chara and Nitella, in the leaves of Vallisneria spiralis, in the epidermal cells and hairs of the common Plantain, etc. It is, moreover, probable that the activity which in these instances is so conspicuous to the eye really exists to a less degree in the protoplasm of all living cells.

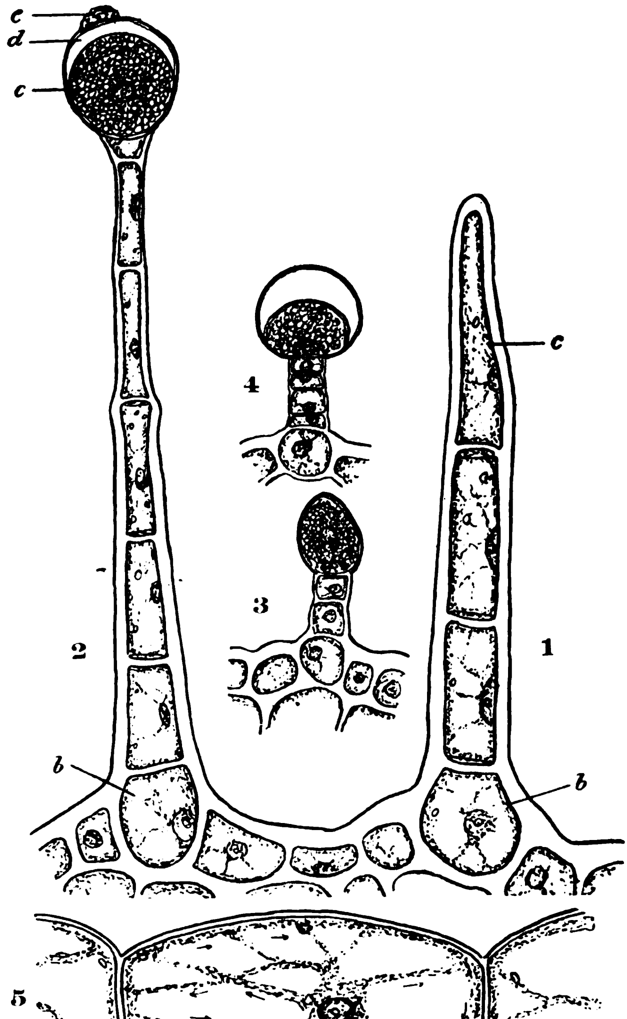

PLATE XLV.—Hairs from Stem of Pelargonium zonale and from Filament of Tradescantia Virginica:

FIG. 1.—A Simple Hair of Pelargonium: *b*, basal cell adjacent to ordinary epidermal cells; *c*, apical cell. Each cell contains protoplasm, a nucleus, and a few leucoplasts.

FIG. 2.—One of the Large Glandular Hairs of Pelargonium: *b*, basal cell; *c*, gland-cell containing densely granular protoplasm; *d*, oleo-resinous secretion between cuticle and the rest of the cell-wall; *e*, exuded oleo-resinous matter.

FIG. 3.—Another form of Glandular Hair from same plant, the gland-cell of which is usually oblong or ovate.

FIG. 4.—A third kind of Glandular Hair from same stem.

(Magnification of Figures 1-4, 330 diameters.)

FIG. 5.—Small portion of Staminal Hair from Tradescantia Virginica, showing currents in the protoplasm of the cell. The arrows indicate the direction of the currents. (Magnification about 300 diameters.)

tiers of cells which are thin-walled, four-sided, considerably longer in a direction parallel to the surface than in the radial direction, arranged in distinct radial rows and more or less distinctly in tangential rows also, the arrangement being so compact that no intercellular spaces are visible. The outer and older tiers of cells are often collapsed—that is, the walls have fallen together—and some of the cells are scaling off at the surface: these are the oldest cork-cells, the youngest being farthest interior. It will be observed also that some of the old cells are opaque from containing air and brownish coloring matters. The walls of the mature cells are also more opaque than those of the younger ones, and the radial walls are more wrinkled the older they are. These appearances belong to nearly all cork-tissue, and by means of them the tissue may readily be recognized.

If with the cross-section be compared a longitudinal one, it will be found that there is little difference in the appearance of the cork-tissue, the most noticeable being the slightly greater average length of the cells in longitudinal view.

(2) Let tests now be applied to determine the composition of the cork. Testing a section with zinc-chloriodide iodine, it is found that all the older cork-cells stain brown, while the very youngest ones show the cellulose reaction. The mature cells are then either cutinized or lignified, the choice being determined by means of another test: Preparing a new section and putting it on a slide, a few drops of concentrated aqueous solution of chromic acid are applied. Watching results closely, it is seen that after a few minutes only the older cork-cells remain, both the cellulose and lignified tissues having been disintegrated and destroyed. The cutinized epidermis would have behaved in the same manner with the same test, and it is concluded therefore that the cork-cells are, chiefly at least, composed of cutin. They are spoken of as *suberized*, but cork-substance or suberin is the same thing as cutin. To confirm the results obtained and to make certain that no mistake has been made, another test is applied: To a fresh section, on a slide, a few drops of a concentrated solution of potassium hydrate are applied: the cork-cells soon assume a yellow color, which, on warming the slide over a lamp, becomes more decided. This is also one of the characteristic reactions of cutinized and suberized tissues.

By a judicious selection of different sections from the same stem all the different stages of cork-development may be observed.

The inner layer of cells in which the division takes place is called the cork cambium, or *phellogen.*

It is not the case in all plants that the cork begins to be formed in the layer of cells immediately beneath the epidermis. In some instances it begins in the epidermis itself; in others a few or several layers beneath the epidermis; and in still others in quite deep-lying tissues. At the close of this exercise is given a drawing of a small portion of the cross-section of the stem of the Bittersweet, showing the cork. Here the formation began by a division of the epidermal cells, and proceeded interiorly until, in the specimen from which the drawing was made, the phellogen-layer has become the fifth from the surface. The cork is ordinarily formed *centripetally* as in the Geranium, but sometimes *centrifugally;* that is, the inner of the two cells produced by the division is the one that develops into cork, while the other remains meristematic.

Cork, it will be observed, is, like epidermis, an admirable protecting tissue. By reason of its physical properties and the absence of intercellular spaces it prevents excessive evaporation from the plant. It also, by virtue of its impermeability to water, prevents injury from parasitic organisms. Bacteria and fungi are thus excluded, to a large extent at least. It is for these reasons that the plant when wounded soon covers the wounded surface with a layer of cork, and even provides a corky covering to the leaf-scar before the leaf separates from the stem.

II. LENTICELS.—Attention has already been drawn to lenticels in the study of twigs, Part I. If there be made several thin sections transversely through the young and still green stem of the Sycamore, it will be found that in some instances the knife has passed centrally through one of these little lens-shaped epidermal swellings. If the crest of the lenticel has not been ruptured, there will always be found at this point a stoma, for lenticels always begin their formation immediately underneath the stomata. The formation of lenticels, in fact, precedes the formation of cork under the rest of the epidermis and initiates the latter process. The cell-division, when once begun, proceeds rapidly, and results in the formation beneath the epidermis of a mass of loosely-arranged cells which press upon the latter, forcing it upward and finally rupturing it, and from the opening thus produced the spongy mass of cork-cells protrudes.

If the formation of the lenticel has but just begun, there will be found only the outer layer of collenchyma-cells in process of division; if well advanced, the whole of the collenchyma beneath the stoma will have become involved, and the collenchyma as such will have disappeared, the tissues of the lenticel having been formed from it by division of its cells. Above, in the outer part of the lenticel, are the rounded, loosely-arranged cells called *packing cells*, and interior to these, next the cortical parenchyma, is a meristem-tissue or phellogen looking quite like the generative layer which produces ordinary cork.

On either side of the lenticel proper are found the outer tiers of collenchyma-cells beginning to divide in planes parallel to the surface; this is the beginning of the formation of cork under the rest of the epidermis, the formation proceeding much as that already described in the Geranium.

The function of a lenticel appears to be that of supplying air to the intercellular spaces; for, although the walls of the cells when mature are cutinized, the cells differ from those of ordinary cork-tissues in having intercellular spaces.

EXERCISE IX.

STUDY OF WOOD-CELLS OR LIBRIFORM TISSUE.

THESE terms include all those thick-walled, fibrous cells, not tracheary in their nature, which occur in the xylem of the vasal bundles of the higher plants, and also the similar fibrous elements which sometimes occur outside of the bundles altogether.

The term "libriform" has reference to the general resemblance the fibres bear to the liber- or bast-fibres often found in the inner bark of gymnosperms and dicotyls. The terms "liber-fibres" and "bast-fibres," as commonly used, are stretched to embrace all those fibres that occur in the phloem ends of vasal bundles, whether they occur in the inner bark or elsewhere in the plant, and whether they occur in gymnospermous and dicotyl plants or in monocotyls.

Libriform fibres differ usually from liber-fibres in being relatively less elongated, less tough and flexible, and less strongly thickened at maturity; but there are numerous exceptions, and in monocotyls particularly the tissues often so completely merge into one as to be wholly indistinguishable by their structure alone. Some authors include the two kinds of tissue under one head, and call them *sclerenchyma-fibres.* This mode of regarding them is convenient if the obvious distinctions between the two tissues as they exist in their more typical forms be not ignored.

While the writer cannot endorse the view that regards what has been called "sclerotic parenchyma" as more nearly related to sclerenchyma-fibres than to parenchyma, still, sclerotic parenchyma and sclerenchyma-fibres agree in the fact that both have lost their cellular character and have become purely mechanical tissues. Moreover, almost every gradation occurs between rounded stone-cells on the one hand and bast-fibres and wood-cells on the other: there are elongated and pointed stone-cells, and very short and thick bast-fibres that would be difficult to distinguish from each other. All of which proves that the hard and fast lines drawn in classifications, useful and even necessary as they are, are lines which do not exist in Nature.

Libriform cells occur in great abundance in the stems of nearly all woody and many herbaceous dicotyls, in the region between the pith and cambium zone; in the meditullium of most woody roots of the same group; and in the stems and roots of many monocotyls and pteridophytes. It is unnecessary, therefore, to point out special examples for study.

The present study is made from the stem of Pelargonium zonale, the general structure of which is already more or less familiar.

(1) Several thin cross-sections are first made from a rather old stem, and, after placing those not required for immediate use in alcohol for future study, one of the sections is laid on a slide and treated with a few drops of the zinc-chloriodide iodine, covered, and examined. The wood which, along with other thick-walled tissues, forms a girdle about the pith is found to be stained a decided brown by the reagent—a reaction which, as already learned, is shown by lignified tissues. As a confirmatory test the phloroglucin reagent is applied to a fresh section and the same tissues are stained red. This lignification extends throughout the whole wall, but in the chloriodide-stained section the middle lamella is a little deeper brown and in the phloroglucin-stained one a considerably deeper red, so that this portion of the wall stands out with great distinctness. All of the cells in this region agree in the lignification of their walls; but some are medullary ray-cells, others ducts or tracheids, and still others are wood-cells. The ducts may mostly be distinguished in their transverse section by their larger calibre, but also, with care, by their markings, which may be seen by focusing up and down. The medullary rays may be distinguished by the fact that they occur in radial rows, are slightly elongated in a radial direction, and are of nearly equal size, while the wood-cells average smaller and are quite unequal in size and irregular in their arrangement.

In outline the wood-cells are irregularly many-sided or prismatic from mutual pressure during growth, and no spaces are discernible between them.

The reason why some cells appear much larger than others is not because there is really so much difference in the actual size, but because they are pointed at the ends, and splice over each other in such a manner that in making a cross-section through the tissue different cells are cut at different levels—some through the middle, others near the ends.

A careful examination of the walls of the cells under a high power and with good illumination shows delicate concentric stratification-lines in the interior thickenings, and now and then very delicate pore-canals, though these are by no means so abundant as in the stone-cells which were studied.

If cross-sections of a young stem be compared with those of an old one, it will be found that in the former the wood-cells are much less thickened, and in a very young stem it will be found that the cell-walls are quite thin and wholly unlignified.

(2) Endeavor is now made to learn more about the cells by isolating them. This is accomplished by operating with Schulze's fluid on longitudinal sections in the manner directed in the study of stone-cells. The relation of parts will more satisfactorily be learned if the sections be cut with considerable care to get them directly lengthwise of the stem. They need not, however, be more than moderately thin. After treatment with the reagent they should be washed with care so as not to tear them, be stained with methyl-green, and then be placed in a drop of clean water on a slide, and covered. The cover is now gently tapped with a needle-point over the centre of the section. This, if not carried too far, and if the tissues have been treated precisely the right length of time in the macerating fluid, will cause the fibres to separate slightly, and yet they may be seen in nearly their natural relations to each other. It will then be observed how the wood-cells splice one over another as has been described.

The cells may now be separated still farther and the shapes of the wood-cells be studied more particularly. The fibres will be found to vary in length from three or four times as long as broad for the shortest ones to twenty or thirty times as long as broad for the longest ones, which attain a length of about one-twentieth of a centimetre. They mostly approach a fusiform shape, but the ends vary considerably, the cells sometimes being rather abruptly pointed at one or both ends and sometimes being forked or lobed. The sides are usually smooth, but sometimes,

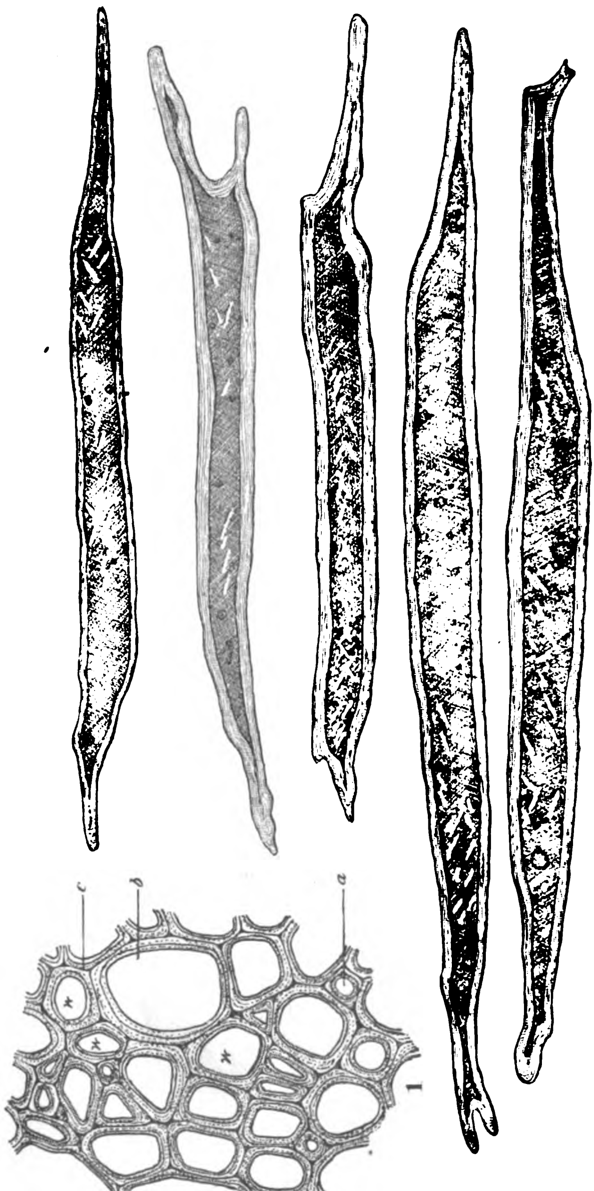

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PLATE XLVIII., FIG. 1.—Small portion of Transverse Section of the Woody Zone of Pelargonium zonale (magnified about 535 diameters): *w*, *w*, *w*, wood-cells; *a*, a wood-cell which appears small because the section passes through it near one end; *b*, a duct; *c*, the middle lamella.

FIG. 2.—Five Wood-cells from the same plant, isolated by means of Schulze's process (magnified 285 diameters).

like pits, but in other respects similar to those of which drawings were made in the last exercise. They are wood-cells that verge toward tracheids.

(2) There will be found other cells, with walls which look like an irregular network by reason of the numerous large pits. In these cells are to be found neither the remains of cross-partitions nor apertures communicating with adjacent cells. The pits are not in the nature of apertures, as one might suppose, but are very thin portions of the cell-membrane. This may be directly proved by means of the zinc-chloriodide iodine test or by staining with some diffusive stain, as eosin, as was done in the case of the pits in pitted parenchyma. These cells are reticulate tracheids, and are in their markings precisely like some of the ducts which occur abundantly in the same plant and associated with them. One of the tracheids is shown on Plate XLIX. (Fig. 1), and beside it (Fig. 2) a portion of a reticulate duct. Other kinds of tracheids with different markings may be found; but, since in their markings tracheids agree with ducts, the other varieties of tracheids will be passed by, and the remainder of this exercise will be devoted to the study of ducts.

Several different kinds of ducts may be found, but by far the most common in the older stems of this plant are the reticulate ducts.

(3) Attention will first be given to these reticulate ducts. The treatment with the maceration fluid usually results not only in the separation of the ducts from adjacent tissues, but in the separation of the cell-components of the ducts themselves, whereby may more easily be observed the perforations in the end partitions which distinguish the ducts from tracheids. These perforations are illustrated on Plate XLIX. (Figs. 2, 3, and Fig. 4, *a*). In this last the perforation is located in the oblique end of the cell. The walls are usually more or less prismatic from pressure against abutting cells, and it is in the flat sides that the thin places or pits occur. These pits are of the same essential nature as those already described in parenchyma- and wood-cells, and, like them, are means of keeping up a lateral circulation through the tissues.

In some instances it will be found that the component cells of the ducts are blunt-ended, in others that the ends are oblique, and in still others that they are tapering, almost like wood-cells. Considerable variations in this respect occur even among the different cell-components of the same duct. The terminal cells in the series, however, are nearly always pointed.

Associated with the reticulate ducts are found some which, by reason of the quite regularly arranged pits elongated in a transverse direction, are more properly called *scalariform ducts*, so named because the markings appear somewhat like the rounds and spaces of a ladder. Between these and the reticulated forms there is every gradation, and sometimes there may be found a cell reticulated on one face and scalariform on another. Gradations also occur between reticulate and spiral ducts, as will presently be seen. More especial attention will be given to scalariform ducts in the next exercise.

(4) The next most widely distributed duct in vascular plants is perhaps the *spiral*. These ducts are especially abundant in that part of the wood nearest the pith. Their peculiarity consists in the fact that the thickenings consist of one or more spiral bands which wind, usually quite regularly, around on the inside of the cell-wall, the rest of the wall remaining quite thin, and even being difficult to recognize unless special means are employed to bring them into view. The reason is that the thin part is of cellulose, which does not stain with the methyl-green. Often the remains of the transverse partitions between the component cells are also difficult to recognize, especially as the spiral thickenings are continuous from cell to cell.

