SCIENCE TEXT-BOOKS

INTRODUCTION TO BOTANY

SPALDING

D. C. HEATH & Co.

GUIDE

TO THE

STUDY OF COMMON PLANTS

AN INTRODUCTION TO BOTANY

BY

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PREFACE.

THESE exercises have been prepared for classes in high schools and other institutions of similar grade, and are intended to indicate, in a general way, the nature of the work that in the judgment of the writer should be undertaken with young people who are just beginning the systematic study of common forms of plant life. They were suggested by frequent inquiries of teachers regarding the preparation in botany now required for admission to the University of Michigan.

No originality is claimed for the subject-matter or its treatment, although much time has been spent in the effort to develop a natural and practicable method of approaching the study of living things. While the study of relationship holds the first place, the attention of the pupil is directed at every step to the physiological significance of observed facts; and although this will hardly be approved by those who attempt to separate sharply the domain of morphology from that of physiology, it has seemed to the writer better to follow Nature than be cramped by such artificial barriers. Some of the exercises will perhaps appear too simple and others too difficult, but a judicious selection on the part of the teacher will do much to correct this.

As to the ground that ought to be covered in such a course, and the proper sequence of subjects, there is naturally great difference of opinion among practical teachers. Theoretically it would seem best to begin with the lowest forms of plants, and work up to the higher; but after careful consideration, and in view of the actual state of things in most of our preparatory schools, a different plan has been adopted.

It is hoped that in spite of mistakes and imperfections, sure to be brought to light if the book is used, it may nevertheless prove serviceable to a rapidly increasing number of teachers who are desirous of improving existing methods of instruction. To Dr. Erwin F. Smith of Washington, D.C., and Miss Effie A. Southworth of Barnard College, who have kindly read the proofs throughout; to Mr. W. H. Rush of the University of Michigan, who has critically reviewed and tested the practical directions; and to others who have aided in various ways, the sincere thanks of the writer are due.

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NATURAL GROUPS OF PLANTS.[1]

[1] Groups above families have been placed in boldface type without attempting their coördination.

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DICOTYLEDONS.

TO THE STUDENT.

You are beginning the study of living things, and it is very important that you should begin in the right way. These practical exercises are intended to help you, but not to do the work for you. Many of the exercises will seem very simple, but if you actually do what is called for, it will be plain why so much stress is laid on knowledge gained by direct personal observation and experiment.[1]

There are a few things that you ought to consider at the outset.

1. First of all, it is essential that you should learn to see things just as they are, and to report exactly what you have seen. Agassiz used to say to his students: "Study to know what *is;* be courageous enough to say 'I do not know.'" Tyndall said to the teachers at South Kensington: "In every one of your experiments endeavor to feel the responsibility of a moral agent. . . . If you wish to become acquainted with the truth of Nature, you must from the first resolve to deal with her sincerely." Darwin in his autobiography[2] writes: "I had during many

[1] "You wish, for example, to get a knowledge of magnetism; well, provide yourself with a good book on the subject, if you can, but do not be content with what the book tells you; do not be satisfied with its descriptive woodcuts; see the actual thing yourself. Half of our book-writers describe experiments which they never made." —Tyndall, *Fragments of Science.*

[2] *Life and Letters*, p. 71.

years followed a golden rule, namely, that whenever a published fact, a new observation or thought, came across me, which was opposed to my general results, to make a memorandum of it without fail and at once, for I had found by experience that such facts and thoughts were far more apt to escape from the memory than favorable ones."

2. When you have seen a thing clearly, be sure to express your conception, whether by drawing, or written description, or both, as accurately as possible. Learn to use scientific language with precision. Write out your observations in full, in the best English at your command. Avoid abbreviations and every other device for saving time. Make your drawings so that an engraver could copy them. Do not hesitate to do your work all over again, if it can be improved, as it probably can be, and do not leave a thing until you have not only a complete observation, but a complete expression of it.

3. Do not be hasty in drawing conclusions. Make a constant practice of comparing the object you are studying with others of the same kind. Note differences and resemblances. Learn by the actual process what it is to acquire a general conception. "Honesty in science means, first, facts well proved, and then conclusions slowly and painfully deduced from facts well proved."[1] In all your work *stop and think*. The mere accumulation of facts, if nothing is done with them, is of little consequence. Constantly ask the question, what does this fact mean? You may or may not be able to answer the question, but that is no reason for not raising it.

4. Cultivate self-reliance, but not self-sufficiency. Study

[1] J. P. Lesley, Presidential Address, Am. Assn. for the Advancement of Science, 1885.

things themselves rather than book descriptions of them, but habitually use the books you are referred to, comparing point by point your own observations with what the authors have to say. The writers cited may or may not be right; they are more likely to be than you are; but both of you may be wrong. The best way is to observe for yourself, then consult the books; then observe again, and continue your observations and comparisons until the exact truth is ascertained. This is the way investigations are conducted, and you are learning how to investigate.

5. This leads to a word on the use of books. Make it a regular practice to look up the references that are given with the exercises. By doing this you will not only become acquainted with some of the most valuable botanical literature, but, what is more important, you will come, in some measure, to understand the habits and methods of the great workers in science, and will, perhaps insensibly to yourself, catch something of their spirit, and learn to work as they did, honestly, accurately, and "with infinite patience."

One of the greatest investigators who has ever lived wrote a few years ago: "Whenever I have found out that I have blundered, or that my work has been imperfect, and when I have been contemptuously criticised, and even when I have been over-praised, so that I have felt mortified, it has been my greatest comfort to say hundreds of times to myself that 'I have worked as hard and as well as I could, and no man can do more than this.'"[1]

[1] Charles Darwin, *Life and Letters*, p. 72.

TO THE TEACHER.

MATERIAL AND METHODS.

In order to use these exercises successfully it will be necessary to adopt the laboratory, as distinguished from the text-book, method of instruction. The practice, still too common, of using ordinary recitation seats and benches for work of this kind is extremely unsatisfactory, and ought to be abandoned. The best arrangement is to have places assigned at long tables — one table in front of each window, so that every student can have a full amount of light. North, east, and west windows are preferable, those on the north side being the best. In every case the pupil is to be provided with the material called for, and this should be typical of its kind and sufficient in quantity. In a large proportion of the exercises the plants needed are common everywhere and easily obtained. When it is impossible to procure them the exercise is to be omitted. It has no significance whatever unless the thing talked about is actually present to the eye. It will generally be found better to secure an appropriation of a few dollars and employ some one regularly to furnish a supply of material than to depend on what the teacher and members of the class can gather. In any case the things to be studied must be systematically provided. They cost far less, but are just as essential as the reagents and apparatus in a chemical or physical laboratory.

Too much emphasis cannot be laid on the importance of securing at the outset a fairly complete equipment. The necessity of following the laboratory method in science teaching is now so universally recognized that it is to be hoped that boards of education will generally adopt the better way and cheerfully pay for it. Having once secured the necessary tables, instruments, and books, the expense from year to year is extremely small in comparison with the result aimed at, viz. *a discipline that can be attained in no other way.*

The use of the microscope, methods of sectioning, mounting microscopic objects, drawing, and other practical operations of the laboratory are best learned of the living teacher. Useful suggestions, however, will be found in the excellent handbooks of Strasburger, Arthur, Barnes, and Coulter, and other laboratory manuals.

DISPOSITION OF TIME.

When practicable, it is much more advantageous to arrange the time given to laboratory work so that each student can work two consecutive hours for a certain number of days each week. When this cannot be done without seriously interfering with the school programme, the following plan is suggested: Give four hours each week to practical exercises, requiring each member of the class to work independently in his own place, precisely as he would at a table in a chemical laboratory, the teacher passing from table to table, giving personal help as it is needed, and from time to time giving notes and directions to the class as a whole. The remaining hour, say on Friday or Monday, or sometimes both, may be used for recitations, reports on laboratory work, and the dictation of notes and references. Exercises to be conducted out of school hours may be assigned at the discretion of the teacher, but generally it will be found that the best work is done in the laboratory under his personal direction.

In the majority of preparatory schools half a year is given to botany. It is very desirable that the time should be extended, but until this is done it is recommended that the exercises be followed substantially as here outlined, with the omission of a part, or possibly the whole, of the microscopic work. If the latter is undertaken, and a reasonable amount of time is given to the study of different families of plants in the spring, a full year will be needed.

WORKS OF REFERENCE.

In connection with the exercises, frequent references are given. In a few cases books of a more or less popular character are mentioned, and some of the most important works in French and German are referred to, inasmuch as they are well-nigh indispensable to the teacher. In general, the works named are easily obtained, and ought to have a place in any respectable school library. Several copies of the books in constant use should be placed on tables in the laboratory, where they can be consulted without loss of time, the students being given to understand that they are expected to look up references as habitually and critically as they would if reading a classical author. One or more of the best periodicals may properly be included in the essentials of the laboratory outfit. The following list, by no means complete, includes some of the most generally useful botanical works.

LABORATORY MANUALS.

Arthur, Barnes, and Coulter, *Plant Dissection*. Henry Holt & Co., New York, 1886.

Bower and Vines, *Practical Botany*, Parts I. and II. Macmillan & Co., London, 1885 and 1887.

Clark, *Practical Methods in Microscopy*. D. C. Heath & Co., Boston, 1893.

Strasburger and Hillhouse, *Practical Botany*. Macmillan & Co., New York. 1889.

These manuals are of the utmost value as laboratory guides. The first is the simplest, and, on the whole, most suitable for beginners. The third contains the latest and most approved methods of microscopical manipulation. The last is most complete, and gives the modern methods of work with such clearness and detail as to render it indispensable in every botanical laboratory. The original work of which it is a translation [Strasburger, *Das kleine botanische Praktikum*. Fischer, Jena] will be preferred by those who read German.

STRUCTURAL AND PHYSIOLOGICAL.

Gray, *Structural Botany* (sixth edition). Ivison, Blakeman & Co., New York, 1879.

Goodale, *Physiological Botany*. Ivison, Blakeman & Co., New York, 1885.