The spiral bands are very readily pulled out of the ducts, and in most sections in which these ducts occur the bands will be found partially drawn out of some of the ducts by the section knife in the process of cutting. When the petiole of a water-lily or that of almost any other petiolate leaf of a vascular aquatic plant is pulled asunder, the spiral threads are pulled out and may often be seen with the naked eye, appearing like delicate cobwebs.

The spiral ducts in most other species, as well as in this, average smaller in diameter than the reticulate and scalariform ones. They differ much among themselves, however, in this respect; they differ much also in the number and closeness of the spirals. In this plant both double- and single-spiraled forms are abundant:

those with a higher number of spirals are rare, but in some water-lilies as many as eight have been found in a single duct. In some, the spirals, whether single or double, are close, while in others they are distant. It has just been stated that connecting forms between spiral and reticulate ducts are sometimes found. Illustrations of this also are found in the Geranium; that is, in some instances thickenings run across and connect the neighboring turns of the spirals, and so form a more or less perfect network. If these thickenings are numerous, the spiral character is obscured and the duct acquires a decidedly reticulate appearance. Hence also, in searching through a quantity of material obtained by macerating a longitudinal section in Schulze's fluid, ducts will probably also be found that are distinctly spiral at one end and reticulate at the other.

In some cases a duct will at one end contain a single spiral, while at the other there is a double one; or the spiral may be double in the middle of the duct and single at each end.

(5) There is a close relation also between spiral and annular ducts. In the Geranium the two kinds are closely associated in the layer of the wood next to the pith. Annular ducts have all the general characteristics of spiral ones except that the thickenings form a series of rings instead of spirals, distributed along the length of the duct on its interior. These rings are sometimes close together, at others widely separated; sometimes they are placed with their plane at right angles to the axis of the duct, but often obliquely to it; and they may be at various inclinations in the same duct. The close relation between annular and spiral ducts is shown by the fact that a duct may at one end be annular and at the other spiral. A portion of a mixed duct of this kind is shown on Plate XLIX. (Fig. 8).

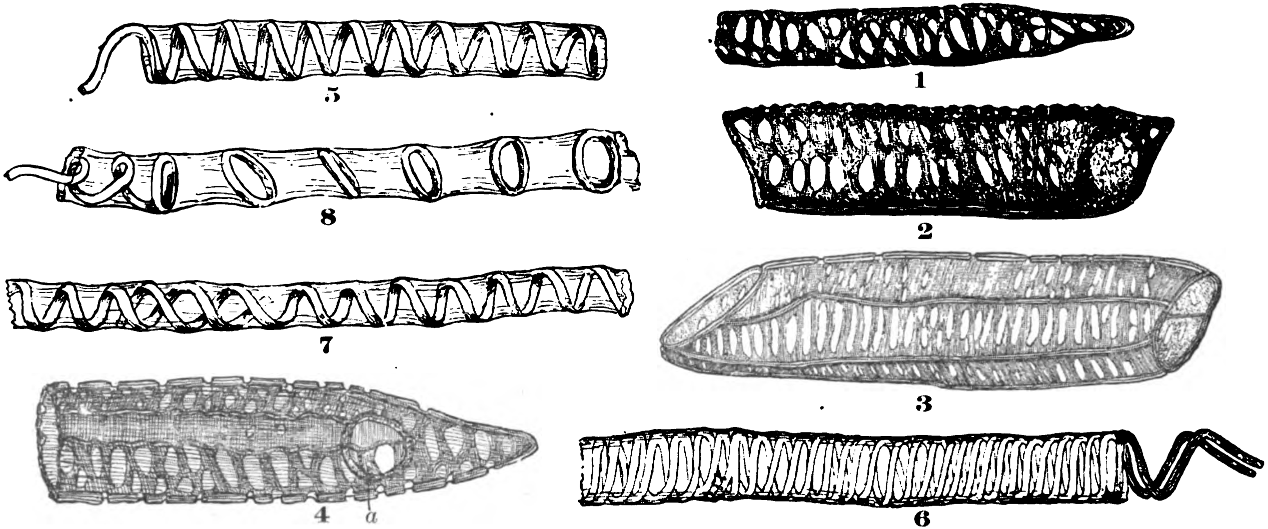


PLATE XLIX., FIG. 1.—A Reticulate Tracheid from the Stem of Pelargonium zonale. The section-knife has passed lengthwise through it near the middle. The unshaded portions are the thin places or pits in the walls.

FIG. 2.—One of the Cell-constituents of a Reticulate Duct from the same plant, also split lengthwise, and showing a large perforation in the oblique end-plate.

FIG. 3.—One of the Cell-components of a duct intermediate between the reticulate and scalariform varieties. The end partitions have entirely disappeared, but their position in the entire duct is marked by a constriction.

FIG. 4.—Part of a Cell of a Reticulate Duct, showing a rounded perforation, *a*, in the oblique end by which the lumen was continuous with that of the next cell in the series forming the duct.

FIG. 5.—Portion of one of the Spiral Ducts containing a single spiral.

FIG. 6.—Portion of one of the Spiral Ducts which has a double spiral.

FIG. 7.—Part of one of the Spiral Ducts, in one portion of which there are two spirals, and in the rest but one.

FIG. 8.—A portion of a mixed Spiral and Annular Duct.

(All the drawings are from the same plant, and all are magnified about 330 diameters.)

EXERCISE XI.

STUDY OF TRACHEARY TISSUES (CONTINUED).

(1) *The Scalariform Duct.*—There was observed in the study of the tracheary tissues in the Geranium stem a form of duct with transversely elongated pits, which duct was described as scalariform. These ducts occur also in many other dicotyls. Typical forms, however, are more readily found in some monocotyls, as in the roots of official Sarsaparilla, in Smilax rotundifolia, *L.*, and in other species of this genus, but especially in the rhizomes and petioles of some ferns, as Aspidium marginale, *Swartz*, A. Filix-mas, *Swartz*, and Pteris aquilina, *L.* In this last plant particularly the ducts are beautifully developed, and they constitute by far the larger proportion of the tracheary tissues of the plant. Beautiful preparations may be made by the following process: Cut the sections quite thin and accurately lengthwise of the vasal bundles. If the sections are made from fresh material, they should be passed through alcohol, transferred for fifteen or twenty minutes to a dilute aqueous solution of iodine-green, rinsed in water, passed through ordinary and then through absolute alcohol, soaked for a few minutes in the eosin oil of cloves, and mounted in xylol balsam. By this method all the lignified portions of the ducts will retain the green stain, while the thin membrane of the pits will have the red color of the eosin.

The ducts, it will be observed, are mostly prismatic, with several or many flat sides where they impinge against adjacent ducts or other tissues; the ends are either strongly oblique or taper-pointed, and where the ends of two of the component cells of a duct splice over one another the ladder-like thickenings usually remain, but the thin membrane between disappears. Each of the flat sides of the duct, if it impinges on another, is marked with the crowded, transversely-elongated, and regularly-arranged pits which constitute the special characteristic of this form of tracheary tissue. Scalariform ducts are usually of large size.

Beautiful and very instructive preparations may also be made by means of the Schulze maceration process, if after the separation of the component cells they are stained by means of iodine-green.

Figure 1 (Pl. L.) shows a part of one of the ducts from the rhizome of Pteris aquilina.

(2) *The Pitted Duct.*—This duct is exceedingly common, especially among woody dicotyls, and is often called the *dotted* duct. It may be studied to advantage in the stems of any of the following plants: the Compass Plant (Silphium laciniatum, *L.*), Bitter Dock (Rumex obtusifolius, *L.*), the Pumpkin (Cucurbita Pepo, *L.*), the Butternut (Juglans cinerea, *L.*), the Walnut (Juglans nigra, *L.*), the Ailanthus (Ailanthus glandulosus, *Desf.*), the Oaks, and the Maples. Ducts of this kind are, like those just described, usually large, often, however, not very thick-walled in proportion to their diameter, and marked with numerous rounded pits which differ much in size, number, and arrangement in different plants. Between the typical forms with circular pits and those with pits transversely elongated so strongly that the ducts may be called scalariform there is every possible gradation.

The very large and complicated ducts found in the stem of the Pumpkin are selected for study in this exercise. It will be sufficient if thin longitudinal and transverse sections be stained with the zinc-chloriodide iodine.

In the transverse section the ducts appear as very large circular apertures in the xylem of the bundles, bounded by a rather thin but distinctly pitted, lignified wall which is backed by numerous small, thickish-walled, and pitted parenchyma-cells.

Under a high power the pits of the duct are seen to be somewhat lenticular spaces in the wall, with short canals connecting them with the interior and exterior faces of the wall. A fortunate staining of the longitudinal section with eosin or with carmine would show that the canals do not extend clear through the wall, but that the pits are still closed by a very delicate membrane—the so-called limiting membrane—the persistent middle lamella of this portion of the wall. They are therefore somewhat similar to, though much smaller and more difficult to study than, the bordered pits in the tracheids of gymnosperms, presently to be examined.

In the longitudinal section are observed the pits crowded in irregular groups, the groups bounded off from each other by elevated unpitted ridges, so that the surface of the duct appears as an irregular network with numerous pits in the meshes.

The pits appear in this section as rounded or oblong areas, each with a minute circle, more transparent than the rest, in the centre. The rounded shape of this central thin portion of the pit is rather exceptional among dicotyls; this portion of the pit is more commonly elongated and slit-like in form.

(3) Let attention now be given to the tracheids of gymnosperms. Any species of Pine, Larch, Fir, Juniper, or Cypress will serve well the purposes of study. In these and most other gymnosperms ducts are rare, and so too are wood-cells; but tracheids, an intermediate tissue, take the place of both, and constitute nearly the whole of the wood of the plant. These tracheids have a structure so peculiar that it is an easy matter to tell a gymnospermous plant from any other by a microscopical examination of the wood.

For this study of tracheids is selected a twig of the Bald Cypress (Taxodium distichum, *Richard.*).

Sections are made in three different directions: (1) transverse, (2) longitudinal-radial, and (3) longitudinal-tangential. A longitudinal-radial section is one that passes lengthwise of the stem and through the centre or nearly so; that is, it is cut in the direction of, or along, the medullary rays. A longitudinal-tangential section is one that passes lengthwise of the stem, but near its circumference, and therefore crosses the direction of the medullary rays. It is of course important that both sections should be thin and be cut parallel to the grain. A straight-grained twig should therefore be selected for sectioning.

Let each of the sections be treated with the zinc-chloriodide iodine, and the longitudinal-radial section first be examined, using for the purpose the low power.

The tracheids will be seen as elongated fibres tapering usually at each end, and looking, except for their larger size and peculiar markings, much like ordinary wood-cells. The markings or bordered pits, as they are called, are large compared with those already studied, though considerably smaller than those of many other Coniferæ. Each pit appears, in this view, as a circle with a much smaller concentric circle in its interior.

The pits are in one or two rows, but not evenly distributed along the length of the cells; in some places they are crowded, in others widely separated.

At intervals crossing the direction of the tracheids are short parenchymatous cells, but with thickened and lignified walls. These cells are arranged like the bricks in a wall. The mass constitutes a medullary ray.

In order that the nature of the pits may be the better understood, the longitudinal-tangential section is now studied. Here are found no markings on the sides which are presented to view, but only on the edges; that is, the disks occur on the sides which face toward the medullary rays, but not on those which face toward the exterior or toward the pith.

Moreover, in this view the pits do not appear round as before, but lenticular. Selecting a pit in which the section appears to have passed through the centre, let it be examined carefully with the high power. It will be found to show a structure like that represented in Figure 3 (Pl. LI.). There is a cavity shaped like a biconvex lens cut through the centre in the direction of the radii of curvature. At *b*, and also opposite on the other side of the lens-shaped area, are rounded apertures. It is one of these apertures which, when the disk is seen in the radial section, appears as the inner circle. At *a* is the thin membrane which divides the lenticular cavity into two parts. It is continuous with the middle lamella, *c*.

The pit, then, is a lens-shaped cavity situated in the common wall between two cells, crossed through its longer diameter by a delicate membrane, and perforated through its shorter diameter (except the membrane, which is continuous) by a circular aperture.

The medullary rays in this view present an appearance very different from that in the radial section, appearing as a row of from three to five rounded cells.

In transverse section the pits, of course, look as they do in the longitudinal-tangential section. The tracheids in this view appear squarish, and on the radial face of the walls are observed the

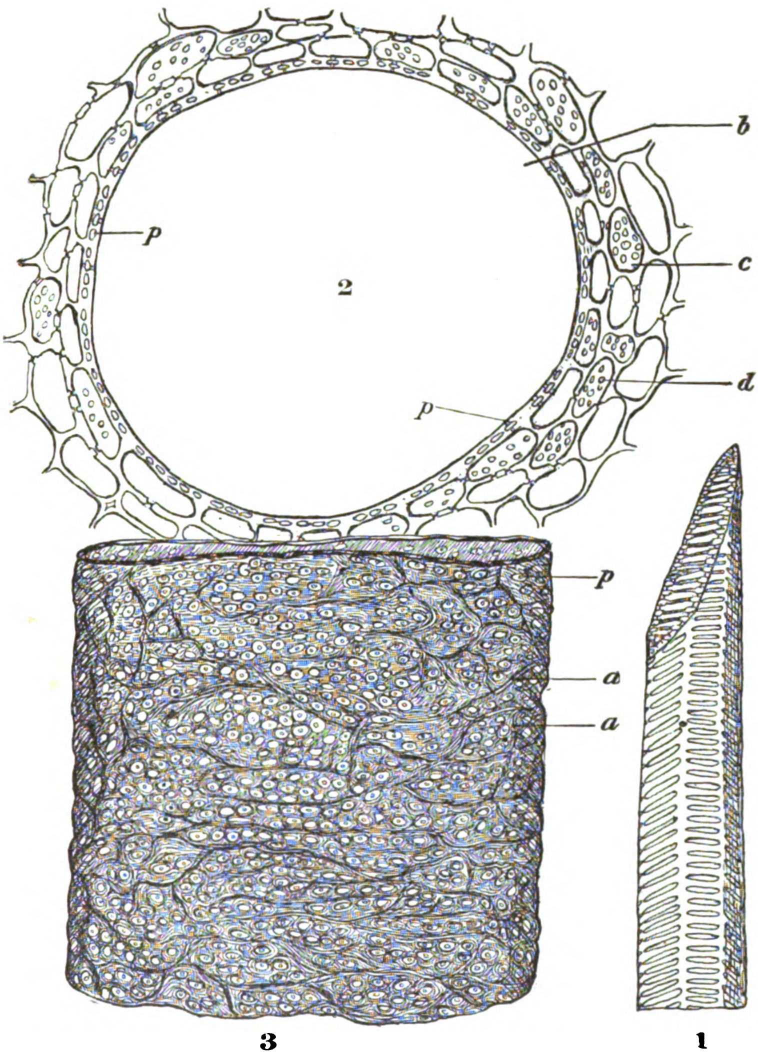


PLATE L., FIG. 1.—Portion of a Scalariform Duct from the underground stem of Pteris aquilina (magnification about 275 diameters).

FIG. 2.—Transverse Section of large Pitted Duct and a few adjacent Parenchyma-cells from the stem of Cucurbita Pepo: *b*, lumen of the duct; *c*, an adjacent parenchyma-cell with pitted walls; *d*, one of the pits; *p*, *p*, pits in wall of duct. (Magnification about 375 diameters.)

FIG. 3.—Longitudinal View of a small portion of one of the same Ducts, showing the pits grouped in the meshes of a network of ridges, *a*, *a*. *p* is one of the pits.

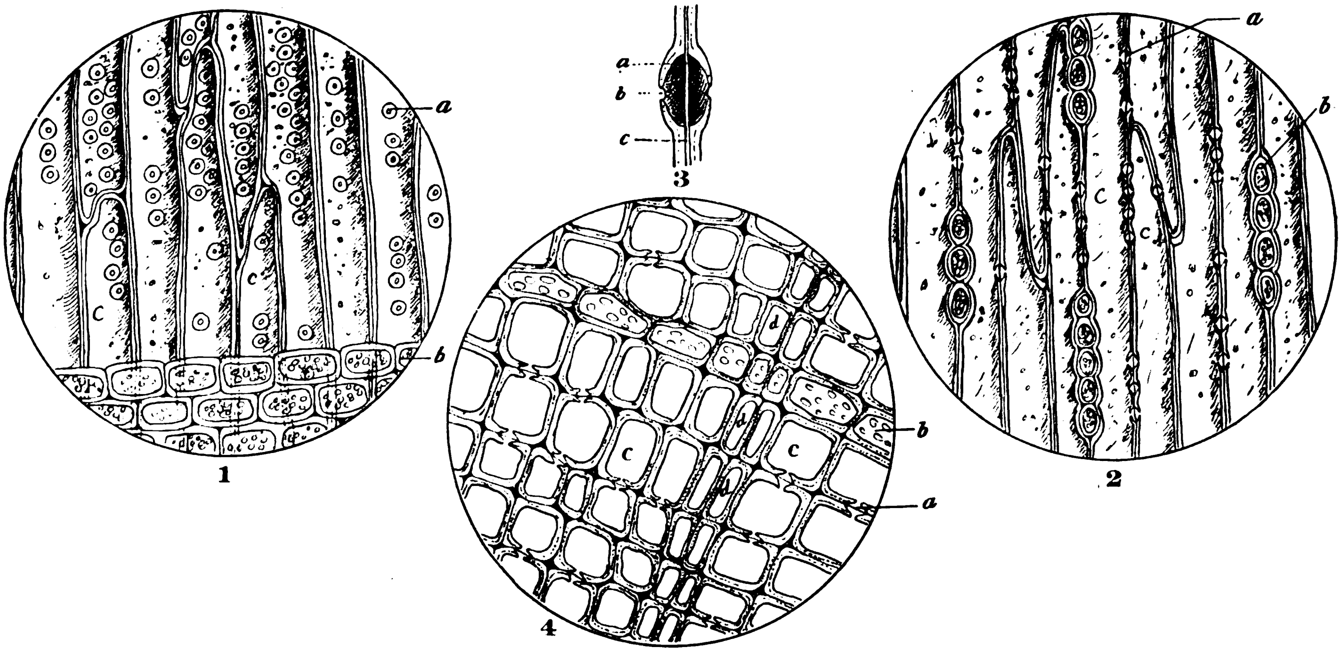


PLATE LI., FIG. 1.—Longitudinal-radial Section of a Twig of the Bald Cypress, showing tracheids with bordered pits: *a*, one of the pits; *b*, medullary-ray cell. (Magnification about 200 diameters.)

FIG. 2.—Longitudinal-tangential Section of the same Twig, showing the pits in a different view: *a*, one of the pits; *b*, one of the cells of a medullary ray; *c*, *c*, tracheids. (Magnification also 200 diameters.)

FIG. 3.—A small portion of Wall, containing a pit much more highly magnified to show its structure: *a*, limiting membrane; *b*, aperture in pit; *c*, middle lamella.