Bessey, *Botany*. Henry Holt & Co., New York, 1888.

DeBary, *Comparative Anatomy of the Phanerogams and Ferns*. Oxford, Clarendon Press, 1884.

Vines, *Physiology of Plants*. Cambridge, University Press, 1886.

Sachs, *The Physiology of Plants*, Trans. by H. Marshall Ward. Oxford, Clarendon Press. Macmillan & Co., 1887.

Haberlandt, *Physiologische Pflanzenanatomie*. Engelmann, Leipzig, 1884.

Frank, *Lehrbuch der Pflanzenphysiologie*. Parey, Berlin, 1890.

Zimmermann, *Die Morphologie und Physiologie der Pflanzenzelle*. Trewendt, Breslau, 1887.

Detmer, *Das pflanzenphysiologische Praktikum*. Fischer, Jena, 1888.

Detmer, *Manuel technique de Physiologie végétale*. C. Reinwald, Paris, 1890. Translation of the last-named work revised and extended by the author.

Bessey's Botany is the least expensive book that covers the ground at all satisfactorily. With Gray's Structural and Goodale's Physiological Botany one is better equipped for work, inasmuch as the whole general subject of organography and physiology is ably and clearly presented in them. Sachs' Lectures on the Physiology of Plants is indispensable.

MORPHOLOGICAL AND SYSTEMATIC.

Goebel, *Outlines of Classification and Special Morphology of Plants*. Oxford, Clarendon Press, 1887.

Luerssen, *Handbuch der Systematischen Botanik*. Haessel, Leipzig, 1879.

Eichler, *Blüthendiagramme.* Engelmann, Leipzig, 1875.

Engler und Prantl, *Die natürlichen Pflanzenfamilien.* Engelmann, Leipzig.

All of these are of great value, especially the rather expensive work of Engler and Prantl, now in course of publication.

FLORAS.

Gray, *Manual of Botany* (sixth edition). Ivison, Blakeman & Co., New York.

Chapman, *Flora of the Southern United States* (second edition). Ivison, Blakeman & Co., 1883.

Coulter, *Manual of the Botany of the Rocky Mountain Region.* Ivison, Blakeman & Co., 1885.

Coulter, *Manual of the Phanerogams and Pteridophytes of Western Texas.* U. S. Dept. Agric., 1892.

Gray, *Synoptical Flora of North America.* (In progress.)

Gray's Manual is commonly bound with the "Lessons" in one volume, but may be had separate in convenient form for the pocket. Dr. Gray's final revision of the "Lessons" has been published under the title, *Elements of Botany.* Ivison, Blakeman & Co., 1887.

CRYPTOGAMIC BOTANY.

Eaton, *Ferns of North America.* Cassino, Boston, 1879.

Lesquereux and James, *Mosses of North America.* Cassino, Boston, 1884.

Farlow, *Marine Algæ of New England.* U. S. Fish Commission, Washington, 1881.

Tuckerman, *North American Lichens.* Cassino, Boston, 1882.

DeBary, *Comparative Morphology and Biology of the Fungi, Mycetozoa, and Bacteria.* Oxford, Clarendon Press, 1887.

v. Tavel, *Vergleichende Morphologie der Pilze.* Fischer, Jena, 1892.

Bennett and Murray, *Handbook of Cryptogamic Botany.* Longmans, Green & Co., London and New York, 1889.

Plowright, *British Uredineæ and Ustilagineæ.* Kegan Paul, Trench & Co., London, 1889.

Underwood, *Our Native Ferns and their Allies.* Bloomington, Ill., 1882.

The list of works on Cryptogamic Botany might be greatly extended. Numerous references to the literature of the algæ will be found in Farlow's work mentioned above, and to that of the fungi in DeBary's treatise. For other references consult Bennett and Murray's Handbook.

GENERAL.

Müller, *The Fertilization of Flowers.* Macmillan & Co., London, 1883.

DeCandolle, *Origin of Cultivated Plants.* Appleton & Co., New York, 1885.

Kerner, *Flowers and their Unbidden Guests.* Paul & Co., London, 1878.

Darwin, *Insectivorous Plants*, and other works. Appleton & Co., New York.

Lubbock, *Seedlings.* Appleton & Co., New York, 1892.

Lubbock, *Flowers, Fruits, and Leaves.* Macmillan & Co., London, 1886.

Goodale, *Wild Flowers of America.* Cassino, Boston, 1882.

Sachs, *History of Botany.* Macmillan & Co., 1890.

Lindley and Moore, *The Treasury of Botany.* Longmans, London, 1874.

Kerner von Marilaun, *Pflanzenleben*, 2 vols. Bibliographisches Institut, Leipzig and Vienna, 1891.

Müller's work on the *Fertilization of Flowers* gives references to the immense and increasing body of literature on this subject. Kerner's work is out of print, but may occasionally be picked up, and is a most charming little book. All of Darwin's books should have a place in such a list.

CURRENT LITERATURE.

The Botanical Gazette. Lake Forest, Ill., $2.50 per year.

Bulletin of the Torrey Botanical Club. New York, $2.00 per year.

Annals of Botany. Oxford, Clarendon Press.

Botanisches Centralblatt. Gotthelft, Cassel.

The *Botanical Gazette* and *Torrey Bulletin* are well-known American journals. The *Annals of Botany* is a new periodical of a high order, with original monographs, criticisms of current literature, etc. The *Botanisches Centralblatt* is indispensable in botanical research.

LABORATORY AND PERMANENT OUTFIT.

1. **The laboratory** should be a large room, properly ventilated, with as many windows as practicable, and used exclusively as a laboratory. An upper room is preferable to a lower one, since the air is clearer and there is less liability to disturbance from passers-by.

2. **The laboratory tables** should be plain and solid, oiled, but not painted or varnished, and large enough to give each student all the space he requires without crowding. Drawers should be placed in the tables, or in a separate case, in which the students' outfit may be kept.

3. **Receptacles for waste materials**, conveniently placed and frequently emptied, and plenty of clean water are indispensable.

4. **A pair of balances**, such as are employed by druggists for accurate weighing, will be required.

5. **Microscopes.** For the compound microscope, the so-called continental stand is preferable, on account of its simplicity, firmness, and convenient size. Two good objectives, $\frac{3}{4}$ and $\frac{1}{5}$ inch, or their equivalent, and two eye-pieces are necessary. Such an instrument may be purchased of a reliable dealer for about $30. It will hardly be practicable to equip the laboratory with lower-priced ones that will prove satisfactory.

Dissecting microscopes of simple construction are needed, but a good hand-lens, properly mounted, will answer the same purpose. See Arthur, Barnes, and Coulter, *Plant Dissection*, p. 2.

6. **Glassware and miscellaneous articles.** A stock of common plates and bowls, beakers, glass tubing, bell-jars, test-tubes, metric rules, etc., will be required, but are best purchased as needed, at the discretion of the teacher.

REAGENTS.

Of the reagents most employed in botanical work the following are required:[1] —

7. **Alcohol.** For preserving plant-tissues, except in cases involving the most delicate operations, three grades of alcohol are all that will be needed. The lowest grade (between 45 and 50 per cent) is composed of equal parts of alcohol of commerce and distilled water. The intermediate grade (between 70 and 75 per cent) is prepared by adding 25 parts of distilled water to 75 parts of commercial alcohol. The highest grade is the alcohol of commerce (approximately 95 per cent).

Parts of plants to be preserved are allowed to remain 24 hours in the lowest grade of alcohol, then for the same length of time in alcohol of intermediate strength, and finally are placed in 95 per cent alcohol, in which they may be kept indefinitely. It is necessary to guard against attempting to preserve too much material in a given quantity of alcohol, as decomposition is likely to take place.

[1] Reference may be made to various works in which reagents and methods are discussed at much greater length. Among these are Strasburger and Hillhouse, *Practical Botany*; Behrens, *Guide to the Use of the Microscope in Botany*; Zimmermann, *Die botanische Mikrotechnik*.

8. **Absolute alcohol.** For finer histological work absolute alcohol and a larger number of grades of commercial alcohol more carefully prepared are necessary.

9. **Iodine solution.** Distilled water 10 c.c., potassic iodide 1 gm., iodine 0.25 gm. Dilute to 250 c.c.

10. **Glycerine.** Pure glycerine is employed in some cases, but equal parts of glycerine and distilled water will generally be found most serviceable.

11. **Schulze's solution.** This may be prepared according to the rule given in Strasburger's *Praktikum*, but it will be found more convenient to employ **Grübler's chlor-iodide of zinc,** which may be obtained of Eimer and Amend, New York.

12. **Potash solution.** One part of solid caustic potash dissolved in 20 parts of distilled water. This reagent attacks glass, and care should be taken to prevent its getting on the objectives.

13. **Glacial acetic acid.**

14. **Sulphuric acid.**

15. **Hydrochloric acid.**

16. **Picric acid.**

17. **Phloroglucin.** One per cent alcoholic or watery solution. Employed with hydrochloric acid as a test for lignin.

18. **Picric aniline blue.** Add picric acid to distilled water until a saturated solution is obtained. To this add slowly a saturated watery solution of aniline blue until it is of a deep blue-green color.

19. **Acetic methyl green.** To a 2 per cent solution of glacial acetic acid add methyl green until the solution is deeply colored.

STUDENT'S OUTFIT.

Each pupil should be provided with the following articles:[1] —

20. **A Coddington lens or achromatic triplet.** Either of these will serve a good purpose. The cheap lenses, mounted in horn, and sold for a dollar or less, are of little use. A good Coddington lens may be purchased of Bausch and Lomb, Rochester, N.Y., for $2.50, and an excellent achromatic triplet of James W. Queen & Co., Philadelphia, for $4.75.

21. **A good pocket knife,** kept sharp.

22. **Razor** of good quality and medium size, hollow ground. The Torrey razor, manufactured at Worcester, Mass., is recommended.

23. **A pair of fine forceps.**

24. **Slides and thin glass covers** for mounting microscopic objects. The glass covers should be of medium thickness, and not less than $\frac{3}{4}$ of an inch in diameter.