FIG. 4.—Transverse Section of same Twig (magnified about 250 diameters), showing, *a*, one of the pits; *b*, a medullary ray; *c*, *c*, tracheids; *d*, *d*, narrower tracheids lying in a zone called a ring of growth.

fluid, staining them afterward with iodine-green. The transverse partitions will thus the better be seen, and perhaps also some fibres will be found that are somewhat branching or forked at their ends.

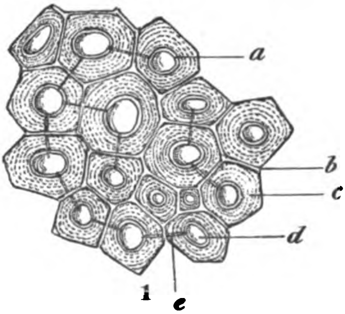
(2) For branching fibres, however, the inner bark of the European Larch is more favorable for study.

Longitudinal sections of the bark are made and are treated with Schulze's maceration fluid; after washing, the tissues are teased apart with needles, are stained with the solution of methyl-green or with that of iodine-green, and are then examined. The fibres are found to be relatively shorter than those of the Compass Plant—many of them so short as closely to resemble stone-cells in appearance; most of them have the walls so excessively thickened that in places the lumen is wholly obliterated; and while the majority of the fibres are fusiform in shape and unbranching, a considerable number may be found that are variously lobed, forked, or branched. An occasional fibre will also be found that has a relatively large lumen or whose wall is but little thickened. In other respects there will be found but little difference between branching fibres and those already studied.

In the typical bast-fibre the lignification of the wall is not nearly so strong as that of the wood-cell or that of the tracheid or duct, though the thickening is usually excessive. In many cases, therefore, the coloration by means of the phloroglucin reagent is but slight, or even in some instances there is no color at all. This is particularly true of the long and tough fibres, such as those in Flax and Hemp, that are so extensively employed in the production of textile fabrics. Perhaps the fact of their being but slightly lignified accounts for their flexibility and tenacity. Very strongly lignified fibres, at any rate, are apt to be harsh and brittle.

(3) At the other extreme from the fibres of Flax and Hemp, so far as their structure is concerned, are the very short and thick fibres of the Cinchonas.

To study these a fragment of the bark of Cinchona Calisaya may be soaked in water for twenty-four hours and then be sectioned, a series of both longitudinal and transverse sections being made. The latter are bleached by soaking them in Labarraque's square-ended cells that differ from the bast-fibres only in their shape. They are sometimes called rod- or staff-cells. With these are also frequently associated ordinary stone-cells, and between the latter and the former may occur every possible gradation.



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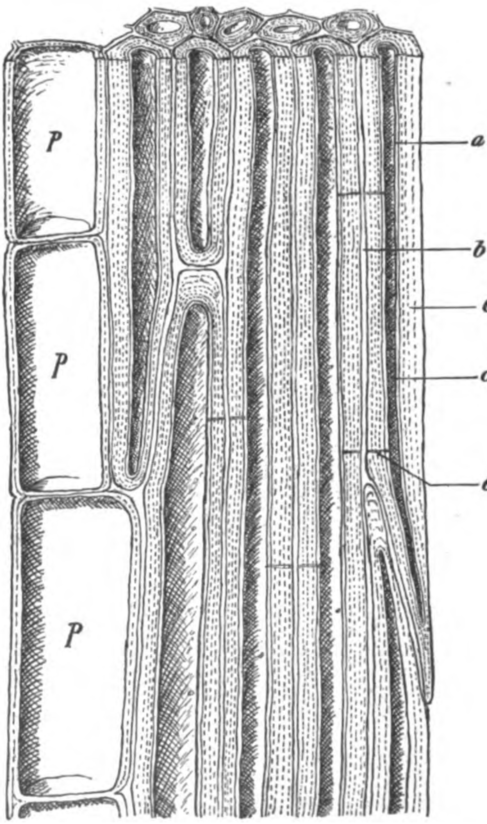

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PLATE LII., FIG. 1.—Transverse Section of a few Bast-fibres from the inner bark of Silphium laciniatum (magnified 830 diameters): *a*, inner unlignified or only partially lignified portion of thickened wall; *b*, middle lamella; *c*, middle portion of wall; *d*, lumen; *e*, pore-canal.

FIG. 2.—Longitudinal Section of Bast-fibres of Silphium laciniatum (magnified 830 diameters). The letters *a*, *b*, *c*, *d*, and *e* refer to the same things as in the transverse section; *p*, *p*, *p*, adjacent parenchyma-cells.

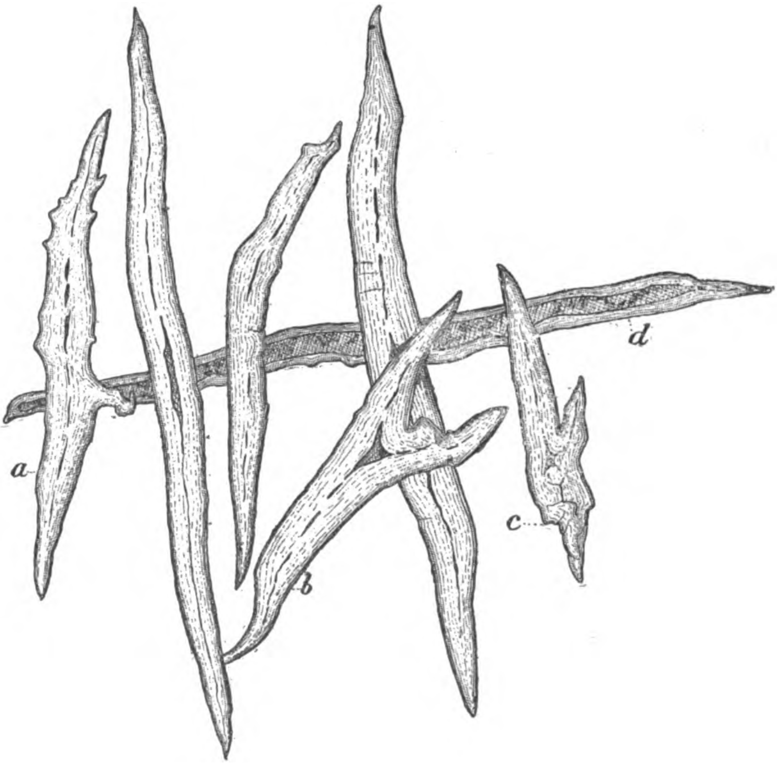

PLATE LIII.—Secondary Bast-fibres from the inner bark of Larix Europæa (magnified about 80 diameters): *a, b, c*, branching fibres, the last approaching a stone-cell in form; *d*, an exceptional fibre with a relatively large lumen. The fibres from which the drawings were made were isolated by means of Schulze's fluid.

EXERCISE XIII.

STUDY OF SIEVE-TISSUE.

SIEVE-TISSUE occurs in the phloem of vasal bundles, very rarely elsewhere in the plant. It constitutes the most characteristic tissue of the phloem, and it is nearly always associated with narrower, elongated parenchyma-cells called "companion-cells." Sieve-cells are almost always considerably elongated in the direction of the length of the vasal bundles in which they occur; their walls are thin and unlignified, but possess in certain parts, usually in the end partitions, more or less thickened plates with numerous minute sieve-like perforations through which proteids and other colloids in the semi-liquid form may circulate from cell to cell of the tissue.

The tissue in most plants, owing to the small diameter and thin walls of the cells and the minuteness of the perforations in the plates, is not an easy one to study, but favorable examples are the following: the stems of the Pumpkin (Cucurbita Pepo, *L.*), the Squash (Cucurbita maxima, *Duchesne*), the Watermelon (Citrullus vulgaris, *Schrader*), and the Hop (Humulus Lupulus, *L.*); the petiole of the Grape (any of the commonly cultivated species); the inner bark of the Slippery Elm (Ulmus fulva, *Michx.*) and the Basswood (Tilia Americana, *L.*); and the rhizome of the Mayapple (Podophyllum peltatum, *L.*).

The sieve-tissue of the Pumpkin will be studied in this exercise, and the preference is given to material which has been preserved in alcohol. Several sections, both longitudinal and transverse, are made, taking care that the former pass lengthwise of one of the vasal bundles in a radial direction, or at least through the phloem portions of a bundle. Several sections may have to be rejected before one is found that will show the tissue to the best advantage.

(1) Treat one of the transverse sections with the phloroglucin reagent, cover it, and examine it with the low power. It will be

observed that there are ten vasal bundles arranged in two circles about the central hollow in the stem. Each of the bundles consists of a xylem mass containing several large ducts as well as many smaller ones, which are stained red by the reagent, and two masses of phloem which are wholly unstained, one facing outward or away from the central hollow, the other toward it. The bundles of the inner circle are the larger, and are usually the more favorable for study.

Having brought a phloem part of one of these bundles to the centre of the field of the microscope, the high power is turned on and the structure is examined. The phloem will be found to be composed mainly of two kinds of cells, one kind rather large, the other much smaller, and all without visible intercellular spaces. The larger cells are the sieve-tubes; the smaller cells are the companion-cells or other intermixed parenchyma-cells. Many of the sieve-cells appear empty because the cells are long and the section has passed between the sieve-plates, which in this case are in the end partitions of the cells; but in some cells will be observed the plates, and unless they are placed too obliquely to the plane of vision there will be seen the numerous delicate apertures in them. These apertures may be empty, or they may be partially, or sometimes completely, filled with albuminous matters and a peculiar thickening substance called *callose*, so that they appear darker than the adjacent wall-substance.

If one of the sections be stained with strong potassium-iodide iodine, there will be found plates whose meshes are deep-brown from the proteids they contain, while the cellulose wall-substance is unchanged in color. The companion-cells are seen to be very rich in proteid matters.

(2) Let now a longitudinal section which has been treated for a few minutes with eosin solution be studied. This solution stains the proteid contents of the sieve-tubes strongly, and so enables one to identify the tissue. These proteids will have been shrunken by the action of the alcohol, so that they do not nearly fill the sieve-tube except in the vicinity of the plate, where they are usually denser and more abundant. Here, however, it will often be found that the shrinking effect of the alcohol has drawn the mass slightly away from the plate, pulling out more or less, so that they may be seen distinctly, the fine threads of

albuminous matter that penetrate its meshes and connect it with that of the next cell.

The companion-cells, though elongated, are much shorter than the sieve-cells, their ends are square or oblique, and their protoplasm is nucleated. In the common wall between these cells and the sieve-tubes will be found minute pits, but no perforations.

Now let there be examined a longitudinal section that has been treated for twenty minutes or more with a weak watery solution of anilin-blue, and mounted either in glycerin or in the chloral-hydrate solution. If mounted in glycerin, the best staining results will be obtained if the section be allowed to remain an hour or more in the glycerin before examining it. Most of the color will then have disappeared from the cell-walls, but will remain in the protoplasm and nuclei of the companion-cells and in the albuminous matters of the sieve-tubes, and the deposits of callose in the pores and on the surface of some of the sieve-plates will be stained a fine blue color somewhat different in tone from the rest, so that they may readily be recognized.

If desired, satisfactory permanent mounts may be made by carrying the sections, after staining, through weak into strong glycerin, and finally enclosing them in glycerin gelatin.

Another method which yields good results is as follows: Wash out the glycerin with water, anhydrate by passing the sections successively through weak, strong, and absolute alcohol, then through oil of cloves tinted with eosin, and finally mount in xylol balsam. By this means the slimy albuminous matter in contact with the sieve-plate acquires a tint different from that of the callus, rendering it easier to distinguish the one from the other.

Satisfactory but more fugitive results are obtained by means of the anilin-blue and the chloral-hydrate solution. After staining with the blue the sections are mounted in the chloral-hydrate solution. The color very rapidly disappears from the cell-walls, but rather slowly from the other parts; at the same time the swelling of the walls and the clearing which the solution produces are of advantage in studying the structure.

Sieve-tissues appear to be an important means of transferring proteid nutriment from one part of the plant to another. The slimy, albuminous matters in the interior of the tubes do not appear to be protoplasm, but to be other proteinaceous material in the process of transfer. The sieve-cells, however, are probably still living cells, for it has been found that the wall is lined with a delicate layer of protoplasm, but a nucleus has not been discovered in them.

The callose of sieve-tubes is something related to, but somewhat different from, cellulose. That it is not identical with cellulose is evident not only from the fact that it stains much more strongly with anilin-blue and corallin, but also from the fact that it is wholly soluble in 1 per cent. potassium-hydrate solution, while cellulose is not.

Callose is not confined to sieve-tubes, but occurs in the hyphæ of some fungi, in certain pollen-grains, in the seeds of certain of the Borraginaceæ, and associated with calcium carbonate in cystoliths and in certain encrusted cell-walls.

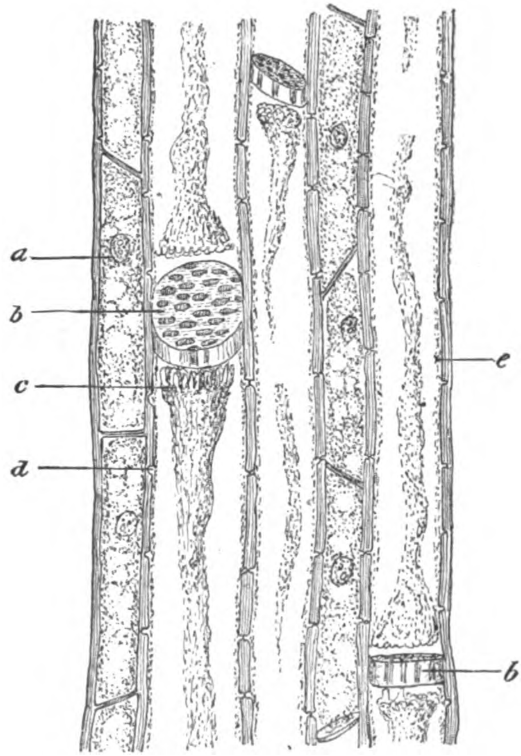

PLATE LVI.—Longitudinal Section of the Soft Bast of Pumpkin stem (magnified 210 diameters): *a*, nucleus of companion-cell; *b*, *b*, sieve-plates; *c*, albuminous matter shrunken away from plate by action of alcohol; *d*, pit in lateral wall of sieve-tube; *e*, thin layer of protoplasm lining sieve-tube.

EXERCISE XIV.

STUDY OF LATICIFEROUS TISSUE.

THERE are two principal kinds of milk- or laticiferous tissue —the simple, and the complex or articulated. For the study of the former kind selections may be made from the following objects: the stem of the common greenhouse plant Euphorbia splendens; the root of the Flowering Spurge (Euphorbia corollata, *L.*); the stem and root of the Common Milkweed (Asclepias cornuti, *Decaisne*); the stem and root of the Purple Milkweed (Asclepias purpurascens, *L.*); the stem and root of the Dogbane (Apocynum androsæmifolium, *L.*); the stem and root of the Canadian Hemp (Apocynum cannabinum, *L.*); the stem of the Fig (Ficus Carica, *L.*); and the stem of the Oleander (Nerium Oleander, *L.*).

For the study of complex laticiferous tissues selections from the following objects may be made: the root of Dandelion (Taraxacum officinale, *Weber*); the root of Chicory (Cichorium Intybus, *L.*); the stems of Wild Lettuce (Lactuca Scariola, *L.*, and *L.* Canadensis, *L.*); the stem and root of Celandine (Chelidonium majus, *L.*); the stem and young capsule of the Opium Poppy (Papaver somniferum, *L.*); the root of Spanish Salsify (Scorzonera hispanica, L.); and the root of Common Salsify (Tragopogon porrifolius, *L.*).

I.—For the study of *simple laticiferous tissue* there is selected from the former list the stem of the common Milkweed.

In the study of laticiferous tissue of any kind the parts of the living plant to be investigated should be cut into pieces, not too small, and immediately be dropped into strong alcohol and there allowed to remain until the liquid has thoroughly penetrated the structure. The object of this treatment is to coagulate the latex before it has had time to escape from the vessels, so that the course of the latter may the more readily be traced.

Having thus prepared the material, thin transverse and longitudinal sections are made and stained, some of them by means of the iodine-green solution. To one or two of the remaining sections of each kind are added a few drops of zinc-chloriodide iodine, and they are set aside for a while until the cellulose walls have acquired the blue color.

Placing one of the green-stained transverse sections under the microscope and examining it with the low power, the milk-tubes may be seen in abundance in the pith and in the middle and inner bark. In the pith and in the middle bark they may readily be recognized by the fact that they are narrower than the adjacent parenchyma-cells, by their more densely granular contents, and by the absence of a nucleus. It will also often be found that their walls are somewhat thicker than those of the parenchyma-cells, particularly if the section be that of a well-matured stem. This difference will be noticeable particularly in the pith and soft bast if to an unstained section a few drops of chloral-hydrate solution be applied.

Moreover, the razor in passing through the tissue frequently draws the elastic and extensible masses of latex more or less out from the tubes, thus aiding in the identification of the tissue. The latex appears opaque and densely granular as viewed by transmitted light.

Turning now to one of the green-stained longitudinal sections, and having identified the laticiferous tubes with the low power, let them be studied minutely with a higher one.

There will be but little difficulty in tracing the tissue by aid of the coagulated latex for considerable distances through the stem, for the latex-cells form tubes of indefinite length. While their general course is lengthwise of the stem, they are nevertheless somewhat wavy or serpentine, though less so in this species than is often the case in other plants. The tubes do not branch freely, although they do so occasionally, and very rarely are the branches of one tube observed to anastomose with those of an adjacent one.

For these reasons, and because the tube with its branches is believed to represent a single cell, even though it may run the entire length of the plant, this variety is called "simple laticiferous" tissue. Wherever it occurs its structural features are essentially similar to those observed in this plant.

circles occur both in the middle and in the inner bark, but not in the wood.

Under a high power the milk-ducts appear to be of considerably smaller diameter than the neighboring parenchyma-cells. Most of them appear circular or oblong in outline because the knife has cut the cylindrical branches of the network nearly transversely, but others appear considerably elongated, because through these the knife has passed obliquely or even in the direction of their length. These are the branches that cross over obliquely or horizontally and connect the ducts into a network.

If now one of the longitudinal sections be examined, a much better idea of this network of vessels will be obtained. The parenchyma-cells in this view are considerably elongated, and if the section run through one of the clusters of milk-ducts it will be seen that the tangled network of vessels has its irregular meshes mostly much elongated in a direction lengthwise of the stem.

If the appropriate tests be applied, it will be found that the walls of the milk-vessels are of cellulose, that the latex, like the rest of the root, is destitute of starch, and that it contains resinous matters in considerable abundance.

To sum up the observations made, the chief difference between simple and complex laticiferous tissue is that the latter exists as a complicated network, while the former consists mostly of independent tubes. This difference corresponds to a difference of origin. A simple milk-tube begins as an ordinary meristem-cell, and grows as the plant grows, forming a long, unbranching, or sparingly branching tube; it is at maturity still a single cell. Complex laticiferous tissue, on the other hand, is produced by the coalescence of a large number of cells to form a network of anastomosing tubes. There appears to be a close relationship between isolated secretion-cells and this form of milk-tissue. In the Poppy family, for example, one finds in some species only the isolated secretion-cells; in some others, as in the Bloodroot, both isolated secretion-cells and those that are arranged in chains approximating a milk-duct in appearance and structure; and in the Poppy and Celandine the fully-developed network of milk-ducts.

The fluid of milk-tissues appears to be partly nutritive, since it contains albumins and carbohydrates; but it is partly, perhaps chiefly, waste or excretory, for the resinous and some of the mineral matters can have no nutritive value to the plant. The excretory matters, however, may still serve the purpose of protection.

The latex is not always of the same color, but differs considerably in different plants: it is often white or yellow, sometimes orange or even deep orange-red, as in Bloodroot, but it is sometimes nearly colorless, as in the Oleander.

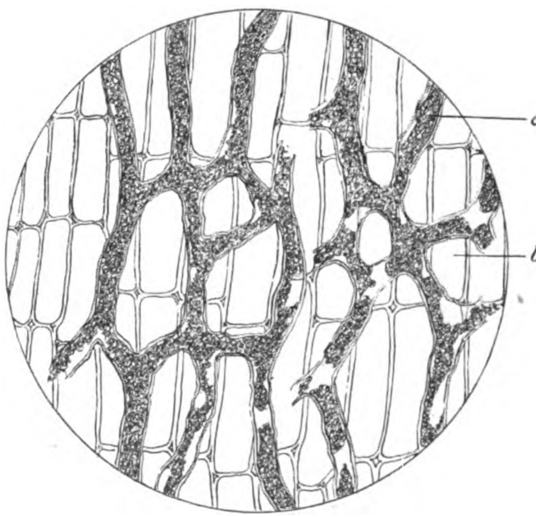

PLATE LVIII.—A small portion of the Cortical Parenchyma of the Dandelion root in longitudinal section, showing complex milk-tissue: *a*, one of the branches of the network of milk-vessels; *b*, one of the parenchyma-cells. (Magnification about 170 diameters.)

EXERCISE XV.

STUDY OF STARCHES.

MOST of the cereals, such as wheat, rye, oats, barley, and maize, and many root- and rhizome-drugs, such as sarsaparilla, calumba, belladonna, bryony, colchicum, and aconite, afford starches interesting to study, and many of these starches show very marked characteristics.

I.—For the first part of this study attention will be given to the Potato tuber, which, as has already been learned, is rich in starchy contents.

Selecting a potato that is ripe or nearly so, a number of sections are made perpendicular to the corky exterior, and a few others parallel to it. Let one of the former be mounted in a drop of water, and be examined first with the low and then with a higher power.

At the exterior is found a layer of cork composed of from fifteen to twenty tiers of tabular cells. The outside layers of this cork are composed of shrivelled, opaque cells which are more or less disrupted and peeling off at the surface. There is no proper collenchyma, but immediately interior to the phellogen-layer are parenchyma-cells smaller in size and more compactly arranged than those farther interior. They are also richer in proteids and much less rich in starch. Few of the cells are quite destitute of the latter, but the granules are small. A rather large nucleus and granular protoplasm are plainly discernible, as well as cubical crystals and rounded proteid bodies of considerable size.

In the parenchyma farther interior the cubical crystals are wanting, and the nucleus, though present in most of the cells, is often difficult to identify by reason of the abundance of starch-grains surrounding it.

Let now a drop of potassium-iodide iodine be placed at the edge of the cover-glass and be allowed to run under by capillary attraction. Watching the effects through the microscope, it is seen that as the reagent comes into contact with the starch-grains they become blue; the color rapidly deepens until the grains can no longer transmit light, and they therefore appear black. The nucleus, protoplasm, and crystals stain brown. The fact that the latter behave with the reagent in a manner similar to protoplasm leads to the inference that they are not inorganic in their nature, as might at first be supposed, but are of a proteid character, as will be proved later on.

It will be observed that the small starch-grains in the exterior parenchyma-cells are not usually isolated, but occur in groups about granular masses of protoplasm, and are often clustered about the nucleus. The starch-formers or *amyloplasts*—proteid particles whose function it is to build up the starch-grain—occur, in fact, in clusters, and if they could be rendered visible one would be found attached to each young starch-grain; but in order to render them visible a special method of staining must be adopted. This will be done presently; but let the structure of the starch-grain itself first be studied.

For this purpose let scrapings with a knife-blade from the freshly-cut surface of a potato be made, and let a small quantity of these scrapings be placed on a slide in a drop of water, covered, and examined. By focusing on some of the larger grains it will be seen that they are mostly ovate in outline, and toward the smaller end is noticeable a rounded spot occasionally fissured by a straight or angular fissure, but more commonly without one. This fissured or unfissured spot is the *hilum* or nucleus, which marks the point where the growth of the grain began. About the hilum may be discerned a series of curves, at first concentric, but farther away becoming more and more eccentric. They are stratification-lines, and their arrangement leads to the conjecture that the growth was at first nearly equal, afterward much greater on one side. This conjecture is confirmed by a comparison of young grains with old or mature ones: in the former the hilum is nearly central, and if any stratification-lines are discernible at all, they are concentric or nearly so; in the mature grain the hilum is much to one side of the centre and many of the curves are eccentric.

If the point of a needle be gently laid on the surface of the

the grains are seen either in clusters of two, three, or more, or else the squared ends or sides show that the grains have been a part of such clusters. There is, however, a goodly sprinkling of grains that are strictly simple, and these are all spherical or nearly so.

Stratification-curves are in this species difficult to detect without resort to the silver-nitrate process, by which, however, a few strata may be seen, though they are not nearly so numerous as in the starch of the potato.

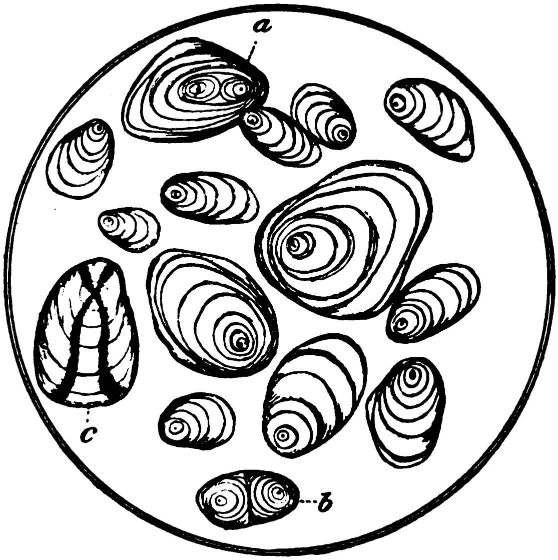

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PLATE LX., FIG. 1.—Starch from Potato (magnified 305 diameters): *a*, a bi-nucleated grain; *b*, a double grain; *c*, a grain as seen under the polariscope.

FIG. 2.—Starch from the Corm of Colchicum autumnale (magnified 310 diameters).

EXERCISE XVI.

STUDY OF ALEURONE-GRAINS.

THE seeds of the following plants afford interesting material: Croton Tiglium, *L.*, Ricinus communis, *L.*, Bertholletia excelsa, *Humboldt* and *Bonpland*, Pisum sativum, *L.*, Delphinium Staphisagria, *L.*, Lupinus varius, *L.*, and Triticum vulgare, *Villars*.

Most plants lay up some portion of their reserve food material in the form of albuminous matters of various kinds, as well as in the form of starch, oil, inulin, and sugar. One of the most important of the albuminous reserve food materials is aleurone, found chiefly in seeds, and most abundantly in oily ones. It usually occurs in the form of rounded granules which are often quite small, but which sometimes attain a considerable size, as in the Croton and Castor Beans and in the Brazil-nut. In many cases the granules appear to be homogeneous in structure or nearly so, but in other cases they contain various substances differing more or less in constitution from the main body of the grain. These substances may be oily matters, mineral crystals, and crystalloids.

For this study is selected the endosperm of the Castor Bean. On removing the seed-coats the endosperm will be found in good condition for sectioning without further preparation.

A number of thin sections should be cut and be set aside, but not in liquid, until required for use as directed.

A section is first mounted in a drop of strong glycerin, and after finding the thinnest part of the section with the low power it is focused upon with the higher one. The aleurone-grains are seen as rather large, nearly spherical or ellipsoidal bodies occupying the larger portion of the interior of the cells. In appearance they are not unlike starch-grains, but appropriate tests easily prove their proteid nature, and prove also that this seed does not contain starch. The aleurone is intermixed with finely granular and rather opaque matters consisting of a mixture of fats and amorphous proteids.

At first the aleurone-grains appear homogeneous, but presently the clearing action of the glycerin comes into play, and through the now more transparent exterior portion of the grain is seen a denser, many sided body, the crystalloid, which is often so large that the rest of the grain forms scarcely more than a pellicle about it. At other times, however, the crystalloid is relatively much smaller, or the grain may even contain two or more crystalloids. There are also usually seen on the interior of the grain, alongside of the crystalloid, one or more small, globular, strongly refractive bodies called *globoids*. They are not organic in their nature, being composed of the double phosphate of calcium and magnesium.

If now the cover-glass be removed, and, after adding a drop of the strong potassium-iodide iodine and allowing it a few minutes to penetrate the structure, it be replaced and the section again be examined, the grains will be found to have acquired a brown color, especially deep in the crystalloids. The reaction indicates their proteid character. The globoids remain unstained.

If there be applied to a section a drop of 1 or 2 per cent. solution of potassium hydrate, the crystalloids will swell rapidly, lose their angles, and disappear as did those observed in the potato.

If now a fresh section be placed upon the slide, covered, and a drop of water be allowed to run under the cover-glass, the oil will be observed to run together and to form drops, probably from the solution of the albuminous pellicles which keep the minute droplets apart; the oil flows out of the ruptured tissues, and may soon be observed in drops at the borders of the section as well as in some of the cells. As the water comes into contact with the aleurone-grains their ground-substance swells and rather rapidly disappears from view, leaving the crystalloids for a few moments standing out sharp and clear; but soon these too begin to swell and to lose their angles, though it takes them a long time to disappear wholly.

If, while the crystalloids are still sharply defined, there be allowed to run under the cover-glass some absolute alcohol, the structure of the grains may still better be seen, the ground-substance being still visible but transparent, and the crystalloids and globoids being sharply defined on the interior. Still more pleasthe fine granules in the cell, not otherwise optically distinguishable as oil-drops, have stained a deep-red color. In this behavior fats agree with volatile oils and resins, but differ from all other substances.

Lastly, let another section be mounted dry, the cover-glass being pressed down rather strongly, so as to force some of the oil out of the cells to the edge of the section. If now a drop of the cyanin solution be allowed to run under the cover-glass, the refractive globules of oil will soon be stained a brilliant blue.

Fixed oils, like aleurone-grains and starch, serve the plant as reserve food materials. They occur in a very large proportion of seeds and spores, and sometimes constitute the greater part of their weight.

Crystalloids also most often occur in seeds, but sometimes elsewhere in the plant. They occur in the epidermis of the Ivy, in the young shoots of the Canna, in the vegetative parts of many marine algæ, in the mycelium of a few fungi, and in minute form they have been observed in the nuclei of the cells of various plants.

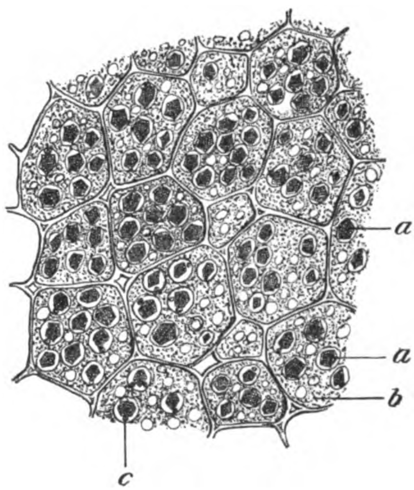


PLATE LXI.—A few Cells from the Endosperm of Ricinus communis, showing aleurone-grains, their contained crystalloids and globoids, and the granular ground substance of the cells, containing proteids and oil (magnification, 330 diameters). Drawing made from a section which had been treated by the tannin-osmic-acid process. *a*, *a*, crystalloids in aleurone-grains ; *b*, granular ground substance of cell ; *c*, a globoid.

tain are the product, in some instances at least, of chemical changes in the chlorophyll. This is the fact, probably, with many of the colors of autumn leaves.

Anthoxanthin is the coloring principle which is perhaps the commonest in the color-corpuscles of yellow flowers.

Most of the shades of violet, blue, and red, as well as now and then a yellow, are due to coloring matters in solution and diffused through the cell-sap. Erythrophyll is the commonest of the red coloring matters belonging to this category, and anthocyanin is the commonest of the blues.

Flowers of any of the following plants may be studied with profit: the Nasturtium (Tropeolum majus, *L.*), the Allamanda (Allamanda Schottii, *Pohl*), the Spiderwort (Tradescantia Virginica, *L*), the Toad-flax (Linaria vulgaris, *Mill.*), the red-flowered form of the Shrubby Mallow (Hibiscus Syriacus, *L.*), and the Red Rose (Rosa Gallica, *L.*).

From this list is selected for special study the flower of Linaria vulgaris, a plant now common throughout the Eastern United States, and known under the popular names of "Snapdragon," "Butter-and-Eggs," and "Toad-flax." The corolla is gamopetalous, bilabiate, and strongly calçarate. The prevailing color is lemon-yellow, but the palate is orange-colored. The latter is also provided with numerous striated hairs. The most favorable portions for study are not the most deeply colored ones, for the hairs and the conical elevations on the epidermal cells interfere with the view of the cell-contents.

A specimen is therefore prepared as follows: Seizing one of the lips with each hand, the lower lip is sharply bent back and the flower is torn down through the spur to the apex of the latter. The epidermis will in most cases strip off from the spur by this method, and after cutting away the other portions with scissors it may be mounted in a drop of water and be examined.

The cells will be found to contain a light-yellow coloring matter dissolved in the cell-sap. Besides this there may with some difficulty be made out the cell-nucleus and the nearly transparent protoplasm. There are also present some small, rounded, dense, and colorless particles which the iodine test would prove to be starch-grains.

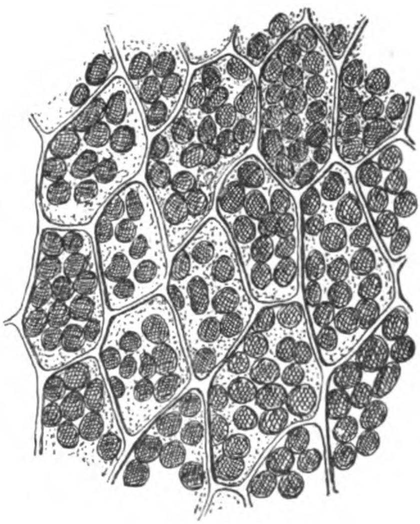
But the diffused yellow coloring matter is not the only one present in this case. In some parts of the epidermis, though not in all, will be found numerous small crystals of a distinctly yellow color and of very various shapes: some are prismatic and square-ended, others are prismatic and have the ends terminated by pyramids, others are in the form of two pyramids placed base to base; many are elongated into acicular forms, some are tabular, and still others form globular or stellate masses, each mass showing a distinctly radial structure. Viewed by polarized light, the crystals give splendid polarization effects, but with reagents their behavior is quite different from that of the ordinary mineral crystals found in plants. If treated with potassium-hydrate solution, they quickly dissolve and disappear, at the same time communicating to the tissue a red or orange-red color. The effect of the solution is most striking if the crystals be viewed by polarized light while the potassium hydrate is permitted to run under the cover-glass.

The crystals are also dissolved, only a little more slowly, by means of the chloral-hydrate iodine solution. This reagent also establishes the fact that fine starch-grains exist in the cells, and most abundantly in those which contain fewest of the crystals.

The crystals are insoluble in acetic acid, but dissolve slowly in hydrochloric acid, more rapidly in sulphuric acid, and in both instances with the production of a red color. In alcohol they are insoluble.

In the bright-yellow corolla of Allamanda the color resides in small, mostly rounded corpuscles which do not polarize light, which are insoluble in potassium-hydrate solution and in alcohol, which are quickly stained a deep-red color by alcannin solution, and which are also stained a deep blue, though more slowly, by cyanin solution.

If the epidermis be stripped off from the lower, deep-red portion of the petal of Hibiscus, and be mounted in water, the cells will appear to be filled with a bright-red sap in which the cell-nucleus is visible as a lighter spot. No granular coloring matter exists in these cells.



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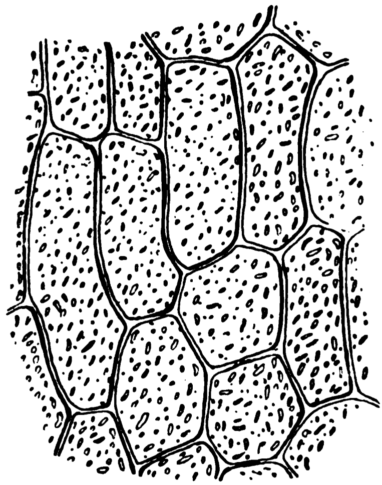

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PLATE LXII., FIG. 1.—A few Cells from the Leaf of a Moss, showing numerous chloroplasts and finely granular protoplasm in the cells (magnified 535 diameters).

FIG. 2.—A few Cells from the same Leaf after treatment with chloral-hydrate iodine, which has destroyed the chloroplasts, leaving the small starch-grains which they contained undissolved, but somewhat swollen (magnified 535 diameters).

EXERCISE XVIII.

STUDY OF INULIN AND SUGAR.

I.—THE roots of any of the following plants, if collected in autumn, contain inulin in abundance, and afford convenient objects for the study of this carbohydrate: the Dandelion (Taraxacum officinale, *Weber*), the Chicory (Cichorium Intybus, *L.*), the Salsify (Tragopogon porrifolius, *L.*), the Burdock (Arctium Lappa, *L.*), the Pellitory (Anacyclus Pyrethrum, *DC.*), the Sow-thistle (Sonchus oleraceus, *L.*), and the Elecampane (Inula Helenium, *L.*).

Inulin, though resembling starch in its chemical nature, and serving the same purpose in the plant, does not naturally occur in the form of solid particles, but in solution in the cell-sap. It may, however, be obtained in the crystalline form by taking advantage of its insolubility in strong alcohol.

The roots of Chicory are selected for this study. They should, immediately after removal from the soil and washing, be cut into pieces a centimetre or a centimetre and a half long, be placed in strong alcohol, and be allowed to remain there for some time—at least several days. The inulin gradually crystallizes out, and may then be seen in the cells and intercellular spaces of the plant.