25. **Needles** mounted in handles.

26. **Camel's-hair brushes** of medium size.

27. **Note-book and drawing paper.** The latter should be unruled, rather heavy, of good quality, and cut to a convenient size for drawings.

[1] In some cases it may be practicable, in order to save expense, for two to use the same outfit; but the practice is not to be commended, except in case of necessity.

28. **Drawing pencils and eraser.** The pencils should be of at least two grades, medium and hard.

If the student pays a laboratory fee, most of the articles named above should be furnished by the school board; if no fee is charged, he may reasonably be required to purchase for himself those that are liable to loss or deterioration through use.

STUDY OF COMMON PLANTS.

I. SEEDS.[1]

MATERIAL REQUIRED.

Common white beans. Other varieties, such as "butter beans," etc.
Peas, oats, wheat, Indian corn, — several varieties of the latter.
Castor oil seeds.
Seeds of white pine, Norway spruce, and other conifers.
Commercial "nuts," such as chestnut, peanut, filbert, almond, Brazil nut, and English walnut.
Seeds of coffee, date, flax, sunflower, tomato.
As many kinds as possible of seeds with winged or hooked appendages or other special arrangements for dissemination.
Seeds of squash, pumpkin, watermelon, muskmelon, cucumber, gourd, and similar collections from other important families.

COMMON BEAN. *Phaseolus vulgaris*, Savi.

I. Compare a number of white beans, and see if they are all alike. Select a good specimen. Observe and describe

1. The shape, surface, and color.
2. Surface markings:
   a. The scar, **hilum**,[2] marking the place where the seed was attached.

[1] General references: Gray, *Structural Botany*, pp. 305–314; Strasburger, *Practical Botany*, Chaps. I and II; Sachs, *Physiology of Plants*; Haberlandt, *Physiologische Pflanzenanatomie*, pp. 277–293.

[2] If any of the terms are unfamiliar and are not sufficiently explained in the text, consult Webster's *International Dictionary*.

b. Near the hilum a minute orifice, **micropyle**, easily seen under a lens.

c. The **chalaza**, the part where the seed coats blend with each other and nutriment enters the growing seed. In this case the chalaza is located externally by a small protuberance near the hilum, on the opposite side from the micropyle.

II. With a sharp penknife or needle remove the integument, **testa**, from a bean that has been soaked in water for a day. Near the hilum a small pointed body, the **radicle**, will be found. Locate it accurately. Does it have any relation to the micropyle?

III. Separate the two halves, **cotyledons**. Examine under a good lens. Notice

1. The form and position of the radicle.
2. The delicate structure, **plumule**, connected with it.

Draw the parts, taking care to represent accurately the leaves of the plumule and their venation.

IV. Examine beans that have lain a few days on moist blotting paper under a bell-jar. What changes have taken place?

What part of the seed has developed into the primary root? What changes has the plumule undergone?

V. With the common bean compare a number of other varieties, "butter bean," "scarlet runner," etc., noting carefully all points of likeness and difference.

VI. Study next the common pea, comparing its structure with that of the bean.

VII. Write a detailed account of your observations of the bean and pea. Introduce drawings or outline sketches whenever the description will be rendered more intelligible by them.

CASTOR OIL SEED. *Ricinus communis*, L.

I. Study first the external features.

1. Shape and surface. Compare different specimens as regards shades and distribution of color.
2. Surface markings:
   a. The conspicuous, thickened protuberance at one end, the **caruncle**, a structure occurring in comparatively few species.
   b. The string-like raphe, extending from the hilum (faintly seen at the edge of the caruncle) to the chalaza, near the other end.

II. Remove the testa and observe the delicate inner seed coat, **endopleura**, enclosing the kernel.

III. Split the kernel longitudinally, so as to expose the embryo. Examine under a dissecting microscope, or with a good lens. Draw the inner surface of one of the halves so as to show

1. The outline and venation of the cotyledon.
2. The short, straight radicle.
3. The surrounding **endosperm** (tissue containing food material).

IV. Record in detail what you have observed. Note important differences between the castor oil seed and common bean.

INDIAN CORN. *Zea Mays*, L.[1]

I. Study closely the external features of the grain. How do the two sides differ?

[1] The grain of corn is really a seed-like fruit, in which the coats of fruit and seed are blended. Specimens for dissecting should be placed in water the day before they are to be used.

II. With a sharp knife make a median longitudinal section perpendicular to the flat sides of the grain. Repeat the process, if necessary, until a good specimen is secured. Observe on the cut surface

1. The strong external membrane composed of the united coats of the fruit and seed.
2. The endosperm, a tissue containing starch and other food materials, very hard in the dry grain, but easily cut in one that has lain some time in water.
3. The embryo, with its conspicuous organ of absorption, **scutellum**, the latter in close contact with the endosperm.

Draw the section.

III. Remove the entire embryo from a grain that has been soaked. Dissect out the parts enclosed in the scutellum. Compare them with the same parts as seen in section. Note

1. The **radicle** pointing toward the small end of the grain, its end covered by the root-sheath.
2. The **caulicle,** attached to the scutellum, and terminating above in
3. The **plumule.**

IV. Take a series of transverse sections and locate each one by comparing it with a longitudinal section. Repeat this until you are perfectly familiar with all the parts and their relative position.

V. Study a grain of corn that has sprouted. What changes has the embryo undergone?

VI. Collect as many varieties of corn as you can and compare them.

VII. Study wheat in the same way that you have Indian corn, and compare the structure of the two grains. Compare oats with both.[1] In what respects are all three alike? Point out the differences between them.

VIII. Write a full account of your observations of these grains. Point out two important particulars in which they differ from peas and beans.

SEEDS OF WHITE PINE. *Pinus Strobus*, L.

I. Observe all the external features. Draw in outline a perfect specimen. Compare the seeds of Austrian pine or Norway spruce.

II. Remove the testa, exposing the kernel enclosed in the delicate inner seed coat.

III. Make both longitudinal and transverse sections of the kernel. Notice

1. The form and position of the embryo.
2. Around this the white, oily endosperm. Draw.

IV. Remove the embryo and examine under a good lens. How do the two ends differ? How many cotyledons are there?

V. Write a complete description. In what important particulars does the seed of the pine differ from those previously studied?

PHYSIOLOGY OF SEEDS.

Storage of Food.

I. Cut through one of the cotyledons of a common bean and scrape the exposed surface lightly with the

[1] Cf. Arthur, Barnes, and Coulter, *Plant Dissection*, pp. 179, 180.

point of a knife. Mount in water a very small portion of the powder thus obtained, and examine under a compound microscope, first with the low, and afterward with the high power.

1. Numerous minute bodies are seen in the field of the microscope. These are grains of bean **starch.**[1] Are they all of the same size? Of the same shape? Draw two or three of them.
2. Focus carefully and study their structure. Are they homogeneous? Compare different specimens in regard to this point.
3. Run a small drop of iodine solution under the cover glass and observe the effect. Notice from the outside how far the reagent has advanced, then examine that part of the slide under the microscope, and see how differently the starch granules look after the iodine has acted upon them.

II. Mount in the same way a bit of wheat flour taken from the inside of a grain of wheat.

1. How do the starch grains compare with those of the bean in form, size, and structure? Are the grains of wheat starch of uniform size?
2. Touch the cover glass lightly with a needle until some of the largest grains roll over. What is their shape? Draw a few grains in different positions so as to represent what you find to be characteristic.
3. Test with iodine solution.

III. Examine corn starch obtained in the same way from a grain of Indian corn.

[1] Useful suggestions for the microscopical examination of starch are given by Strasburger, *Practical Botany*, pp. 4–15.

1. Compare the grains of corn starch with those of the bean and wheat. Draw.
2. Test with iodine solution.

IV. Cut a grain of oats in two, obtain some of the starch as directed in the preceding cases, and examine microscopically. The compound grains of starch present a widely different appearance from the simple ones of Indian corn, wheat, and beans. Study their structure carefully, and draw one or more. Test with iodine.

From this and preceding observations what do you conclude in regard to the usual form and structure of starch? What as to its reaction with iodine?

V. Cut a sunflower akene in two, and remove a small portion of the endosperm. Mount in water and apply slight pressure to the cover glass. Under the compound microscope numerous highly refractive drops of oil will be seen coming out of the broken tissue. Focus carefully on an oil drop, and observe its sharply defined border. What changes does it undergo as the focus is altered?

Various other oily seeds, such as those of the squash, tomato, pine, English walnut, etc., may be studied in the same way. Enough of these should be examined to ensure familiarity on the part of the student with the appearance of fatty oil under the microscope.

VI. Soak a date seed in water a day or more until it can be cut easily. Pare off a portion of it with a knife or scalpel, so as to expose a smooth, even surface, and then with a razor make extremely delicate sections of the endosperm. Mount some of these in glycerine, and others in Schulze's solution. Microscopic examination shows that the date seed consists chiefly of the greatly thickened walls of the cells that compose its substance. Watch the action of Schulze's solution. The blue color that presently appears indicates **cellulose.**

VII. Examine similar sections of a coffee seed prepared and mounted in the same way. Notice how the cell walls differ from those of the date seed.

VIII. Remove the testa of a castor oil seed, and cut a few thin sections from the endosperm. Mount in pure glycerine, and examine with the high power.

1. The sections show (best on the edges where they are very thin) the cells of the endosperm filled with numerous rounded bodies. These are **aleurone grains.** They are of frequent occurrence in oily seeds, and constitute an important food substance.
2. Draw a cell with its contents. Examine the aleurone grains closely, and see if you can detect any structure. The small rounded body most frequently seen at one end of the aleurone grain is called a **globoid.**
3. Run a drop of water under the cover glass and watch the effect. Some of the aleurone grains presently show, besides the rounded globoid, an angular **crystalloid.**

   Draw again a cell with its contents so as to show the changes that have taken place.
4. After the water has had sufficient time to act on the cell contents, it is evident that they are becoming disorganized, and drops of oil are seen to have passed out of the section.

NOTE. — It is important that all of these features should be satisfactorily made out before proceeding farther. It may be necessary to prepare a considerable number of slides, and possibly will require several hours. The essential fact is that in the castor oil seed two sorts of food are stored: one non-nitrogenous, in the form of fatty oil; the other nitrogenous, in the form of aleurone. We shall find the same association of nitrogenous and non-nitrogenous food substances in other seeds.

IX. Prepare sections of the endosperm of a flax seed, and, as before, examine some in glycerine and others in water. How do the aleurone grains compare in size, form, and structure with those of the castor oil seed?[1]

X. Make a transverse section of a grain of wheat that has lain in water a few hours, cutting it in such a way that the section will show the coats of the grain and a portion of the endosperm. Mount in water. Notice

1. The large cells making up most of the endosperm. What do they contain?
2. Outside of these a layer of cells, rectangular in section, containing aleurone.
3. The behavior of the substances contained in the different cells when iodine is applied. Draw a portion of the section.
4. The arrangements for protection of the embryo, together with its food supply, by means of the united fruit and seed-coats. [The former consists of several layers of cells with strongly thickened walls, the latter of two very thin layers immediately outside the cells that contain aleurone. Tangential sections treated with sulphuric acid, compared with the transverse sections, will make the structure plain.]

XI. Record in full what you have ascertained regarding reserve materials and their storage in seeds. What are the different kinds of non-nitrogenous food substances thus

[1] Cf. Frank, *Lehrbuch der Pflanzenphysiologie*, p. 158.

far met with? How are they recognized? Mention cases where you have found them associated with aleurone.[1]

Protection.

I. Examine an orange with reference to the protection of the embryos. Make a transverse section of the fruit, and note carefully all the protective arrangements.

II. Study an apple in the same way.

III. Compare a number of commercial "nuts"; *e.g.* almond, chestnut, peanut, hickory nut, Brazil nut. Which are the most effectually protected? How do they compare with other fruits in this respect?

IV. Make a transverse section of a grain of Indian corn and examine the pericarp microscopically. Notice the multiplication of thick-walled cells and their arrangement. Draw.

V. After observing as many other seeds as are obtainable, summarize your observations of the ways in which the embryo is protected against mechanical injuries, wetting, destruction by animals, attacks of fungi, etc. Are any that you have examined poorly protected?[2]

Dispersal.

I. Examine the seeds of common milkweed, *Asclepias Cornuti*, Decaisne. Compare those of the trumpet creeper, *Tecoma radicans*, Juss. Make an outline sketch of both.

II. Study as many as can be obtained of the following: Seeds of willow or poplar; fruits of elm, birch, maple, ash, clematis, hop tree, *Ptelea*, iron-wood, *Ostrya* or *Carpi-*

[1] Cf. Sachs, *Physiology of Plants*, pp. 323–340.

[2] Cf. De Candolle, *Origin of Cultivated Plants*, p. 395.

nus, thistle, dandelion, wild lettuce, cotton grass, *Eriophorum.*

In the air of a still room see whether any of these fall perpendicularly from a height of a few feet. What is the case when the air is disturbed by fanning?

III. Examine the fruits belonging to some or all of the following genera: Agrimonia, Geum, Desmodium, Circæa, Galium, Lappa, Xanthium, Echinospermum, Cynoglossum, Bidens, Cenchrus.

Describe the various appendages and compare them as to their efficiency.

By means of a thread suspend weights to one of the hooked appendages of the burdock and ascertain how great a weight the hook will bear.

IV. Write out a list of fruits attractive to animals, taking care to include only such as you have yourself observed.

V. Discuss any other arrangements for dispersal of seeds with which you are familiar. Read one or more of the references given below.[1]

RELATIONSHIPS INDICATED BY SEEDS.

I. Examine seeds of mustard, radish, cabbage, and other cruciferous plants, comparing them with reference to their form and size, form and position of the embryo, nature of reserve material, and other points of difference and resemblance. The study will be facilitated by comparing seeds that have been planted two or three days.

[1] Darwin, *Origin of Species*, Chap. XII; Lyell, *Principles of Geology*, Vol. II, Chap. XL; Hill, *Am. Nat.*, 1883, pp. 811, 1028; Hildebrand, *Verbreitungsmittel der Pflanzen;* Wallace, *Darwinism.*

Draw and describe the various parts of some of the different seeds.

II. Compare in the same way peas, beans, lima bean, lupine, and peanut. Are they essentially alike in structure? Mention points of difference.

III. Compare seeds of squash, pumpkin, watermelon, muskmelon, cucumber, and gourd.

IV. Compare seeds of tomato, egg plant, pepper, stramonium, and hyoscyamus.

V. Compare the seed-like fruits of sunflower, dandelion, thistle, lettuce, and salsify.

In all the groups thus studied ascertain whether the seeds are more alike than different. Sections should be made and drawings introduced wherever they are needed to render the descriptions more intelligible. Some of the groups may be omitted if necessary, but the observations should be thorough and complete as far as they are carried.

SPECIAL STUDIES.[1]

I. Polyembryony in the genus Citrus. This requires an extended comparison of seeds of different varieties of orange, lemon, and other citrus fruits.

II. Arillate seeds. A study of the seeds of *Celastrus scandens* and other arillate species.

III. Relation of the embryo to the reserve material. Arrangements that favor a prompt supply of food

[1] A few subjects for special study are given in connection with this and other exercises simply as examples of many that will naturally suggest themselves. In most cases the studies suggested require independent investigation, while others, such for example as number IV, give opportunity for reading and reporting on papers of special interest, particularly those in recent periodical literature.

to the embryo in early stages of germination. Cf. Haberlandt, *Physiologische Pflanzenanatomie*, p. 288 *et seq*.

IV. Peculiar cases of plant dissemination. Cf. Berthoud, *Botanical Gazette*, XVII (1892), p. 321.

V. Identification of species by means of seeds. An interesting application will be found in the determination of weed seeds of frequent occurrence in grass and clover seed. Cf. Beal, *Grasses of North America*, I, p. 215.

REVIEW AND SUMMARY.

The seeds we have studied have been selected from three great classes of plants. To the first class belong the bean, castor oil, and other plants, the seeds of which have two cotyledons; to the second, wheat, Indian corn, and, in general, all plants with one cotyledon; and to the third, pines and their allies, many of which have more than two cotyledons. The distinctions between these classes are in many respects fundamental, so that an examination of the seed of a given plant is generally sufficient to enable us to determine its class in the vegetable kingdom.[1]

Furthermore, we have found that there are more restricted groups of plants, called families, the seeds of which are in many cases, though not in all, so nearly identical in structure as to indicate at once their family relationship. The squash, melon, and cucumber belong to one of these families; the tomato, egg plant, and stramonium to another, and so on. We conclude, therefore,

[1] Seedless or "cryptogamic" plants will be studied later. What is said in the present chapter and those immediately following applies to the higher or seed-bearing plants, including Gymnosperms.

that the structure of seeds is an important factor in the determination of relationship.[1]

This being the case, it becomes necessary to formulate certain general conceptions of form and structure, and to adopt descriptive language by which they may be expressed with clearness.[2]

Morphology of seeds.

The essential parts of a seed are the protective coats and the embryo with its store of food. The seed-coats commonly show a division into an external, hard, often colored, layer, the testa, and an internal, more delicate one, the endopleura; the former term, however, is frequently employed to designate the coats collectively. In many species the endopleura is wanting. Externally the testa may be smooth and polished, as is the case with the seed of the castor oil plant, or it may be covered with hairs, as cotton seeds are, or, again, it may be extended into a wing, like that belonging to the seeds of the catalpa, and various other modifications may occur, having, as a rule, a direct relation to protection or dissemination. An additional coat, usually colored and fleshy, known as the aril, is rarely present.

Seed-coats.

The parts of the embryo are the radicle, cotyledons, and plumule. As we have seen, it may have one, two, or several cotyledons, and accordingly is said to be monocotyledonous, dicotyledonous, or polycotyledonous. The embryo varies greatly in different species as regards form, position, and size, being straight or curved; occupying the whole space within the seed-coats, or only a small portion of it; the cotyledons alike or dif-

Embryo.

[1] See, for example, Rowlee, *Bulletin of the Torrey Botanical Club*, XX (1893), p. 1, and Rolfs, *Botanical Gazette*, XVII (1892), p. 33.

[2] For a more extended treatment of the morphology of seeds cf. Gray, *Structural Botany*.

fering in size or shape, and so on;[1] but these peculiarities are generally constant and characteristic in the species, or group of species, in which they occur. Whatever the form and position of the embryo, the radicle points towards the micropyle.

Endosperm.

Food materials of various kinds are stored up for the use of the plantlet during germination. If the tissue containing such reserve materials surrounds the embryo, it is called the endosperm, or, using an old phraseology, the seed is said to be albuminous. If, on the contrary, the reserve materials are stored within the embryo itself, even if they are of precisely the same nature, the seed is said to be without endosperm, or exalbuminous.[2] The terms are not well chosen, but have become so fixed as to render it necessary to recognize them.

Hilum, raphe, chalaza, micropyle.

Certain structural peculiarities are intimately connected with the developmental history of seeds. They are attached to the mother plant by a minute stalk through which nutritive materials are conveyed during their period of growth, but from which they break away at maturity, leaving a scar called the hilum, such as is plainly seen on the common bean. From the hilum, in the great majority of cases, extends a fine, fibrous bundle, the raphe, like that of the castor oil seed, either the entire length of the seed, or for a shorter distance, ending in a point, the so-called chalaza, where the seed coats cohere with each other and with the parts within. The raphe is simply a continuation of the stalk through which food materials were carried to the developing seed, the chalaza being the point where the materials

[1] Cf. Lubbock, *Seedlings.*

[2] For the rare cases in which a distinction must be made between endosperm and perisperm, see Gray, *Structural Botany,* p. 310.

were distributed to the interior of the seed. The hilum is in almost all cases a conspicuous feature, readily seen by the unaided eye, or with the help of a lens. The chalaza and raphe, on the contrary, are frequently obscured by the growth of the seed-coats. The micropyle is the opening between the seed-coats, readily seen in early stages of development, but often not easily recognized from the outside of the mature seed. Its position is most readily determined by opening the seed and finding the radicle, which, as already said, points toward the micropyle.