Sections, either transverse or longitudinal, of the root may be made and be mounted either in strong alcohol or in strong glycerin for study. The crystals dissolve too rapidly if mounted in aqueous fluids. They may be seen under the low power as spherical, spheroidal, or nodular masses in the cells, and particularly in the radial, fissure-like, intercellular spaces in the bark. They are transparent and refractive, and they show a central dark spot or radial fissure and several concentric circles as well as numerous fine radial lines. The masses are not always spherical: sometimes they are hemispherical and formed against one side of the cell-wall, and sometimes there may even be found a sphere-crystal which is bisected by the cell-wall, one-half of the crystal lying on one side of the wall, the other half on the other side. Sometimes several of the crystalline spheres starting from neighboring centres will be seen to have coalesced to form a nodular mass, each part, however, preserving its concentric and radial structure.

The markings and the structure of these sphere-crystals are better seen if a section be treated for a few minutes with strong alcoholic solution of iodine, which penetrates between the fine crystals composing the mass, staining it yellowish. The effects of the stain will show more distinctly if the section, after removal from the iodine, be dipped for a moment in alcohol to wash away the excess of iodine; but this immersion must not be of too long duration, or the whole structure will be decolorized.

If to a section mounted in strong alcohol or in strong glycerin is added a little water by allowing it to run under the cover-glass, it will be found after a short time that solution has begun to take place, and the radial structure may then be seen more distinctly. The masses, in fact, are made up of delicate, needle-like crystals radiating from a common centre.

To another section of the same material let there be added a single drop of 10 per cent. solution of thymol in strong alcohol, then, after a few minutes, a single drop of strong sulphuric acid, the object then be covered, and the slide be warmed over a lamp-flame: the crystals will have dissolved and disappeared, but a red color will have been produced in the section, showing the presence of a carbohydrate. The reaction is not, however, distinctive of inulin, since any other soluble carbohydrate behaves in the same way. But the test often enables one to distinguish between sphere-crystals of inulin and similar ones of other substances—for example, those of calcium phosphate, which may be associated with inulin in the cells.

II.—Let attention now be given to another carbohydrate—namely, sugar, or, rather, to the sugars, for there are several of them. Objects favorable for the study of these substances are the following: the stems and young fruits of Maize (Zea Mays, *L.*); the stems of Sorghum (Holchus saccharatus, *L.*); the stems of Sugar-cane (Saccharum officinarum, *L.*); the root of the Sugar-

If even after long boiling no red deposit takes place, inulin, mannite, or starch may be present, but neither glucose nor saccharose sugars.

The common Carrot contains cane-sugar, and a section of this may now be tested, so as to observe the difference in the reaction between the two sugar groups.

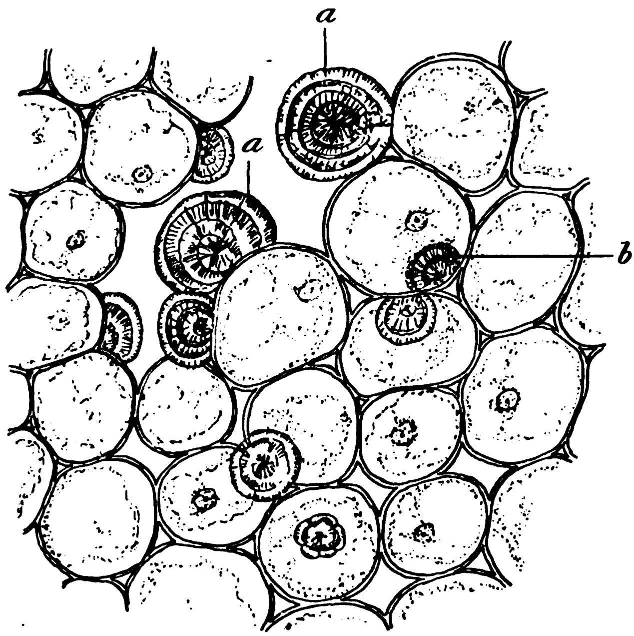


PLATE LXIV.—Cross-section of a small portion of the Parenchymatous Tissues from the inner layer of the bark of the root of Chicory (magnified 330 diameters). The root had been soaked for some time in strong alcohol before sectioning. *a, a*, sphere-crystals of inulin in an intercellular space; *b*, a smaller crystal, partially disintegrated, in a cell.

EXERCISE XIX.

STUDY OF SECRETION-SACS.

SECRETION-SACS are cells which at maturity have lost their protoplasm, and therefore their proper cellular character, and become filled with secreted matters. Their forms differ in different plants, but more commonly they resemble parenchyma-cells in appearance and in the character of their walls. Sometimes, however, they are much elongated and might be mistaken for laticiferous tissue, and sometimes their walls are thickened and more or less lignified. They are usually classified, according to the nature of their contents, into resin-sacs, mucilage-sacs, crystal-sacs, tannin-sacs, etc. Many are mixed in their character, containing both mucilage and crystals or both resins and mucilage; or along with resinous contents there may be tannic or alkaloidal principles.

The following objects afford good examples of the principal groups:

(1) *Resin-sacs:* the rhizome of Ginger (Zingiber officinale, *Roscoe*); the rhizome of Sweet Flag (Acorus Calamus, *L.*); the bark of the Sweet Bay (Magnolia glauca, *L.*); the rhizome of Bloodroot (Sanguinaria Canadensis, *L.*); and the stem of the Lizard's Tail (Saururus cernuus, *L.*).

(2) *Mucilage-sacs:* the root of the Marshmallow (Althæa officinalis, *L.*); the bark of the Slippery Elm (Ulmus fulva, *Michx.*); and the bark of the Basswood (Tilia Americana, *L.*).

(3) *Crystal-sacs:* the root of Yellow Dock (Rumex crispus, *L.*); the root of Rhubarb (Rheum officinale, *Baillon*); the root-bark of the Pomegranate (Punica Granatum, *L.*); and the bark of Cascara Sagrada (Rhamnus Purshiana, *DC.*).

(4) *Sacs containing crystals and mucilage:* the bulb-scales of the Squill (Scilla maritima, *L.*); the bulb-scales of Amaryllis (Amaryllis formosissima, *Willd.*); the stems of the Spiderwort

(Tradescantia Virginica, *L.*); the stems of the Green Dragon (Arisæma Dracontium, *Schott.*); and the roots of Orchis (Orchis mascula, *L.*).

(5) *Tannin-sacs:* the rhizome of Cranesbill (Geranium maculatum, *L.*) and the stem of the Horseshoe Geranium (Pelargonium zonale, *Willd.*).

I.—Let the first study be that of the rhizome of Calamus. Either the fresh rhizomes or the dried ones to be had in apothecary shops may be employed. In the latter case the material should be soaked for a few hours in water before sectioning.

Let both a transverse and a longitudinal section be mounted in a drop of water and be examined with a low power. The tissues will be found to be composed largely of parenchyma, which, like that of the Yellow Water-lily, is very loosely arranged, with large and rather regular intercellular spaces. Most of the parenchyma-cells contain small starch-grains besides protoplasm and a nucleus, but here and there among these cells are others of considerably larger size and rounded in outline, in whose interior neither protoplasm nor starch is discoverable, but which contain a refractive liquid sometimes intermixed with brownish solid matter. These cells are the secretion-sacs.

If one of the sections now be treated with Russow's potassium hydrate, the solid matter in the secretion-sacs, which before was merely brownish, becomes a deep red-brown, while the walls of the sacs are more sharply defined. Many of the sacs, it will be observed, contain none of the brown matter, but are filled, and often strongly distended, with the transparent refractive liquid, which shows no signs of saponification even after long immersion in potash solution. It may be concluded, therefore, that this liquid is probably a volatile oil. This conclusion is verified by treating fresh sections respectively with alcannin solution and with cyanin solution. Both the solid and the liquid contents of the secretion-sacs become strongly stained by these reagents. The liquid, therefore, is a volatile oil, and the brownish solid matter is a resin. Sometimes the latter appears to be crystalline; more frequently a definite structure is not discernible.

In the longitudinal section the sacs mostly present the same appearance as in the transverse section, but occasionally one appears slightly elongated or ellipsoidal.

II.—For the study of mucilage-sacs let a series of cross- and longitudinal sections of the root of the Marshmallow now be made, and be transferred to alcohol until required for use. On placing one of the cross-sections on a slide in a drop of glycerin and examining it with the low power the mucilage-sacs will be seen as transparent rounded cells rather freely but irregularly scattered through a smaller-celled parenchyma which is very rich in starch. The secretion-sacs are very numerous both in the soft tissues of the woody zone—the part, that is, within the cambium zone—and in the middle and inner bark.

If to a fresh section a drop of potassium-iodide iodine be applied, the contents of the secretion-sacs remain unstained, indicating that no proteids are present; but if, instead, a drop of the zinc-chloriodide iodine be applied, or if to the section already stained with potassium-iodide iodine a drop of sulphuric acid be added, the contents will acquire a deep-brown color, the mucilage being stained by these reagents.

The contents of the sacs appear nearly homogeneous, except that sometimes in or near the centre of the sac may be seen a few minute dark granules, probably mineral in their character. With good illumination, however, there may be observed in specimens treated with a mixture of sulphuric acid 2 parts and water 1 part, or in the specimens that have been treated with the iodine and sulphuric acid, a very delicate concentric stratification in the mucilaginous contents. An attempt has been made in the accompanying drawing (Pl. LXV., Fig. 2) to imitate the stratification-lines, but they are much more numerous and delicate than could well be shown in a drawing.

The walls of the sacs, like those of the adjacent parenchyma-cells, are unstained by anilin chloride and hydrochloric acid, but are stained blue with the iodine and sulphuric acid; they are therefore composed of cellulose. The walls have also about the same thickness as those of the adjacent parenchyma-cells.

In longitudinal section the mucilage-sacs usually appear somewhat elongated, but seldom attain a length more than twice as great as their thickness. They may be regarded, therefore, as parenchyma-cells whose protoplasmic contents have disappeared, giving place to mucilage which has come to occupy the whole interior of the cells.

III. Let the next study be that of the mucilage- and raphides-bearing sacs of Arisæma Dracontium. Having cut a supply of sections, transverse and longitudinal, preferably from the fresh stem, one of each kind may be mounted in a drop of water and be examined with the low power. In the cross-section, among the loosely-arranged parenchyma-cells, there will here and there be seen smaller cells with dark, apparently minutely granular contents. These cells are the sacs to be studied, but they will be understood much better by studying the longitudinal section. Here it will be seen that the sacs, though narrow, are often much elongated—frequently several times as long as their transverse diameter—though short ones are also found; and the solid matters in them, which in the transverse section appeared granular, is here seen to consist of great numbers of long, needle-like crystals mostly lying parallel to each other and to the length of the cells. These crystals are the so-called *raphides*.

In sections cut from fresh tissues and mounted in water as has been directed the crystals may often be seen shooting out through the end partitions into adjacent cells. This is caused by the mucilage contained in the sacs along with the crystals. The mucilage swells by the imbibition of water until rupture of the end walls, which are weaker than the lateral ones, takes place, and some of the crystals escape with the escaping mucilage.

By acetic acid the crystals are not attacked, but by hydrochloric acid they slowly disappear without effervescence; they are therefore composed of calcium oxalate.

The mucilage is stained brownish by iodine and by sulphuric acid, but not so strongly as is the mucilage of the Marshmallow. It stains also with soda-corallin.

IV.—The tannins are abundant and widely-distributed substances. They occur associated with other matters—living protoplasm, proteids, starch, etc—in various tissues, but sometimes cells appear to be especially set apart as containers for them. These cells are called tannin-sacs.

If sections of the stem of Pelargonium zonale be mounted in a drop of water and be examined, cells will be seen among the starch-bearing parenchyma-cells of the pith and cortex, which cells are filled with granular matters, but contain neither starch nor proteids. These cells are tannin-sacs, for if to a fresh section that has not been treated with water a drop of the ferric-alum solution be applied, a blue-black precipitate will immediately be formed in them, so dense in its character as to render the sacs perfectly opaque even after the sections have been boiled in carbolic acid.

These secretion-sacs are precisely similar in shape and in the thickness and composition of their walls to the adjacent parenchyma-cells. In fact, many of the parenchyma-cells that still contain living protoplasm and starch are shown by the test to contain also considerable proportions of tannin. The blue-black color may also be seen in the meristem-cells of the cambium zone, in the soft bast-tissues of the inner bark, and even to a limited extent in the wood.

In studying the distribution of tannin in the tissues, of course the test-solution should be applied to sections that have not been treated with water or with any other tannin solvent, otherwise the tannin will have been diffused by the solvent to cells other than those in which it was secreted, and wrong conclusions may be drawn. The best results are obtained by mounting the section, dry, on a slide and then letting the ferric solution run under the cover-glass.

If to another section a drop of 10 per cent. solution of potassium bichromate be applied in a similar manner, there will be seen in the tannin-containing cells a dense reddish-brown precipitate; if to still another section a little of a solution of ammonium molybdate in an aqueous solution of ammonium chloride be applied, there will be seen a yellowish-brown precipitate in the tannin-bearing cells.

There are a few other substances besides the tannins that produce similar precipitates with these reagents, but if in any case precipitates of the color above described be attained with all three of these reagents, one may be fairly certain that the precipitates are due to the presence of tannic matters.

If permanent preparations are desired, thin sections which have been treated with the ferric solution may be boiled in strong carbolic-acid solution to clear them, and then be mounted directly in xylol balsam.

V.—In Exercise IV., in which was studied the petiole of the Begonia, there were observed among the collenchyma- and parenchyma-cells some cells which contained stellate masses of crystals which by suitable tests were proved to be composed of calcium oxalate. Agglomerated crystâls of this character are exceedingly common in plants. Sometimes they are associated in the cells with proteids, starch, etc., but sometimes they occupy the cell-cavity to the exclusion of other matters.

Accompanying the bast-fibres in the bark of the Slippery Elm and Locust are very numerous short parenchyma-like cells, each usually containing a crystal of calcium oxalate. The crystals are clinorhombic, and, since they polarize beautifully, are best studied by the aid of polarized light. They are perhâps the commonest of all forms of plant-crystals.

Specimens for study by polarized light are best prepared by boiling the sections in carbolic acid to clear the tissues and then mounting them in balsam.

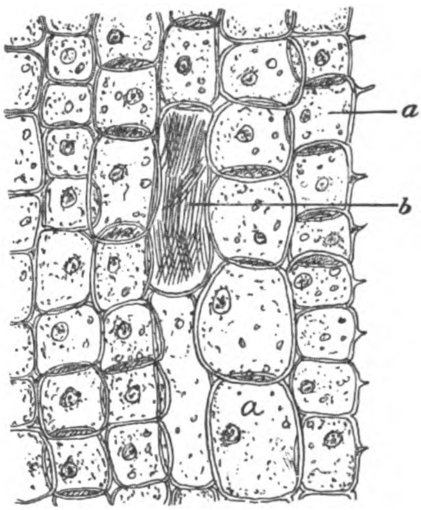


PLATE LXVI.—Small portion of Longitudinal Section of Stem of Green Dragon (magnified 100 diameters): *a*, *a*, parenchyma-cell containing protoplasm and minute starch-grains; *b*, a sac containing mucilage and numerous raphides.

EXERCISE XX.

STUDY OF INTERCELLULAR AIR-SPACES AND SECRETION-RESERVOIRS.

FOR the study of air-spaces selections may be made from the following plants: the fragrant White Water-lily (Nymphæa odorata, *Ait.*), the Yellow Water-lily (Nuphar advena, *Ait.*), the Bulrush (Scirpus lacustris, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Bur-reed (Sparganium eurycarpum, *Engelm.*), the Pickerel-weed (Pontederia cordata, *L.*), the Water Plantain Alisma Plantago, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), the Arrow-leaf (Sagittaria variabilis, *Engelm.*), the Carrot (Daucus Carota, *L.*), the Cow Parsnip (Heracleum lanatum, *Michx.*), and the Common Parsnip (Pastinaca sativa, *L.*). The most convenient parts to employ are the stems, though in most cases the leaves and roots also afford good studies.

For the study of secretion-reservoirs the following are recommended: the roots and stems of the Spikenard (Aralia racemosa, *L.*); the rhizomes of Wild Sarsaparilla (Aralia nudicaulis, *L.*); the roots of Pellitory (Anacyclus Pyrethrum, *DC.*); the young fruits of the Orange (Citrus Aurantium, *Risso*); the stem of the Compass Plant (Silphium laciniatum, *L.*); and the stems and leaves of any species of Pine or Fir.

The three umbelliferous plants mentioned in the former list also possess secretion-reservoirs which are good for study.

Intercellular air-spaces exist more or less abundantly in nearly all multicellular plants, and they probably serve the important purpose of supplying air to the interior tissues, where it is needed for respiratory purposes. In most land-plants these air-spaces are small and angular, but in aquatics they are usually of large size and often have very regular forms. They are, moreover, of two kinds—those formed by the splitting of the cell-wall that is common to two or more adjacent cells, and those formed by the destruction of some of the cells of a tissue. Those produced by the forms distinctly requires the use of a very high power. It is difficult to surmise what can be the use of these trichoblasts.

Removing now the cover-glass, applying one or two drops of anilin chloride, after a few moments as much hydrochloric acid, and again examining, it is found that the trichoblasts have acquired a deep-yellow color which proves them to be strongly lignified; in fact, they are about the only lignified tissue present, even the depauperated vasal bundles showing little if any lignification.

By comparing the longitudinal and the transverse sections it will be seen that the large intercellular spaces form regular channels extending long distances through the petiole or stem, only interrupted here and there by loose masses of branching cells. These cells, like the trichoblasts, are really a kind of internal hair, but, unlike the latter, are not lignified. They originate in a little sac-like outgrowth from one of the cells in the wall of the passage. The sac elongates and branches profusely, and the branches are broken up into cells by the formation of transverse partitions. In favorable longitudinal sections the masses may be seen attached by the base to the wall of the passage. The walls of these hair-cells, it will be observed, are very thin, and it is possible that they are of service to the plant in absorbing gaseous food-material from the air-passages.

The air-passages in the petiole are in communication with those in the rhizome on the one hand, and with those of the leaf and with the stomata on the upper surface of the latter on the other, so that they constitute a complete system of aërating channels throughout the plant.

II.—For the study of secretion-reservoirs the rhizome of Aralia nudicaulis is selected.

Focusing upon a transverse section mounted in a drop of water, there are seen in the middle layer of the bark numerous rather large spaces resembling a good deal those of Nuphar, just studied. But if the section is of a fresh stem, there will be seen clinging to the wall of the passage some refractive droplets which are remnants of the liquid that in the living plant filled the reservoir.