Form as determined by direction of growth.

The form of the seed is also determined largely by the direction of growth of the ovule. In the majority of cases, of which the castor oil seed is a good example, the developing ovule turns upon its longitudinal axis in such a way as to take an inverted position, so that in the mature seed the hilum and micropyle are close together, the chalaza at the opposite end, and the raphe running the whole length of the seed. Such seeds are said to be anatropous. Others, as, for example, the seeds of stramonium, are simply much curved, bringing both chalaza and micropyle near the hilum, one on either side of it. This is the so-called campylotropous form. In comparatively few species, of which buckwheat is an example, the axis of the ovule remains straight throughout its development, and the seed is said to be orthotropous. Modifications, particularly of the first and second forms, are of frequent occurrence. Cf. Gray, *Structural Botany*, pp. 278, 279.

Physiological adaptations.

Physiologically, seeds present many points of interest. The arrangements for dispersal, for protection, and for the support of the embryo in germination are among the most important.

A species generally has a better chance of survival if the seeds are conveyed to some distance from the plant on which they are produced. By this means they are less likely to come into as close competition with each other as if they grew up together around the parent plant; they are also brought into other conditions of soil and surroundings, and the chances for cross-fertilization are greater, which, as we shall see, is often a marked advantage. Accordingly it is found that a variety of structures exist that are directly adapted to the dissemination of seeds. Thus many seeds are distributed by the action of the wind. These are most frequently light in weight and provided with appendages in the form of wings or hairs, such as those of the catalpa, poplar, milkweed, and many others. Seeds distributed by animals are often concealed within brightly colored or otherwise attractive fruits; in other cases they are provided with hooks or other appendages by which they become attached to the wool or hair of various animals, and the seeds of many water-loving plants are carried in the mud that adheres to the feet of aquatic birds. The seeds of still others are washed by oceanic currents to the shores of distant islands or continents, and, finally, the agency of man, both intentional and unintentional, becomes a potent factor in the distribution of plants.

Dispersal.

By these and other agencies the forms that constitute the vegetation of the earth have come to occupy the places in which we now find them, and it becomes for every species that we meet a fascinating and often intricate problem to endeavor to ascertain how it came to be where it is.

Protection.

It is plain that from the time they leave the mother plant to the time of germination, seeds are exposed to numerous dangers, and that they require protection. This is afforded in part by the shape of the seed, most frequently a combination of strong arches, by which the danger of crushing is lessened; in part by the hard testa, which sometimes has a compact, polished exterior that resists the entrance of water and germs; and in some cases by bitter or otherwise distasteful substances stored up in the seed. In addition to these means of protection the embryo is often securely packed in the midst of abundant endosperm, and not infrequently still other provision is made for its safety.

Reserve materials.

Microscopic examination of a seed shows the presence of one or more kinds of reserve materials. As a rule, starch, or some other non-nitrogeneous substance, is associated with aleurone or its equivalent, thus supplying all the essential food elements. Oil, as a condensed form of food, is largely employed in small seeds and those that are transported by the wind, since by the use of this material greater lightness, volume for volume, is secured than if starch were employed. Cellulose takes the place of starch or oil in the date and some other seeds, which, as Haberlandt has pointed out, are in this way rendered less liable to decay and the attacks of animals during their long period of germination.[1] It is also seen upon the careful study of almost any seed that the reserve materials are so placed as to be ready for immediate use when wanted, either lying in the cells of the embryo itself or packed closely around it, and there brought into immediate relation with its absorbing tissue.

Other adaptations.

Still other physiological adaptations will be apparent as a greater number of seeds are examined and their structural peculiarities brought to light. As an example may be mentioned the fact that anatropous seeds by curving upon themselves during the early stages

[1] *Physiologische Pflanzenanatomie*, p. 285 *et seq.*

of their development bring the micropyle into such a position as to favor the entrance of the pollen tube. Again, the hairy appendages of numerous achenia, such as those of the dandelion and related plants, are so placed as to bring the radicle on the lower side as the object alights on the surface of the ground.[1] Such adaptations are of so constant occurrence that the student can hardly fail to receive the impression, in general a correct one, that the simplest structural facts are likely to have some important physiological significance. On the other hand, there are numerous cases of "accidental" peculiarities, for which no reason is manifest, and which at present are not explained.

[1] Cf. Rowlee, *l.c.*

II. GROWTH OF PLANTS FROM THE SEED.

MATERIAL REQUIRED.

Seedlings of the common bean, pea, sunflower, white mustard, flax, and hemp, from one to four weeks old.[1]
Seedlings of Indian corn and wheat of various ages.
Pine seedlings from a few weeks to a few months old.
Seeds of squash and other cucurbits in early stages of germination.

I. Take seedlings of different ages of the plants named in the first list above. Wash the roots and let them stand in a dish of water to prevent drying. Compare them and satisfy yourself as to the following points:

1. Do they all have a **taproot?**
2. Do they all have a **hypocotyl**, *i.e.* a stem supporting the cotyledons?
3. How do the cotyledons of the different plants differ
   a. As to form and size?
   b. In function? Have any of them wholly lost their function as foliage leaves? Are there any apparently transitional forms, as if this function were partially lost?
4. How does the pea differ from the sunflower in the time of unfolding the proper foliage leaves? Can

[1] The seeds should be sown at intervals of a few days, some in sand, others in moist (not wet) sawdust, and still others on folds of damp blotting paper under a bell-jar. There should be three or four lots of as many different ages. Pine seedlings, which are rather difficult to raise, may be obtained from nurseries.

you suggest any reason for this difference? How do the other seedlings compare in this respect?

II. Compare the seedlings of Indian corn and wheat that have attained the height of several inches.

1. Describe the cotyledon. Has it undergone any change during the process of germination?[1]
2. Is there a taproot?
3. Mention all the points in which the two plants are alike; those in which they differ.

III. Compare the seedlings of the Indian corn and wheat with those of the pea, bean, etc., previously studied. Point out all the essential differences, noting especially

1. Number of cotyledons.
2. Venation of foliage leaves.
3. Position and form of leaves.
4. Presence or absence of a persistent taproot.

IV. Examine seedlings of the white pine or other species of pine. In what important feature do they differ from any of the young plants thus far studied?

V. Summarize your observations and show how the class to which a plant belongs may be determined by inspection of the seedling.[2]

VI. Comparing the seedlings of different dicotyledonous plants (beans, sunflower, etc.), ascertain whether any of them have the two cotyledons unlike in size or shape. Is there anything to indicate that the form of the embryo is determined by that of the seed?[3]

[1] The protective sheath is regarded as a part of the cotyledon, while the other part, the scutellum, remains in the grain. Cf. Lubbock, *Seedlings*, II, p. 587.

[2] Cf. Gray, *Structural Botany*, Chap. II.

[3] Lubbock, *Seedlings*, I, pp. 30–34, 75–77.

VII. Notice the way the different seedlings break through the ground. Do those of all the dicotyledonous plants behave alike? How do they compare with those of Indian corn and other monocotyledons?[1]

VIII. Examine seedlings of squash, melon, or cucumber, comparing specimens that are just rupturing the testa with older ones. Observe the position and structure of the "peg," and the way it aids in throwing off the seed-coats.[2]

IX. Ascertain whether direction of growth is affected by external conditions.

1. Compare mustard or other seedlings grown in the dark with others growing in front of a window.
2. Turn on their sides some of the pots with seedlings a few inches high, and after a day or two notice the result.
3. Observe the effect of slow change of position in neutralizing **geotropism** and **heliotropism**.[3]

X. Take up a seedling of wheat about two weeks old, and examine the grain.

1. Notice how it differs from a grain that has not sprouted.
2. Remove a small portion of the endosperm and examine under a high power of the microscope. Compare the starch grains with those of wheat that has not sprouted. What changes have taken place? Draw some of the grains that show "corrosion."

[1] Darwin, *Power of Movement in Plants*, p. 77 *et seq.*

[2] Darwin, *l.c.*, p. 102.

[3] For this purpose an instrument known as a klinostat is employed. Cf. Goodale, *Physiological Botany*, p. 408; Sachs, *Physiology of Plants*, p. 684. Less expensive apparatus is easily devised.

3. Examine in the same way starch from the endosperm of a corn seedling that has attained several inches in height.

XI. Write a detailed account of the phenomena of germination as far as you have observed them.

SPECIAL STUDIES.

I. How seedlings break through the ground. A further comparison, including the study of as many species as practicable.

II. Results of planting certain seeds wrong side up.[1]

III. Results of removal of cotyledons at an early stage of growth.

IV. Whether detached embryos are capable of germination.

V. Conditions most favorable to germination.

VI. Length of time that seeds retain their vitality.

VII. How far seedlings of the same family are alike in structure and habits.

VIII. Changes capable of demonstration under the microscope that take place in reserve materials during germination.

REVIEW AND SUMMARY.

In our study of seedlings we have found that the same parts are present that were observed in the seed, but marked changes have taken place in size, position, texture, and other particulars. The distinctive features of the

[1] Cf. Darwin, *l.c.*, pp. 103, 104.

great classes, however, are as strongly marked as they were in the seed, and each class exhibits in its seedlings characteristic, though not always distinctive, habits.

Dicotyledonous seedlings.

The radicle of dicotyledonous seedlings elongates and extends downwards as the primary root, and at the same time in most species grows upward, forming the "hypocotyl," at the upper extremity of which the cotyledons are borne. In some species, as in the pea, the hypocotyl is wanting, or is extremely short, the cotyledons remaining in the ground instead of being lifted into the air. In such cases a rapid development of the "epicotyl," or first internode of the plumule, takes place, thus securing to the young leaves as they unfold full exposure to air and light. The hypocotyl (or, if this is wanting, the epicotyl) breaks through the ground in the form of an arch, an arrangement for the protection of the delicate growing point.[1]

Monocotyledonous seedlings.