It will be seen, furthermore, that the cells immediately surrounding the reservoir are smaller in size and more densely granular in their contents than those a little farther removed. They are the secreting cells, and the liquid which they secrete is discharged, by some means not yet well understood, into the reservoir where it accumulates. The contents of these reservoirs differ widely in different plants: in some they are mucilaginous, in others oleo-resinous, and in still others there may be a milk-like emulsion consisting of a mixture of resinous and mucilaginous matters. In the present instance the transparency and fluidity point to the presence of an oleo-resin; this conclusion may be confirmed by an application of the alcannin and cyanin tests. These tests would better be applied to the fresh sections, and to longitudinal sections in preference to transverse ones, for the very fluid oleo-resin too readily escapes from the reservoirs in the transverse section.

A careful study of the longitudinal section, particularly of one that has been treated with the alcannin solution in order that the reservoirs may easily be traced, shows that the reservoirs are cylindrical, unbranched, nearly straight, and that they extend long distances in the direction of the length of the rhizome.

The young and growing above-ground stem affords an opportunity to study the development of this type of intercellular space, the schizogenous. A cross-section of such a stem will show clusters of three or four granular cells about a small intercellular space. Lower down in the stem, a similar section will show clusters of a like character except that the number of granular cells is larger and the space they enclose is also larger. The three or four cells with which the development began have increased, mostly by radial division, to a considerable number. This is the usual method of development of reservoirs of this class.

The air-spaces of Nuphar are also of the schizogenous variety.

If sections be made of the rind of the immature fruit of the Orange, lysigenous reservoirs will be seen in different stages of development. In the earlier stage there is only a small cluster of granular cells; in a little later one, a larger cluster, with indications that the central cells are undergoing disintegration; and in a still later one the central cells have disappeared and a drop of oil occupies their place. This area of disintegrating cells containing the oil-globule is surrounded by layers of secreting cells, some of which may in turn break down and so increase the size of the oil-cavity.

EXERCISE XXI.

STUDY OF VASAL BUNDLES: THE CONCENTRIC BUNDLE.

VASAL bundles, or, as they are often called, "fibro-vascular bundles," constitute the tough, stringy tissues of plants. The harder portions of most stems and roots, and the framework of veins in leaves, consist chiefly of vasal bundles. They are pre-eminently the strengthening and conducting portions of the plant structure. A vasal bundle is usually made up of a considerable variety of tissues, and these are arranged in two groups which differ from each other quite widely in the character of their elements. One group is called *xylem* and the other is called *phloem*. Some bundles are composed of one of each of these groups; others, of two or more strands of phloem or of xylem or of both. The bundle may or may not be marked off from the surrounding tissues by a distinct layer of cells called the bundle-sheath or *endodermis*. Both phloem and xylem usually contain a variety of tissues, but different plants, as well as different parts of the same plant, differ as to the number of kinds in each. The essential tissue of the xylem, however, is tracheary tissue (which may include either tracheids or ducts or both), and that of phloem is sieve-tissue. Accompanying the tracheary tissue in the xylem are often found wood-cells and wood parenchyma-cells, ordinary parenchyma-cells, and sometimes secretion-cells of various sorts; and associated with the sieve-tissues in the phloem are usually companion-cells, often ordinary parenchyma and bast-fibres, and sometimes secretion-cells and laticiferous tissues.

Vasal bundles are classified according to the relative arrangement of the phloem and xylem masses or strands. Three different types are recognized—the *concentric*, the *collateral*, and the *radial*.

In the concentric type one of the elements, either phloem or xylem, occupies a central position and is surrounded by the other; there are hence two varieties—the one in which the xylem is central and the phloem forms a cylinder which surrounds it, and the other in which the phloem is central, surrounded by the xylem.

In the collateral type the phloem and the xylem are located side by side. There are three varieties: the closed collateral, in which there is no meristem or cambium between the phloem and the xylem; the open collateral, in which there is a meristem-layer between the two elements; and the bi-collateral, in which there are two phloem masses with a xylem mass lying between them. Such a bundle is usually open on one or both sides; that is, between the xylem and one or both of the phloem masses is meristem-tissue.

In the radial type the xylem is arranged in the form of rays, or like the spokes of a wheel, and the phloem masses lie between the xylem-rays, usually well toward the exterior of the bundle.

The following diagrams will show at a glance the relative arrangement of phloem and xylem in the different bundles, and also the position of the meristem-layer in those bundles which possess one.

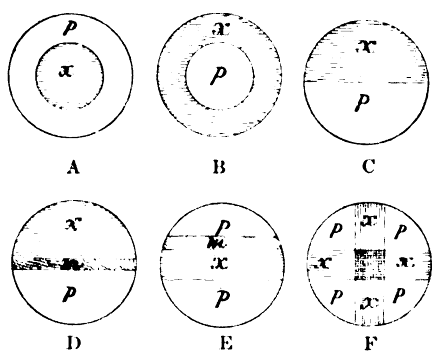


FIG. 7.—A, Concentric bundle with the xylem interior; B, concentric bundle with the xylem exterior; C, closed collateral bundle; D, open collateral bundle; E, bi-collateral bundle; F, radial bundle (*p*, phloem; *x*, xylem; *m*, meristem).

Let this exercise be devoted to the study of concentric bundles. Good examples for study may be found in the stem or the petiole of almost any common fern, as, for example, the Common Brake (Pteris aquilina, *L.*), the Marginal Shield-fern (Aspidium marginale, *Swartz*), the Male Fern (Aspidium Filix-mas, *Swartz*), and the Common Polypody (Polypodium vulgare, *L.*); in the stems of the Selaginellas, as Selaginella rupestris, *Spreng.;* and in the rhizomes of the Blue Flag (Iris versicolor, *L.*), the False it is not an easy thing to detect any sieve-plates, these are the sieve-elements. The sieve-tissues are associated with elongated, slender, almost fibrous, but unlignified companion-cells, rich in protoplasm, but not containing starch. These cells are most abundant immediately exterior to the sieve-elements. Still farther exterior, and immediately interior to the endodermis, is a layer of somewhat elongated parenchyma-cells, of rather larger calibre than the other parenchyma-cells in the phloem area. They are very rich in small-sized starch-grains.

The endodermis, which sharply limits the bundle on the outside, is composed of long, prismatic, rather thin-walled cells which in transverse section appear somewhat lengthened tangentially. Their radial walls are marked with a dark streak and are much more fragile than the other portions of the walls, so that often they are ruptured clear around the bundle in cutting a section. The endodermis when old has its walls usually more or less cutinized, and in the radial walls a little red color is developed by the phloroglucin reagent.

Exterior to the endodermis are the relatively large parenchyma-cells, rich in large-sized starch-grains.

II.—For the study of concentric bundles in which the xylem is exterior, let a series of sections, longitudinal and transverse, now be made of the rhizome of Smilacina racemosa.

The same methods may be employed as in the preceding study, or, if permanent preparations are desired, the gentian-violet and eosin process will give admirable results. The sections, made from material which has been fixed by means of alcohol or acetic alcohol, are first washed if the latter reagent has been employed, then stained with anilin-water gentian-violet, then washed, first in ordinary alcohol and afterward in absolute alcohol, then placed in eosin oil of cloves for a few minutes, and lastly mounted in xylol balsam.

As in the fern, the tracheary elements of the xylem stain with the phloroglucin and anilin-chloride reagents, while the phloem elements do not; but here, in most of the bundles, at least, the former are arranged in a zone about the latter. In a few instances, however, bundles occur in which the xylem ring is incomplete; that is, it is interrupted at one point by soft tissues allied to those of the phloem part of the bundle. Such a bundle might be regarded as a closed collateral bundle in which the xylem has nearly enclosed the phloem. In fact, since closed collateral bundles are much the more common in the stems of monocotyls, and since in some monocotyls they are found associated with concentric bundles which have a central phloem, there are good reasons for regarding the latter as only a modification of the former.

Another difference between the bundle with a central phloem and the other type of concentric bundle is the fact that there is no endodermis to separate the bundle from adjacent tissues. The parenchyma-cells in contact with the xylem elements are only a little smaller than the ordinary parenchyma-cells of the stem.

The longitudinal section shows that the xylem consists almost wholly of tracheids with small bordered pits, that the phloem consists of thin-walled sieve-tubes with very oblique plates, and that the sieve-tubes are associated with long parenchyma-cells rich in protoplasm and containing greatly elongated fusiform nuclei.

In the great majority of bundles having a central phloem the structure is substantially the same as that observed in the example just studied. This variety seldom if ever occurs elsewhere than in the stems and leaves of some monocotyls. Concentric bundles of the other type—that, namely, in which the phloem is exterior—are the kind characteristic of the stems and leaves of nearly all ferns. Only in rare instances are they found in cycads and dicotyls.

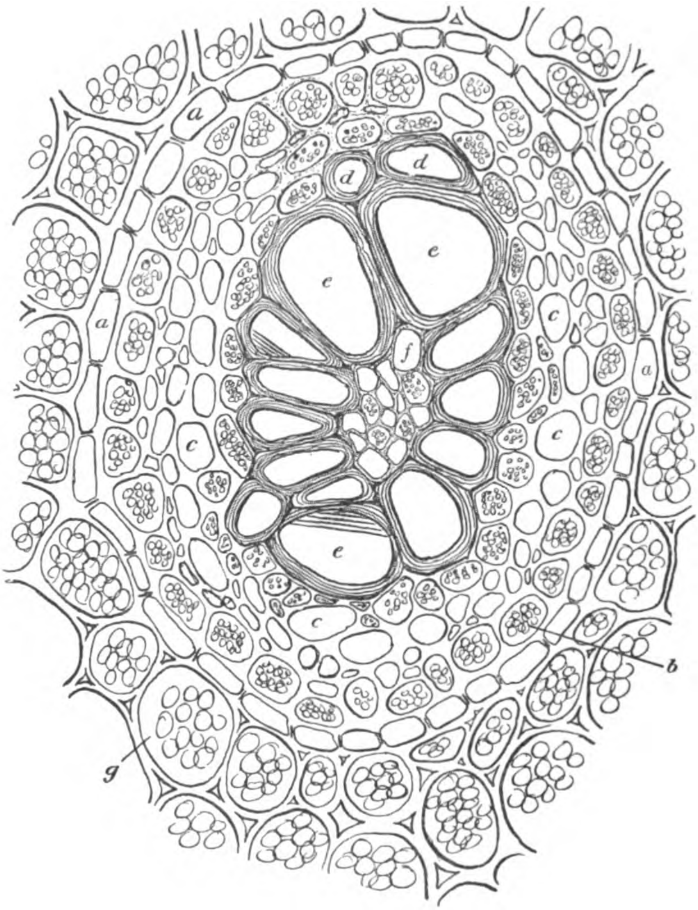


PLATE LXIX.—One of the smaller Concentric Bundles in the Rhizome of Pteris aquilina (magnified 330 diameters): *a*, *a*, *a*, cells of the endodermis; *b*, cell of starch-bearing parenchyma from the layer of cells immediately beneath the endodermis; *c*, *c*, *c*, sieve elements; *d*, *d*, spiral ducts at one end of the xylem mass; *e*, *e*, *e*, scalariform ducts in the xylem; *f*, parenchyma-cell in interior of xylem mass; *g*, parenchyma-cell from fundamental tissues exterior to the bundle, containing large starch-grains.

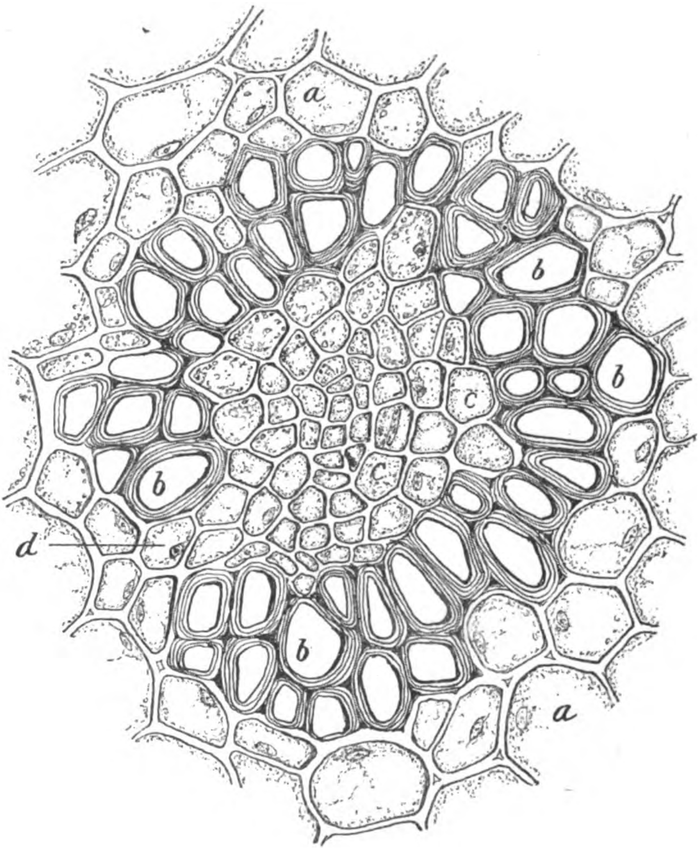


PLATE LXX.—A Concentric Bundle drawn from Transverse Section of Rhizome of Smilacina racemosa (magnified 330 diameters): *a, a*, parenchyma-cells exterior to bundle; *b, b*, pitted tracheids of xylem; *c, c*, sieve elements of phloem; *d*, an opening in the xylem-ring.

EXERCISE XXII.

STUDY OF COLLATERAL BUNDLES.

COLLATERAL bundles occur in the stems and leaves of a few ferns, including the genera Ophioglossum and Osmunda, and in the stems of the Equisitaceæ, but with these exceptions are confined to the stems and leaves of phanerogams, of which they are characteristic.

In the ferns mentioned, in the Equisetaceæ, and in monocotyls the bundles are usually closed; in dicotyls they are usually open. In the great majority of dicotyls the open bundles are of the sort which consists of one xylem and one phloem strand, but a few, as the members of the natural order Cucurbitaceæ, are of the bi-collateral variety.

Convenient plants for the study of closed bundles are the following: the Greenbrier (Smilax rotundifolia, *L.*), the Spider-wort (Tradescantia Virginica, *L.*), the Corn (Zea Mays, *L.*), the Bulrush (Scirpus lacustris, *L.*), the Water Plantain (Alisma Plantago, *L.*), the Arrow-head (Sagittaria variabilis, *Engelm.*), and the Yellow Nelumbo (Nelumbo lutea, *Pers.*).

Good plants for the study of open bundles are the Yellow Parilla (Menispermum Canadense, *L.*), the Virgin's Bower (Clematis Virginiana, *L.*), the Dutchman's Pipe (Aristolochia Sipho, *L'Her.*), the Sycamore (Platanus occidentalis, *L.*), the Bittersweet Solanum Dulcamara, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), and the Basswood (Tilia Americana, *L.*).

For bi-collateral bundles the following plants are excellent: the Pumpkin (Cucurbita Pepo, *L.*), the Squash (Cucurbita maxima, *Duchesne*), and the Wild Cucumber (Echinocystis lobata, *Torr.* and *Gray*).

I.—For the study of a closed bundle let sections be made of the stem of Tradescantia Virginica. On staining a cross-section with the phloroglucin or the anilin-chloride reagent the bundles are readily recognized, and they are seen to be scattered without

The stem of Saururus is herbaceous and dies down at the close of the season of growth, and although the activity of the cambium continues until flowering, it soon after ceases, and the bundles, before the death of the stem, become closed. In the stems of dicotyl shrubs and trees, however, the stoppage of growth in the cambium zone is only temporary; in the spring activity is resumed, and so the bundles increase in length in a radial direction year by year.

III.—For the study of bi-collateral bundles let sections be made of the stem of Cucurbita Pepo, thirty or forty centimetres back of its apex, where the bundles will be found fairly mature.

The xylem portion of the bundle is easily recognized by the very large ducts which occupy its outer four-fifths or more. These ducts have already been studied (see Exercise XI.). In the interior portion of the xylem—that is, in that portion which faces toward the centre of the stem—which is also the first-formed portion, are a number of scattered ducts of much smaller size, which are mostly spiral and annular. The tissue which, in the xylem, fills in the spaces between the ducts consists chiefly of elongated parenchymatous cells with thin walls, and a few cells somewhat thicker-walled and more fibrous in their character, but hardly sufficiently fibrous to be called wood-cells.

At the outer and inner ends of the bundle are the phloem masses, consisting of large and well-developed sieve-cells and smaller companion-cells, both of which have already been studied (see Exercise XIII.). No proper bast-fibres occur in the bundle.

Between the exterior phloem mass and the xylem is a band of meristem-tissue, several layers of cells thick, and between the inner end of the xylem and the inner phloem mass is a somewhat thinner layer of the same tissue. Such a bundle, therefore, increases in length in a radial direction by the formation of new cells in both these layers, some of the cells when mature contributing to the thickness of the xylem tissues, and others to that of the phloem masses.

It is very instructive to compare sections of bundles in the older with those in the younger portions of the stem. It will then be seen how much the bundles have increased in length, and in what portions of the bundles the greatest increase of cells has taken place.

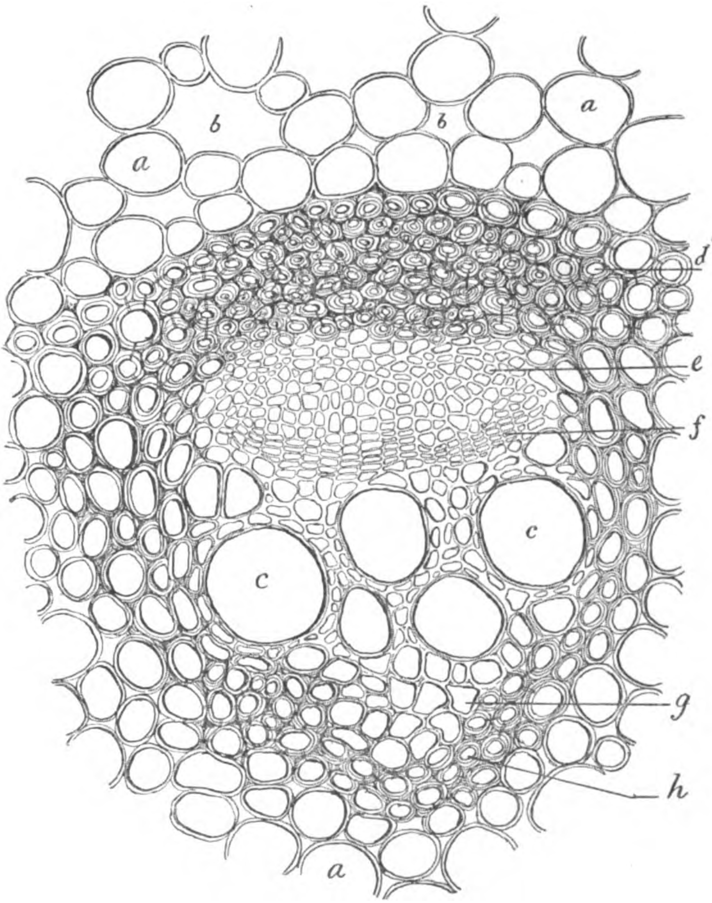


PLATE LXXII.—An Open Collateral Bundle from the above-ground Stem of Saururus cernuus (magnified 210 diameters): *a, a,* parenchyma-cells of the fundamental tissues exterior to the bundle; *b, b,* intercellular spaces, *c, c, c,* large ducts in the younger portions of the xylem; *d,* bast-fibres; *e,* soft bast-tissues; *f,* meristem layer; *g,* spiral duct in older part of xylem; *h,* wood-cell.