Monocotyledonous seedlings exhibit considerable variety among themselves, although several pretty distinct types may be recognized. In the grasses the scutellum, which represents a part of the cotyledon, remains enclosed in the grain, and the straight plumule is erect, instead of arched, as it breaks through the ground. In many other species, as for example the date palm, a peculiar modification of this mode of germination is seen. As before, a part of the cotyledon remains in the seed as an organ of absorption, but the other end elongates and grows downward, forming a sheath from which the first leaf afterward emerges.[2] A more or less conspicuous primary root may be present, as in Indian

[1] Cf. Darwin, *Power of Movement in Plants*, pp. 87, 88.

[2] See figures of palm seedling, Goebel, *Classification and Special Morphology of Plants*, p. 432.

corn, or it may be hardly distinguishable from the secondary roots, as is the case with wheat.

Seedlings of gymnosperms.

Seedlings of pines and their allies (gymnosperms), aside from the fact that many species have more than two cotyledons, can hardly be said to possess characters specially distinctive of their class. In many cases the testa is carried up on the tips of the cotyledons, and afterwards thrown off by their bulging outwards. In some species the cotyledons remain under ground.

Cotyledons and their modifications.

Cotyledons, as a rule, perform functions widely different from those of ordinary green leaves, and accordingly present striking modifications of form and structure. While in some cases they unfold and deport themselves as foliage leaves, in others, as for example the pea and acorn, they have lost nearly all resemblance to leaves, and serve merely as storehouses of reserve materials; while in still other cases, as in the grain of corn or wheat, the cotyledon becomes largely an organ of absorption. Interesting transitional forms are seen in the common bean and other plants in which the cotyledons rise above the surface and turn green, but soon dry up after their reserve materials are exhausted. The embryos of some dicotyledonous plants produce but one cotyledon, the other being rudimentary. A curious instance is that of the orange, in the seed of which several embryos are formed with cotyledons varying greatly in size. In various species of cacti both cotyledons are rudimentary, being represented by minute bodies only a millimeter or two in diameter. In the latter case the radicle is thickened and serves as a storehouse, the cotyledons become superfluous, and are finally reduced to insignificant appendages, an illustration "of the principle of compensation or balancement of growth, or, as Goethe expresses it, 'in order to spend on one side, Nature is forced to economize on the other side.'"[1] A considerable number of seeds, notably those of certain plants belonging to the mustard family, have one cotyledon larger than the other, an arrangement naturally following the way the embryo is packed in the seed. These and various other peculiarities may be seen in the embryo before germination, but are more pronounced in the young seedling.

During germination the reserve materials stored in or around the embryo are drawn upon for the sustenance of the seedling. Microscopic examination of the endosperm of a grain of wheat or Indian corn, after the seedling is well started, shows that the starch granules have undergone remarkable changes due to the action of a ferment that gradually dissolves them. Other reserve materials, such as oil, aleurone, etc., undergo similar changes, by which they are fitted for absorption, but these are too complicated to be discussed in an elementary work. Those interested in the chemistry of germination should consult Sachs, *Physiology of Plants*, and later articles in various botanical periodicals.

Changes in reserve materials.

Certain external conditions are essential to germination. Of these the most important are (1) a suitable amount of water, (2) proper temperature, and (3) access of oxygen. Simple experiments are easily conducted to establish these facts, which are also, in part, matters of familiar observation. Thus when a crop of grain has been sown it is well understood that it will not come up if the earth is too dry, and that it is more likely to decay in the ground than to germinate if it is too wet,

Conditions of germination.

[1] Cf. Darwin, *Power of Movement in Plants*, pp. 94, 98; Lubbock, *Seedlings*, II, p. 6.

and careful experiments go to show that seeds sprout more promptly and surely with a less amount of water than is commonly supplied in artificial cultures. Too high or too low a temperature is equally unfavorable, although there is a pretty wide range within which most seeds will germinate. An even temperature is found to be more favorable to prompt germination than a variable one. Finally, if oxygen is excluded, even if all other conditions are fulfilled, germination fails to take place. It is for the purpose of securing an abundant supply of oxygen that we leave the sawdust lying up loosely, rather than closely packed, about the seeds, when we are raising seedlings in the laboratory. For the same reason, a light, loose soil is more favorable for gardening than a compact and heavy one. These conditions are well known, and are taken into account in practical operations, although a comparison of different seeds during germination establishes the equally important fact that both individual and specific peculiarities exist. Some seeds require more moisture than others, and the degree of temperature most suitable for germination varies with different species, and so on. An interesting series of experiments on the conditions of germination and the individual peculiarities just referred to has been carried out at the Cornell University Experiment Station. For an account of these, see *Science*, XIV (1889), p. 88.

Attendant phenomena.

Some of the phenomena connected with germination are of much interest and are easily observed. The first step consists in the forcible absorption of water, manifested by the great increase in size of germinating seeds, and the pressure they exert if an attempt is made to confine them in a closed vessel. Testing with a thermometer shows that the process of germination is accompanied by a rise of temperature, and chemical examination indicates absorption of oxygen and exhalation of carbon dioxide; in other words, respiration is going on.

Duration of vitality.

The length of time during which seeds retain their vitality has been the subject of much discussion. Stories, frequently repeated, of the growth of grain many centuries old, taken from Egyptian tombs, and of raspberry seeds from a Roman skeleton in England, etc., are generally discredited, for the reason that sufficient proof is lacking. On the other hand, a series of experiments, conducted for a long period by a committee of the British Association for the advancement of science, shows that some seeds have certainly retained their capacity for germination from twenty to forty years, and even longer.[1]

[1] Report of British Association, 1857, Dublin meeting.

III. THE ROOT.

MATERIAL REQUIRED.

Roots of Indian corn and other seedlings used in the preceding exercise.
The lower parts of a fully grown corn-stalk, showing the supporting roots.
Aërial roots of English ivy, or trumpet-creeper.
Turnips and other fleshy roots from the market.
Slips of Verbena, Tradescantia, and other common conservatory plants.

I. Examine more in detail the roots of seedlings already studied.

1. Taking specimens of Indian corn of different ages, note
   a. Where the secondary roots arise.
   b. Whether any of them have given rise to roots of a higher order.
   c. How they compare in these particulars with those of wheat.
2. Compare the roots of the sunflower, bean, and pea with reference to the same points.

II. Study the root-hairs of various seedlings, beginning with some that are growing on blotting paper.

1. On what parts of the roots are they produced?
2. Remove, with a pair of fine forceps, a portion of a root where it is thickly covered with root-hairs.

(The roots of wheat or oat seedlings are excellent for this purpose.) Mount in water, taking care not to injure the delicate tissue by undue pressure. Examine under a high power of the compound microscope.

a. Observe the structure of the root-hairs.

b. Ascertain how they are connected with the body of the root. Draw.

c. Run iodine solution under the cover glass, and watch the effect. What do you infer as to the permeability of the cell membrane and the capacity of the cell contents for absorption?

3. Pull up a specimen that has grown in clean sand. Shake off as many of the adherent particles as possible. Examine under a good lens. It will be seen that many grains of sand still remain attached. Ascertain whether this is due in any way to the presence of root-hairs.

III. Cut off the tips of some of the fine roots of wheat or oats grown under a bell-jar. Mount in water, and examine with the compound microscope. Select a good specimen, and draw the end carefully so as to show the root-cap.

IV. Determine in what part of the root increase in length takes place. Use for this purpose roots of Indian corn, peas, or sunflower, growing on moist blotting paper under a bell-jar. With a camel's-hair brush and india ink make a series of marks at intervals of a millimeter, beginning at the apex of the root. Replace the bell-jar, and ascertain by subsequent observations, about a day apart, where elongation has taken place.

V. Determine the direction naturally taken by roots.

1. Pull up beans or peas that have been growing in sawdust, and observe the entire root system. How do the secondary roots compare with the primary in their direction of growth? If roots of a higher order have been formed, ascertain whether they take the same direction as either of the preceding. Would it be advantageous for the plant if all grew downward?
2. Take a germinating pea or squash seed, with a radicle a centimeter or more in length, and fasten it to a cork by a pin so that the radicle will point horizontally. Keep it in a moist atmosphere under a bell-jar, and exclude the light by covering with a dark cloth. Observe the subsequent growth of the radicle. Vary the experiment by turning other specimens so that the radicle will point nearly vertically.
3. Tie a piece of netting over the mouth of a beaker or wide-mouthed bottle filled with water, and place on it a number of seeds of white mustard that have just begun to germinate. Allow the apparatus to stand in front of a window without being disturbed, filling with water occasionally, so that the growth of the seedlings will be uninterrupted. Observe the direction taken by the roots.

VI. Examine different roots with reference to their mechanical functions.

1. The supporting roots of Indian corn. Notice where they originate, their direction of growth, and their double action as braces and guys.
2. Aërial roots of the English ivy, or trumpet-creeper. Compare these with ordinary roots.

3. Examine under a lens the structure of a blackberry root, or that of some other common woody plant. Cut a transverse section, and notice the position of the wood elements. Compare this with their arrangement in the stem. A little reflection will show that the arrangement of the mechanical elements corresponds with the very different conditions that obtain in root and stem. The former must be so constructed as to resist a force that tends to pull it out of the ground; in the latter, on the other hand, resistance to a lateral and vertical force must be provided for.[1]

Other roots should be examined in the same way. Those of Indian corn seedlings will be found useful.

VII. Compare fully grown turnips and carrots, radish, or salsify with the roots of seedlings of the same plants. What changes of form and structure have they undergone?

VIII. Study the formation of adventitious roots, as seen in Verbena and other plants, grown by florists from slips. Adventitious roots of Tradescantia can be obtained by placing a fresh branch in a closed bottle so that the cut end will stand in a little water at the bottom.

SPECIAL STUDIES.

I. Protection of the growing point of the root. A number of water plants furnish excellent material for microscopic study of the root-cap. Among them are *Lemna minor*, common everywhere in stagnant waters, and *Pontederia crassipes*, frequently grown in artificial ponds. Certain aërial

[1] Cf. Haberlandt, *Physiologische Pflanzenanatomie*, p. 125 *et seq.*

roots, as those of Pandanus, commonly cultivated in conservatories, also have remarkably developed root-caps.

II. Conditions affecting the formation of root-hairs. An interesting investigation is suggested by Haberlandt, *Physiologische Pflanzenanatomie*, p. 147 *et seq.*

III. Propagation of plants by slips and cuttings. Ascertain what plants are regularly propagated in this way by florists and what conditions are necessary.

IV. Reserve materials stored in roots. Examination of the blackberry, elecampane, and other roots, to determine the nature of the food substances contained in them.

V. Influence of moisture on the direction taken by roots. "Search for water" by roots of trees.

VI. Minute anatomy of roots. (This may be deferred with advantage until the stem is studied microscopically.)

VII. Estimate of the total length of the root system of some common plants. Johnson, *How Crops Grow*, p. 242.

VIII. Roots of parasites. Sections of roots of Comandra or mistletoe, with a study of their relation to the plants on which they have fastened.

REVIEW AND SUMMARY.

Roots function as organs of absorption, as storehouses of reserve materials, and as a mechanical means of holding the plant firmly in its place.

As organs of absorption, it is essential that they should have a large extent of surface in contact with the soil. On pulling up seedlings of different sorts it is apparent that the total length of their roots is many times that of the aërial parts, and this is frequently still more striking when the earth is carefully washed away so as to expose the whole root system of older plants. The surface is further increased by the formation of root-hairs. These are delicate, elongated cells, arising from the roots back of their growing point, and so numerous under favorable conditions as to give them a densely hairy appearance, easily noticeable to the unaided eye. By their adhesive surface the root-hairs attach themselves closely to the particles of soil, and by means of acid excretions aid in preparing for absorption the crude food materials of the earth. These substances, in solution, are then taken up and carried to the parts within. It is, moreover, through the agency of the root-hairs that the enormous volume of water evaporated by the leaves of plants in full foliage is taken up from the soil and started on its upward course.[1]

Roots as organs of absorption.

The roots of many plants, particularly those that live more than a year, fulfil an important function as reservoirs of reserve materials upon which the plant draws when it begins anew its period of active growth. Suitable tests show that starch and sugar are the food substances most commonly stored in roots; inulin also occurs, though more rarely. These and other vegetable products are described in detail by Sachs in his *Physiology of Plants*. The shape taken by roots that serve as storehouses is sometimes quite characteristic. As examples

Roots as storehouses.

[1] Johnson, *How Crops Grow*, p. 243; Haberlandt, *Physiologische Pflanzenanatomie*, pp. 148, 149.

may be mentioned, the napiform roots of most turnips, the conical roots of carrot, salsify, etc., the moniliform roots of some pelargoniums, and so on.

Besides acting as organs of absorption and as storehouses of reserve materials, roots fulfil an important function in holding the plant firmly in its place. A study of the arrangement of their tissues shows a manifest adaptation to this function, the mechanical elements being placed compactly at the center, a position in which they are able to resist to the best advantage a pulling force that tends to break the root or draw it out of the ground. Such aërial roots as those of the poison ivy serve to hold the stem securely to some external support, and the prop roots of Indian corn that arise a little above the surface of the ground constitute an admirable system of braces and guys, by which the stalk, with its heavy load of ears, is enabled to maintain an erect position. Considering the size and weight attained by a single cornstalk with its fruit, and its exposure to heavy winds and rain, it is difficult to conceive of a more effective and, at the same time, more simple mechanical arrangement.

Mechanical functions.

In their mode of growth roots exhibit a remarkable adaptation to their environment. Growth in length takes place just behind the tip, which is thus free to turn in any direction, curving aside as it meets obstacles, and directing its way towards moisture or food, as occasion requires, without involving any disturbance of the older parts that have already become fixed in the soil. The growing point is covered by the root-cap, and thus protected from injury.

Mode of growth.

The primary root grows perpendicularly downwards, but the secondary roots, reacting differently to the pull of gravitation, grow down obliquely, while roots of a higher order extend indifferently in various directions. The result is such a distribution of the root system as to bring it into contact with the soil far more perfectly than if the roots grew down together in a common bundle. It has been noticed, however, that if the end of the primary root is destroyed one or more of the secondary roots near it grow vertically downward to take its place.[1]

Primary and secondary roots.

While the branches arising from the first or primary root are properly called secondary, the same term is also frequently applied to roots of a higher order, and is sometimes rather loosely extended to those given off by the stem and other parts of the plant. The latter, however, are commonly spoken of as adventitious. Aërial roots, such as those of the ivy and trumpet-creeper, properly fall under this head. Other adventitious roots are of great importance in the practical operations of florists and gardeners, enabling them to increase their stock by taking advantage of the capacity of slips and cuttings for promptly forming roots. The readiness with which cuttings of willows and poplars produce adventitious roots, together with their rapid growth, has led to their extensive planting in the western states, and many troublesome weeds owe their pertinacious hold on the soil to the same habit.

Adventitious roots.

In a comparatively small number of plants, of which the dodder is a familiar example, adventitious roots take the form of suckers which penetrate the tissues of other plants, on which they live as parasites. The plant thus attacked is called the host, from the relation in which it stands to its parasite. But few flowering

Parasitic habits.

[1] Darwin, *Power of Movement in Plants*, p. 196.

plants have become truly parasitic, the habit, as it occurs in the vegetable kingdom, being chiefly characteristic of fungi.

Minute anatomy.

In their microscopic structure roots exhibit essentially the same tissues and elements as are found in the stem, which we shall soon study in detail. There are, to be sure, certain differences of arrangement, already mentioned in connection with the mechanical function of roots, that cannot here be discussed at length. Those who wish to make a thorough study of the minute anatomy of roots will find the necessary assistance in such works as Strasburger's *Practical Botany* and De Bary's *Comparative Anatomy of the Phanerogams and Ferns*.

IV. THE STEM.

MATERIAL REQUIRED.

Fresh shoots of apple-tree, grape-vine, oak, elder, and basswood.
Stalks of Indian corn put up in alcohol after they have attained full size. Stems of common greenbrier, *Smilax rotundifolia*, L.
Shoots of white pine from one to three years old, preserved in alcohol. Similar specimens of arbor vitæ or of red cedar.
Specimens of white oak, hickory, ash, Norway spruce, palm, and other woods, showing transverse and longitudinal sections.
A collection of greenhouse plants, including rose geranium, primrose, Coleus, Tradescantia, and others.
Tendrils of grape-vine, spines of honey locust, common potato, and such other modified stems as are procurable.

STRUCTURE AND MODE OF GROWTH.

I. Study first the gross anatomy of a number of woody stems.

1. With a sharp knife make a transverse section of a one-year-old shoot of an apple-tree. Examine under a good lens, and draw an enlarged outline, showing the position and relative proportions of pith, wood, and bark.
2. Separate the bark into its three layers,
   a. External, **corky layer**.
   b. Middle, **green layer**, not sharply delimited from the
   c. Inner bark, or **bast**.

   Try the strength of these different parts by separating and pulling upon them.

3. Examine the wood closely. Notice the **medullary rays,** appearing like lines radiating from the pith. Careful inspection shows numerous openings in the wood between the medullary rays. These are the ends of vessels that convey water and air through the stem. It can also be observed that the pith is made up of minute cells. These structures may be seen still more readily in the grapevine.
4. With the stem of the apple-tree compare those of the grape-vine, common elder, and oak, making transverse sections, as before. In what respects do they all agree? How do they differ?

II. Examine the stem of Indian corn, making both transverse and longitudinal sections. What part of the stem has the firmest tissue?

Make an outline sketch of the transverse section, showing the position of the woody parts as they appear under a good lens. Compare with this a similar section of the stem of a palm or other monocotyledonous plant. Common greenbrier is suitable for this purpose.

III. Study shoots of white pine, two or three years old, that have lain some time in alcohol. Indicate by means of a diagram the relative position of pith, wood, and bark.

Using an older, dry specimen, that has been cut so as to show a smooth transverse section, notice the succession of **annual rings.** How does the outer edge of each ring differ from the inner? Determine the age by counting the number of rings. Examine the stem of the arbor vitæ or red cedar, and see if it corresponds in structure with that of the white pine.

IV. Write an account of the different stems you have studied. Show how the stem of a monocotyledon, such as Indian corn, differs from that of the apple-tree and other dicotyledonous plants. With which do the stems of the conifers (pine, arbor vitæ, etc.) agree?

V. Ascertain the age of specimens of white oak, hickory, ash, pine, and Norway spruce, by counting the annual rings. The work must be done with care, in order to insure accuracy. In examining large sections, draw a straight line from the center to the periphery, and mark off on it intervals of exactly one inch, beginning on the outside. Count the number of rings in each division and record them in their order. Compare the rapidity of growth of the pine and spruce; of the ash and hickory.[1]

MINUTE ANATOMY.

I. Take fresh shoots of the apple-tree, and cut a number of transverse sections. Mount some in water, others in glycerine, and still others in Schulze's solution for microscopic study.[2] Examine first with the low power. Taking the parts in order, beginning with the outside, we find

1. The outer bark, or **cork,** consisting of several layers of flattened cells with reddish-brown contents. (The remains of the epidermis outside of the cork may be disregarded.)
2. The middle bark, or **cortical parenchyma,** consisting of a broad zone of cells with green contents (chlorophyll). Near the inner edge of this zone are bundles of thick-walled elements, **bast fibers.** The

[1] Other species may of course be used if more convenient.

[2] The success of the work depends upon having good sections to study. Worthless ones must be thrown away, and sectioning continued until entirely satisfactory specimens are obtained.

latter are nearly colorless, their very small cavity showing as a dark point at the center.