EXERCISE XXIII.

STUDY OF RADIAL BUNDLES.

RADIAL bundles are characteristic of the roots of all phanerogams and pteridophytes; they occur also in the stems of the Lycopodiaceæ. As has already been stated, their peculiarity consists in the fact that the xylem masses are arranged in a radiate manner with phloem masses between the rays; but they present a very considerable variety of forms, differing from each other not only in the number of rays, but in their length, in the degree of lignification, and in the structure of the pericambium-layer and the endodermis. There are bundles that have as few as two xylem-rays, and others that have as many as forty or fifty. The different varieties are named according to the number of rays they possess, those with two rays being called diarch, those with three rays triarch, and so on. The diarch bundle sometimes so closely approaches the concentric in structure that careful study is required to distinguish them.

The radial bundles in the roots of dicotyls and gymnosperms usually differ from those in the roots of monocotyls in being fewer-rayed and in having a thinner-walled endodermis, though the rule has its exceptions.

The roots of the following plants afford convenient studies: the Creeping Crowfoot (Ranunculus repens, *L.*), the Mayapple (Podophyllum peltatum, *L.*), the Black Cohosh (Cimicifuga racemosa, *Nutt.*), the Culver's Root (Veronica Virginica, *L.*), the Amaryllis (Amaryllis formosissima, *Willd.*), the Onion (Allium Cepa, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Skunk Cabbage (Symplocarpus fœtidus, *Salisb.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Yellow Lady's Slipper (Cypripedium pubescens, *Willd.*), the Maize (Zea Mays, *L.*), the Sarsaparilla (Smilax officinalis, *Kunth*), and the Moonwort Fern (Botrychium Virginianum, *Swartz*).

I.—For the first part of this study let sections be made of the root of Podophyllum peltatum.

In sectioning, the roots should be held between pieces of pith, according to the directions given for sectioning thin objects in the Introduction to Part II. Excellent sections, both longitudinal and transverse, may be produced by this method. The sections are best handled by means of a moistened camel's-hair brush.

One set of sections would best be treated with the anilin-chloride reagent to differentiate the lignified xylem-elements; but in order that all the cells of the bundle may be seen distinctly another set should be treated with chloral-hydrate solution and be heated so as to clear the tissue of starch; or permanent preparations of great beauty may be made by bleaching the sections with Labarraque's solution, washing them thoroughly, and staining first with iodine-green and then, after thorough washing, with ammonia carmine. The sections are then, after gradual anhydration by the alcohol process and clearing with oil of cloves, mounted in xylol balsam.

The bundle will usually be found to be pentarch, but sometimes it is hexarch; more rarely it has fewer than five rays, being at times even triarch. The xylem-rays have at their exterior terminations very narrow reticulate ducts, while in the later-formed portions of the rays farther interior the ducts are larger and are mostly scalariform. The central portion of the bundle may or may not contain a few scattered ducts, but the greater portion is composed of elongated parenchymatous cells.

The phloem-tissues, which, as usual, consist chiefly of sieve- and companion-cells, are located between the xylem-rays, well toward the outer extremities of the latter, and are separated from them by two or three layers of thin-walled parenchyma-cells on either side. In sections which have been cleared with any of the usual clearing agents, as potassium-hydrate or chloral-hydrate solution, the sieve- and companion-cells may readily be distinguished from the other tissues by their glistening walls.

Immediately interior to the endodermis is a zone consisting of two layers of thin-walled cells of rather larger calibre than either the phloem-cells or the endodermal cells, and containing small quantities of fine-grained starch. This zone is the pericambium-layer or phloem-sheath. Its cells retain the power of

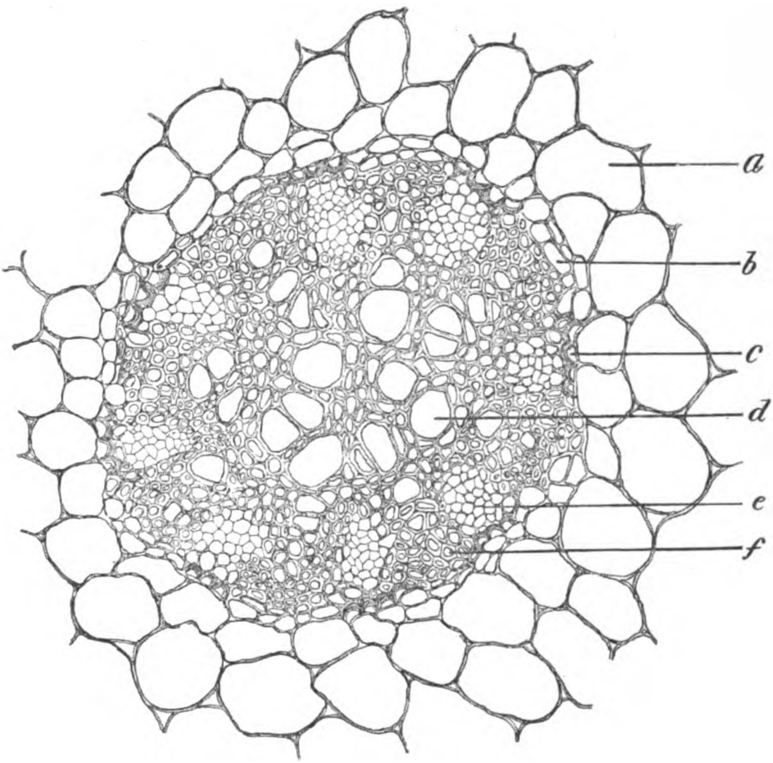


PLATE LXXV.—Radial Bundle of Root of Cypripedium spectabile (magnified 115 diameters): *a*, parenchyma-cell exterior to bundle; *b*, endodermal cell opposite end of a xylem-ray: it is tangentially elongated and thin walled; *c*, a thick-walled endodermal cell opposite the end of a phloem mass; *d*, large reticulate duct near centre of bundle; *e*, phloem mass; *f*, lignified cells bordering xylem-ray.

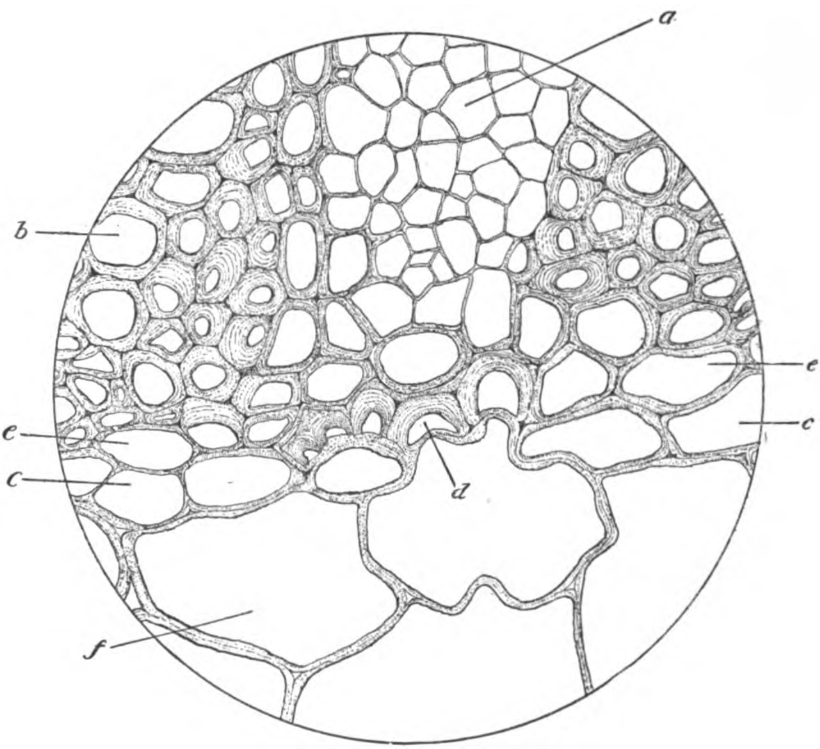


PLATE LXXVI.—Small portion of one of the Radial Bundles of Cypripedium root (magnified 500 diameters): *a*, a sieve-cell of the phloem; *b*, one of the ducts in a xylem-ray; *c*, *c*, thin-walled endodermal cells opposite the ends of xylem-rays; *d*, a thick-walled endodermal cell opposite phloem mass; *e*, *e*, pericambium-cells; *f*, parenchyma-cell exterior to bundle.

EXERCISE XXIV.

STUDY OF ROOTS.

Two different types of root structure exist in the higher plants —that observed in monocotyls, and that observed in dicotyls and in gymnosperms. These two types differ from each other less in their original structure than in their after-development or in the secondary changes which they undergo. In general, it may be said that the roots of monocotyls possess a central radial bundle, usually many-rayed and enclosed by a thick-walled endodermis, which bundle undergoes few secondary changes, while the roots of dicotyls and gymnosperms possess a central radial bundle, usually few-rayed and enclosed by a thin-walled endodermis, which bundle undergoes profound secondary changes.

Monocotyl roots favorable for study may be observed in the following plants: the Amaryllis (Amaryllis formosissima, *Willd.*), the Sarsaparilla (Smilax officinalis, *Kunth*), the Pothos (Pothos pertusa, *Roxb.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Blue Flag (Iris versicolor, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Yellow Lady's Slipper (Cypripedium pubescens, *Willd.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Reed Bent Grass (Calamagrostis longifolia, *Hook.*), and the Maize (Zea Mays, *L.*).

The roots of the following dicotyls afford good studies: the Buttercup (Ranunculus septentrionalis, *Poir.*), the Beet (Beta vulgaris, *Willd.*), the Carrot (Daucus Carota, *L.*), the Culver's Physic (Veronica Virginica, *L.*), the Monkshood (Aconitum Napellus, *L.*), and the Black Cohosh (Cimicifuga racemosa, *Nutt.*).

From among gymnosperms, the roots of any species of Pine or Fir may be studied.

I.—In the first part of this study attention is directed to the way the root grows in length and the structure it shows at its apex. For the purpose of elucidating these points the root of on all sides of this area are arranged in rows focusing at this growing-point. At *i* is the younger portion of the root-cap, with its cells still arranged as just described, while at *h* and *h'* are the older portions of the cap, composed of larger and thicker-walled cells in which the radial arrangement has become obscured. At the surface of the cap the cells are even becoming disintegrated. At *f* is a transparent area consisting of the thickened and mucilaginous outer wall of the epidermis. At *d* is distinguishable, though not without some difficulty, the endodermis, constituting the inner layer of the cells of the cortex. At this stage in the development of the endodermis it is clear that it belongs to the cortex rather than to the central cylinder. At *c* is a row of cells already considerably larger than the neighboring ones: they constitute the beginnings of a duct. Higher up in the root it would be found that the cells composing the row had lost their protoplasm, that their walls had acquired distinct markings, and that the transverse partitions had wholly or partially disappeared.

The student should carefully compare a transverse section of the older portion of a root with the longitudinal section just studied, trace the correspondence of parts, and also note the changes which have developed during growth.

In nearly all phænogamous plants the structure and growth of the root at its apex resemble those of Calamagrostis; but in some of the higher cryptogams (the Ferns and Equisetæ) the growing-point or *punctum vegetationis*, corresponding to *g* in the drawing, consists of a single cell instead of a cluster of cells. In these plants all the tissues of the root—root-cap, epidermis, cortex, and central cylinder—originate by the successive cutting off of cells from a somewhat triangular generative cell located at the punctum vegetationis.

II.—Let now the secondary changes that usually take place in the central cylinder of the roots of dicotyls and gymnosperms be studied in the adventitious roots which spring from the rhizome of Cimicifuga racemosa.

In a root twelve or fifteen centimetres long, sections made a centimetre or two back of the apex will show scarcely any change; three centimetres or so back of the apex, considerable changes will be observed; and four or five centimetres back,

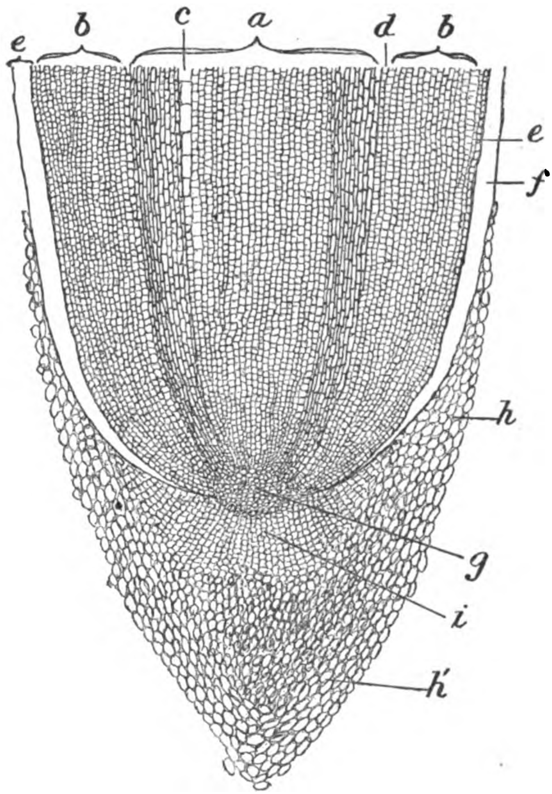


PLATE LXXVII.—Longitudinal Section through the centre of the Root-tip of Calamagrostis longifolia (magnified about 100 diameters): *a*, plerome-cylinder; *b*, *b*, periblem; *e*, *e*, dermatogen; *c*, duct in process of formation; *d*, endodermis; *f*, thickened, mucilaginous outer wall of forming epidermal layer; *g*, punctum vegetationis; *h*, *h'*, older portions of root-cap; *i*, younger portion of root-cap still showing radial arrangement of its cells.

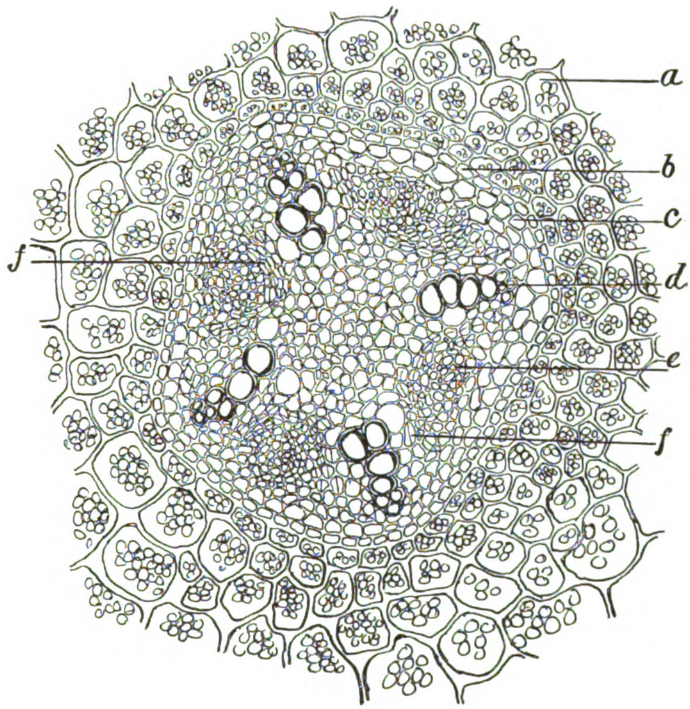


PLATE LXXVIII.—Part of Transverse Section of younger portion of Root of Cimicifuga racemosa, showing radial bundle not much changed by secondary formations (magnification, 100 diameters): *a*, starch-bearing parenchyma-cell of the cortex; *b*, endodermis; *c*, pericambium; *d*, small ducts at the outer extremity of one of the four xylem-rays; *e*, phloem mass; *f*, *f*, meristem tissue beginning to form back of the phloem mass and between it and the xylem-rays on either side.

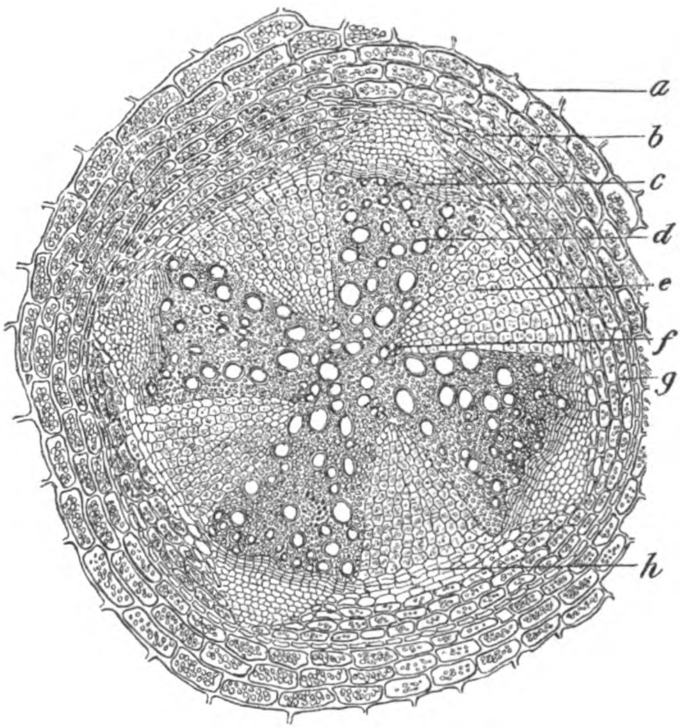


PLATE LXXX.—Part of section of still older portion of a Root of Cimicifuga racemosa (magnification about 50 diameters): *a*, a starch-bearing parenchyma-cell of the cortex; *b*, endodermis; *c*, cambium; *d*, duct in secondary xylem; *e*, one of the starch-bearing cells of the broad, wedge-shaped medullary ray; *f*, outer extremity of one of the four original xylem-rays; *h*, cambium of medullary ray.

EXERCISE XXV.

DIFFERENT TYPES OF STEMS.

AMONG vascular cryptogams and phanerogams four different types of stem structure may be recognized: the fern type, the club-moss type, the monocotyl type, and the dicotyl type.

The fern type may be studied in the rhizomes of the following ferns: Polypodium vulgare, *L.*, Pteris aquilina, *L.*, Aspidium Thelypteris, *Swartz*, A. spinulosum, *Swartz*, A. marginale, *Swartz*, and A. Filix-mas, *Swartz*.

The club-moss type may be studied in the following species of Lycopodium: L. clavatum, *L.*, L. Selago, *L.*, L. inundatum, *L.*, and L. obscurum, *L.*

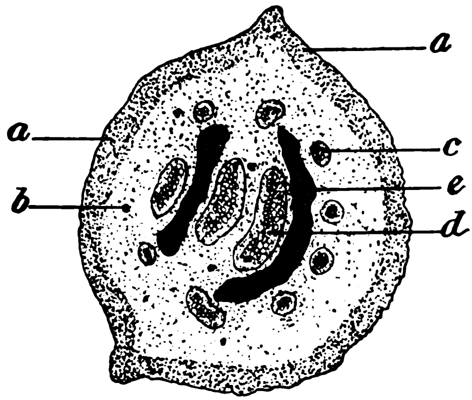
The monocotyl type is conveniently studied in any of the following plants: the Greenbrier (Smilax rotundifolia, *L.*), the Asparagus (Asparagus officinalis, *L.*), the False Solomon's Seal (Smilacina racemosa, *Desf.*), the Solomon's Seal (Polygonatum biflorum, *Ell.*), the Tiger Lily (Lilium tigrinum, *Ker*), the Wild Yellow Lily (Lilium Canadense, *L.*), the White Hellebore (Veratrum viride, *Ait.*), the Pickerel Weed (Pontederia cordata, *L.*), the Spiderwort (Tradescantia Virginica, *L.*), the Indian Turnip (Arisæma triphyllum, *Torr.*), the Indian Corn (Zea Mays, *L.*), and the Wheat (Triticum vulgare, *Villars*).

The dicotyl type is well illustrated in the stems of any of the following: the Black Cohosh (Cimicifuga racemosa, *Nutt.*), the Cocculus (Cocculus Carolinus, *DC.*), the Yellow Parilla (Menispermum Canadense, *L.*), the Virgin's Bower (Clematis Virginiana, *L.*), the Basswood (Tilia Americana, *L.*), the Silver Maple (Acer dasycarpum, *Ehrh.*), the Licorice (rhizome) (Glycyrrhiza glabra, *L.*), the Witch Hazel (Hamamelis Virginiana, *L.*), the Parsnip (Pastinaca sativa, *L.*), the Pumpkin (Curcurbita Pepo, *L.*), the Pipe Vine (Aristolochia Sipho, *L'Her.*), the Sycamore (Platanus occidentalis, *L.*), the Lizard's Tail (Saururus cernuus, *L.*), and, among gymnosperms, the White Pine (Pinus Strobus, *L.*), the garded differently: each plate of xylem with the adjacent plates of phloem might be looked upon as constituting an incomplete concentric bundle like that in ferns. Thus the central cylinder would be composed of a group of imperfectly-formed concentric bundles enclosed by a common endodermis. In the stems of the Selaginellæ, related to the Lycopodii, there are usually two or more separate concentric bundles arranged side by side. The relationship is thus seen between the concentric and the radial bundle.

The club-moss type of stem, then, is one in which the central cylinder is occupied either by a single radial bundle or by two or more concentric bundles arranged side by side.

III. The Monocotyl Type.—For the study of the monocotyl type of stem let transverse sections be made of the stem of the common Maize. A section stained by means of the anilin-chloride reagent will serve the purpose well. Under a very low magnifying power the stem presents the appearance shown in Figure 1 (Pl. LXXXII.). On one side of the stem is a notch, *a*, into which fitted the axillary bud borne on the node below. At the exterior of the section is the epidermis, composed, as usual, of a single stratum of cells. Interior to this is the cortex, composed, in the present instance, of only a few layers of thin-walled cells, and not separated from the central cylinder by a sheath, as is sometimes the case in this type of stem. The central cylinder is composed of parenchymatous ground tissues through which very numerous bundles are scattered. These bundles are smaller and closer together next the outside, where sometimes two or more partially coalesce. The bundles are all of the closed collateral type, and, as is usual in this kind of stem, the phloem faces exteriorly and the xylem faces toward the centre of the stem. The xylem portion of each bundle usually contains about two large ducts toward its outer face, next the phloem, and several smaller ones toward its inner face, where also there is usually to be found an irregular intercellular space of considerable size. The bundle is ensheathed by thick-walled fibres, most abundant and thickest walled at the outer and inner ends of the bundle. Those fibres at the outer or phloem end may be called bast-fibres; those at the inner or xylem end, wood-cells.

The closed collateral bundle is commonest in the stems of mono-



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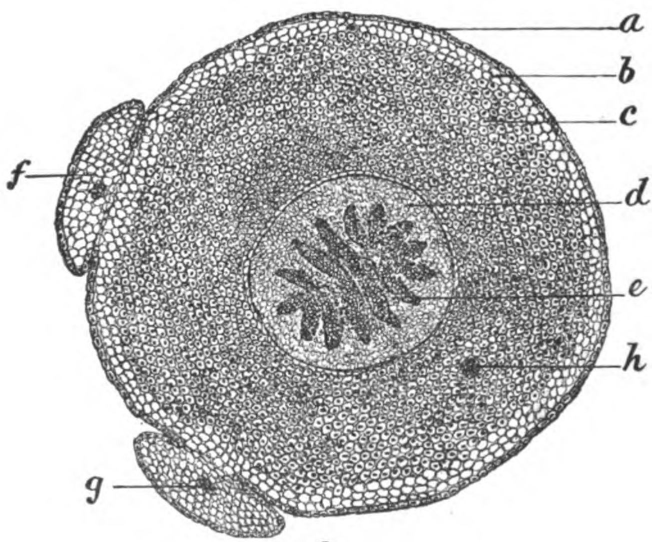

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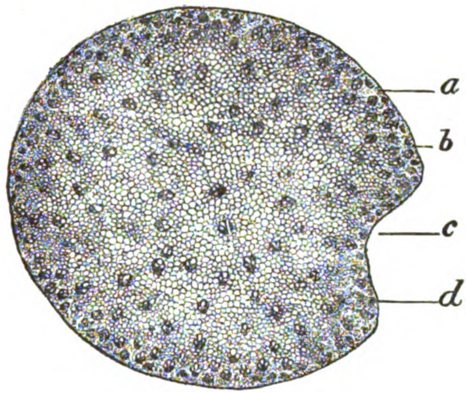
PLATE LXXXI., FIG. 1.—Transverse Section of Rhizome of **Pteris aquilina** (magnified about 7 diameters): *a, a*, hypoderma; *b*, small cluster of sclerenchyma-fibres in cortex; *c*, one of the circle of concentric bundles; *d*, one of the two interior large bundles; *e*, one of the two large brown masses of sclerenchyma-fibres.

FIG. 2.—Transverse Section of Stem of Lycopodium obscurum (magnified 30 diameters): *a*, epidermis; *b*, thin-walled cells of cortex beneath epidermis; *c*, sclerenchyma-fibres constituting the principal portion of the cortex; *d*, soft tissue (pericambium) in outer portion of central radial bundle; *e*, one of the xylem-rays; *f*, a leaf-base; *g*, vasal bundle in another leaf-base; *h*, a vasal bundle passing off to supply a leaf.



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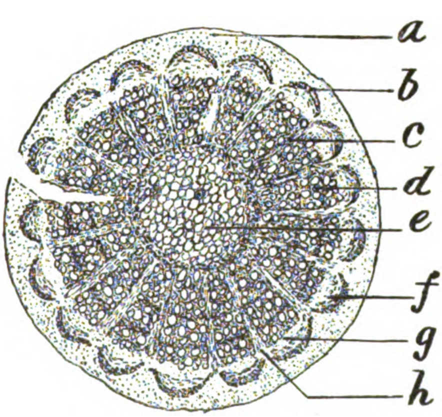

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PLATE LXXXII., FIG. 1.—Transverse Section of Stem of Maize (magnified about 4 diameters): *a*, epidermis; *b*, thin cortex; *c*, indentation caused by a bud formed on internode below; *d*, one of the small bundles among the crowded ones at the outside of the central cylinder.

FIG. 2.—Transverse Section of Stem of Menispermum Canadense in the third year of its growth (magnified 8 diameters): *a*, cortex; *b*, crescent-shaped mass of bast-fibres; *c*, medullary ray; *d*, xylem of a bundle; *e*, pith; *f*, soft tissues of phloem; *g*, fascicular cambium; *h*, interfascicular cambium.

EXERCISE XXVI.

STUDY OF LEAF STRUCTURE.

LEAVES, so far as their internal structure is concerned, are of two principal types, the *bifacial* and the *centric.* These types differ chiefly in the arrangement of the chlorophyll-bearing parenchyma. In the bifacial type the parenchyma consists of two quite different layers facing the upper and lower surfaces respectively. The layer facing the upper surface has its cells compactly arranged and usually elongated in a direction perpendicular to the epidermis, forming what is called *palisade* parenchyma; the layer facing the lower surface has its cells loosely arranged and usually little if at all lengthened perpendicularly to the epidermis. In leaves of this kind the blade is always flattened, and habitually presents the deeper green surface, next which lies the palisade layer, upward or toward the stronger light. This surface usually has few or no stomata, while on the other surface they are numerous.

In the centric type of leaf there is but little structural difference between the parenchyma-layers facing the two surfaces, and seldom is anything resembling a palisade tissue developed next either surface, although, as a rule, the parenchyma is more spongy in the interior, is larger-celled, and contains less chlorophyll than the parenchyma adjacent to the surfaces. Terete, acicular, and succulent leaves usually belong to this class, but it may include flattened and even membranous forms. In this case, however, the two surfaces are nearly equally exposed to the light, and both possess stomata.

The following plants afford a good variety for study: *Bifacial leaves:* the Male Fern (Aspidium Filix-mas, *Swartz*), the Sago Palm (Cycas revoluta, *Willd.*), the Begonia (Begonia discolor, *H. K.*), the Eucalyptus (Eucalyptus globulus, *Lab.*), the Rue (Ruta graveolens, *Willd.*), the Oleander (Nerium Oleander, *L.*), the Rubber Tree (Ficus elastica, *Roxb.*), the Nettle (Urtica dioica, *L*), the Beech (Fagus ferruginea, *Ait.*).

Centric leaves: the Austrian Pine (Pinus Laricio, *Poir.*), the Showy Lady's Slipper (Cypripedium spectabile, *Salisb.*), the Wheat (Triticum vulgare, *Villars*), the Adam's Needle (Yucca filamentosa, *L.*), the Sweet Flag (Acorus Calamus, *L.*), the Hyacinth (Hyacinthus orientalis, *Willd.*), and the Daffodil (Narcissus Pseudo-narcissus, *L.*).

I. Bifacial Leaves.—(1) Let the leaf of Ficus elastica first be studied. The leaf being leathery and firm in texture, sections of it may readily be made, without hardening in alcohol, by placing portions of it between flat pieces of pith and cutting through both pith and leaf. Specimens which have laid for some time in alcohol are to be preferred, because they have been rendered more transparent by the removal of the chlorophyll. The sections would better be made transversely, across the direction of the lateral veins.

A section may be mounted in a drop of carbolic-acid solution or in one of chloral hydrate, or, if the leaf had previously been treated with alcohol, in glycerin, and then be examined first with a low and afterward with a high power.

It will be observed that the epidermis of both upper and lower surfaces is composed of three tiers of transparent cells; but the upper epidermis is thicker than the lower, by reason of the larger size of the cells in its two inner layers. A two- or more layered epidermis is not uncommon among the leathery evergreen leaves of warm climates. Probably the thickness of the epidermis both tempers the intensity of the sun's rays and retards evaporation from the leaf.

At intervals in the inner tier of epidermal cells on the upper side, and more rarely on the lower, are very large cells containing each a botryoidal mass attached by a stalk to the cell-wall as shown at *b*, Figure 1 (Pl. LXXXIII.). This mass is called a *cystolith*. Bodies of this kind are not common in plants, rarely occurring outside the orders Urticaceæ, Acanthaceæ, and a few species of the Cucurbitaceæ.

Interior to the upper epidermis are seen the palisade cells arranged in two tiers. In both tiers the cells are lengthened in a direction perpendicular to the epidermis, but the cells of the exof thick-walled cells constituting a hypoderma. Immediately interior to the hypodermal tissue is a single layer of much elongated palisade cells. The second layer in this case is but slightly developed. This is followed still farther interior by a spongy parenchyma composed of thickish-walled, somewhat lignified, and strongly pitted parenchyma. The cells in this region, nearly midway between the two surfaces of the leaf, contain little if any chlorophyll, while those near the palisade tissue on the one hand and the lower epidermis on the other contain chlorophyll, though in less quantity than do the palisade cells. The cells are all regular in form, and are mostly much lengthened in a direction perpendicular to the midrib and parallel to the epidermis.

Focusing up and down on this tissue, it is found that, like other spongy parenchyma, it is very loosely arranged, but here the spaces are larger and more regular than in the leaf of Ficus elastica.

Next the lower epidermis is an interrupted layer, or in places two layers, of chlorophyll-bearing cells which are slightly elongated in the other direction—namely, perpendicularly to the epidermis—thus constituting a very imperfectly developed palisade tissue. The interruptions in this layer are the places where the air-chambers occur over the stomata, which are very numerous between the midrib and the margin on the lower surface, but which are not found elsewhere in the leaf.

Examining the same sections with the high power, it will be found that the stomata located in the single-layered epidermis present some striking peculiarities. Referring to Plate LXXXIV., the air-chamber over one of the stomata is shown at *f*, and an exterior opening at *h*. This, however, is not the stoma proper, but is rather the opening into a vestibular cavity which leads to the stoma above. A favorable section shows the guard-cells as indicated in the drawing. Where they meet, as at *i*, there is an excessive thickening which is also strongly lignified, while the rest of the wall remains relatively thin, and that portion which faces the vestibular cavity is wholly unlignified.

The cells bounding the vestibular cavity are long cells, pointed at their exterior ends and curved, and so placed as to form a dome-shaped prominence in the lower epidermis, the dome being perforated at the top by a rounded aperture. The arrangement of these cells will be understood better by reference to Figure 1

Good sections are easily made, either of fresh or of alcoholic material, by cutting the leaves between pieces of pith. In order to understand the structure well, it is advisable to clear the sections by means of carbolic acid, or, better, by treating them with Labarraque's solution until colorless, washing them thoroughly and double-staining—say with iodine-green and ammonia carmine—and, after anhydrating, mounting them in balsam.

The sections are nearly straight on one edge (the ventral, as will be shown by studying the bundles) and strongly curved, nearly semicircular, on the other. The excessively thick-walled and one-layered epidermis is punctured at frequent intervals, as well on the ventral as on the dorsal surface, by stomata. Beneath the epidermis is a hypoderma composed of two or three layers of thick-walled fibrous cells interrupted only where the stomata occur. Interior to this hypoderma, on both sides of the leaf, is a peculiar, thin-walled, chlorophyll-bearing parenchyma. The walls of its cells are thrown into numerous folds which project into the cell-lumen. Arranged at nearly equal intervals in this parenchyma, around the axial portion of the leaf, are from four to six secretion-reservoirs in which the circle of secreting cells is ensheathed by one of thick-walled cells.

The axial portion of the leaf is separated from the rest by a distinct sheath of rather large and not very thick-walled cells, interior to which, and surrounding a pair of collateral vasal bundles, are several layers of parenchyma-cells possessing bordered pits similar to those of the tracheids so characteristic of the woody portions of gymnosperms.

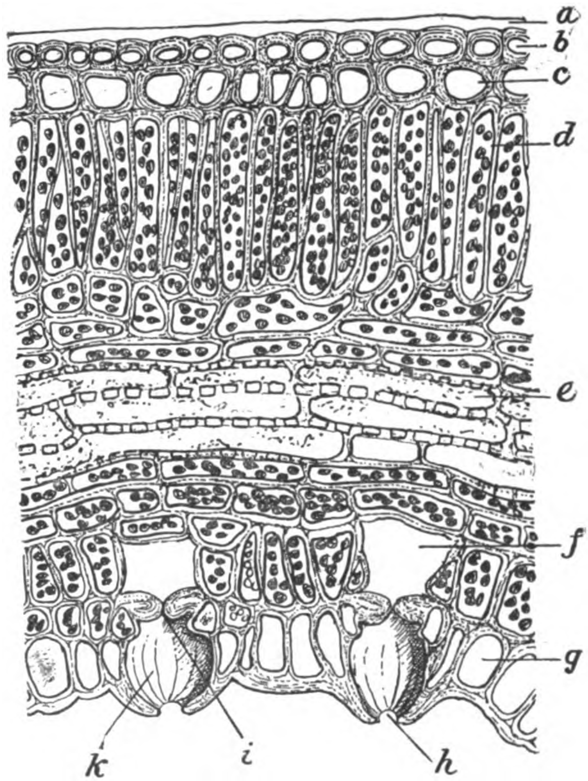
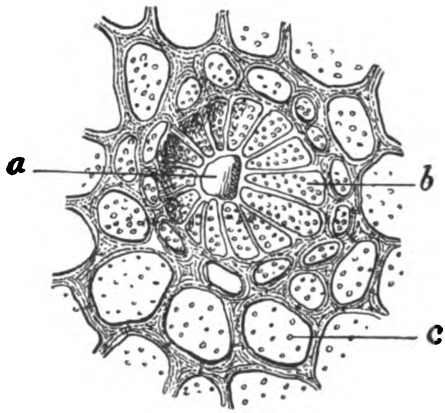


PLATE LXXXIV.—Small portion of the Cross-section of the Leaflet of Cycas revoluta (magnified 210 diameters): *a*, cuticle; *b*, epidermal cells; *c*, hypoderma; *d*, palisade parenchyma; *e*, pitted cells in middle portion of spongy parenchyma, which contain few if any chloroplasts; *f*, air-chamber above stoma; *g*, ordinary epidermal cell of lower epidermis; *h*, opening into vestibular cavity of stoma; *i*, a stoma; *k*, vestibular cavity.



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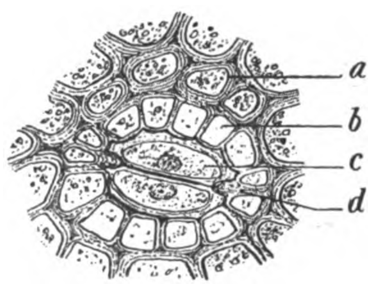

2

PLATE LXXXVI., FIG. 1.—View of small portion of Lower Epidermis of Cycas leaf as seen from below (magnified 330 diameters): *b*, one of the cells forming the dome-shaped vestibule of the stoma (the outer ends of the cells are strongly cutinized and their walls are pitted); *a*, vestibular opening; *c*, ordinary epidermal cell (its walls are also pitted).

FIG. 2.—Small portion of Epidermis from lower side of Cycas leaf, cut parallel to and near the surface, opening the vestibular cavity so as to show the stoma (magnification, 330 diameters): *a*, ordinary epidermal cell; *b*, base of one of the vestibular cells; *c*, one of the guard-cells; *d*, strong lignified thickening at the end of the stoma.