3. The inner bark. This is best studied in stems four or five years old. It is composed of
   a. **Sieve-tubes,** narrow elements with light-colored walls.
   b. **Bast parenchyma,** much wider cells frequently containing chlorophyll.
   c. Bundles of **bast fibers** similar to those already described.
4. **Cambium.** In the winter a sharp line of demarcation between wood and bark is seen, but in spring there is formed a zone of fresh tissue known as the cambium, from the inner cells of which a new layer of wood is produced, and from the outer ones a new layer of bark. See VII below.
5. The wood. In this observe the following:
   a. **Vessels** with large openings.
   b. **Wood fibers,** smaller elements with narrow lumen and thick wall.
   c. **Wood parenchyma.** This is more easily made out on longitudinal section.
   d. **Medullary rays,** extending from the pith outwards and continuous with those of the inner bark.
6. Pith, consisting of very large cells marked by numerous pits.

II. Prepare next a number of radial longitudinal sections, mounting as directed above, and study in the same order, comparing them, step by step, with corresponding parts of the transverse sections.

1. Ascertain whether the cork cells present the same appearance on transverse and longitudinal sec-

tions, and in the same way compare the cells of the cortical parenchyma as seen in both.

2. Taking the inner bark next, the sieve-tubes are easily recognized by their narrowness and length, and also by their soft, light-colored walls, while the bast parenchyma consists of much shorter and wider cells. The medullary rays present a marked appearance, looking, on radial sections, like brick work.

3. Look for crystals of calcic oxalate, often found in considerable numbers in cells adjacent to the sieve-tubes.

4. The bast fibers are to be looked for in places corresponding to their position in the transverse section. They may or may not be found in some of the longitudinal sections. Why?

   When you have found them, note the points in which they differ from all the other elements of the bark.

5. Passing to the wood, the large pitted vessels are at once recognized. It is seen that they are composed of long cylindrical cells placed end to end, their dividing walls having been absorbed, or with only traces of them remaining, so that they form continuous ducts. The wood fibers also are greatly elongated, but are much narrower. Their walls are very thick and the ends tapering, fitting to each other so as to make a very compact and solid tissue.

   Notice whether the medullary rays present the same appearance in the wood as in the bark. Test the contents with iodine solution. Cells resembling those of the medullary rays, but extending lengthwise of the stem, will be found. These constitute the wood parenchyma.

6. The pith comes last, and presents no difficulties.
7. Having compared the two sections throughout, go over them again and see if all is clearly understood. Make yourself familiar with all the details of structure. Note what cells contain chlorophyll, where starch occurs, the action of Schulze's solution on different parts, whether the sieve-tubes show any peculiarities corresponding to their name, how the cork originates, the manifest resistance of the cork cells to reagents, and so on. Write a full account, and introduce drawings wherever they are required to make the description clear.
8. Finally cut tangential longitudinal sections, and compare with the preceding.

III. Stem of Indian corn. Cut thin transverse sections. Examine first with the low and afterwards with the high power. The following parts are seen:

1. The **epidermis** and sub-epidermal tissue, forming a continuous peripheral zone of thick-walled cells.
2. **Fibro-vascular bundles,** more numerous near the outside of the stem.
3. **Fundamental tissue,** consisting of large cells similar to those composing the pith of the apple-tree stem.

IV. To understand these parts it will be necessary to compare them carefully with the same structures as seen in longitudinal section. Accordingly, with both transverse and longitudinal sections on the slide, study each part in detail.

1. Observe the **epidermis** from both points of view. Draw a few cells.
2. The **fibro-vascular bundles** present a somewhat complicated structure. They are bounded externally

by strong bands of thick-walled cells, composing the so-called **bundle-sheath**, which may be continuous, or thinned out on the sides of the bundle.

The bundle itself presents two parts for study: first, the **xylem**, or wood, which includes the two conspicuous pitted vessels (recognized by their very large openings), and the parts immediately adjacent; and second, the **phloëm**, or bast portion, marked by the peculiar appearance of its elements on transverse section, its small cells being fitted in at the angles between larger ones in such a way as to give the effect of mosaic work.

Studying first the xylem, on both transverse and longitudinal sections, we find that it consists of

a. The large pitted **vessels** already noticed. Examine their structure carefully, observing particularly the remains of the partition walls in the form of heavy rings, indicating the origin of the vessels in rows of cells placed end to end. One or more smaller vessels lie between them, and a little nearer the center of the stem. One of these is conspicuously marked by heavy thickenings in the form of rings, and is called an annular vessel. Frequently the surrounding tissue is absorbed, leaving only the rings of the annular vessel to mark its place.

b. Thick-walled elements lying between the large pitted vessels.

c. Elements with thinner walls surrounding the annular vessel. Some of these, as already stated, have disappeared, leaving an irregular open space.

The two sorts of elements that compose the phloëm are easily recognized on both transverse and longitudinal sections.

a. The **sieve-tubes** are large, with nearly or quite transparent contents, and here and there a perforated transverse septum looking like a sieve.

b. The smaller cells placed at the angles of the sieve-tubes are the **cambiform**, or companion, cells. Their thicker contents, smaller diameter, and the absence of sieve-plates at once distinguish them from the preceding.

Having identified all the parts that have been named, study them closely, and after you have become perfectly familiar with the position and structure of the different elements, draw and describe them. Meantime, look for any additional features to which your attention has not thus far been specially directed. See if you can recognize the **protophloëm**, a small group of rather indistinct cells lying between the phloëm and the bundle-sheath.

Study, too, more carefully, the structure of the sieve-tubes. Try the effect of picric aniline blue on these and other parts of the bundle. Apply Schulze's solution to other sections, and phloroglucin (followed by hydrochloric acid) to still others, and note the results. What parts of the bundle are lignified? How about other parts of the stem?

3. The **fundamental tissue**. Examine the large cells composing the tissue, using both transverse and longitudinal sections. Ascertain whether the large cells of which it is made up present the same

appearance and structure in all parts of the stem. Test the contents for starch.

V. Having become acquainted with the minute anatomy of the stem, study it from a mechanical point of view, endeavoring to ascertain whether the thick-walled mechanical elements are grouped in such a way as to secure strength with economy of material. Notice the disposition of the heavy sub-epidermal tissue in a continuous hollow cylinder, the arrangement of the fibro-vascular bundles, and the way in which the elements composing the bundle-sheath are distributed.[1]

VI. Stem of white pine. The structure of the stem of conifers presents various interesting peculiarities, but the arrangement of the parts and mode of growth are nearly identical with those of dicotyledonous stems, and, moreover, have been so fully treated in a number of laboratory guides as to render it unnecessary to repeat directions for their study. The student is recommended, however, to carry out substantially the same plan of work on the stem of the white pine as is outlined in the section on the Scotch pine in Arthur, Barnes, and Coulter's *Plant Dissection.*

VII. Cambium. Nearly all woody species in temperate regions of the globe form distinct annual rings which mark the growth of the wood from year to year. In order to understand the process a study of the cambium should be made. Shoots of the white pine four or five years old are suitable for this purpose. They should be cut during the season of active growth, say from June to August, and placed in alcohol. If properly hardened, transverse sections may be obtained that show very perfectly the new wood and bark formed by the division of the delicate

[1] Cf. Strasburger, *Practical Botany*, p. 88, and footnote.

cambium cells. Test for lignin, and study the mode of development of the wood.[1]

PHYSIOLOGY OF THE STEM.

Protection.

I. Examine under a lens the stem of the cultivated verbena, primrose, and other plants from the greenhouse.

II. Mount portions of the epidermis of each in water, and examine with the compound microscope. Draw and describe the various epidermal appendages.

III. Make a careful study of the protective arrangements of the common thistle, teasel, honey locust, cactus, and blackberry. Ascertain the morphological character of their various protective structures.

IV. Examine various woody stems, such as those of the hickory and oak. Notice

1. The thickness of the bark.
2. How it accommodates itself to the growth of the tree.

V. Enumerate any other means that you have observed by which the stems of plants are protected.

Mechanical Support.

I. Study the arrangement of the wood elements of the stem of the common elder. Compare it with a stalk of wheat; with the stem of a palm. Is the material economically employed?

II. Make a transverse section of the stem of coleus. Examine with the low power of a compound microscope.

[1] In connection with his study of the structure of stems, the student should read Gray's *Structural Botany*, pp. 67–82.

Draw an outline sketch, locating the position of the mechanical elements.

III. Cut through an old tendril of a grape-vine. Notice the disposition of the wood elements. Test its strength.

IV. Study under the compound microscope the bast fibers of basswood and other common plants.

V. Write a brief account of what you have ascertained regarding the mechanical arrangements for the support of the plant. Read Goodale, *Physiological Botany*, pp. 188–194; Haberlandt, *Physiologische Pflanzenanatomie*, p. 96 *et seq.*

Transportation of Food in Solution.

I. Cut a short branch from a grape-vine. Immerse the cut end in a colored solution, such as red ink. After some time make transverse sections, and observe how far and through what parts of the stem the colored fluid has penetrated.[1]

II. Repeat the experiment, using a fresh leafy stem of Tradescantia for the purpose. Place finely powdered indigo in the water and allow the plant to be exposed to sunlight. This time take the precaution to cut the stem under water so as to prevent the entrance of air. If the cut is made slanting, and the whole operation skillfully performed, the particles of indigo can be seen under the compound microscope as they enter the vessels of the Tradescantia.

Storage of Food.

I. Cut a common potato in two. Make thin sections from the exposed surface, and examine with the compound

[1] On the ascent of water in woody plants, see H. Marshall Ward, *Timber and Some of its Diseases*, Chap. IV (Nature Series).

microscope. Draw one or two cells with their contents, taking care to show details of structure.

II. Examine in the same way sections from various other underground stems, such as ginger, mandrake, etc.

III. Prepare sections from pieces of a dahlia "tuber"[1] that have lain in commercial alcohol for some weeks. Draw a few cells, showing the peculiar sphere-crystals of inulin.

IV. In some stems, as, for example, an onion bulb, sugar is stored. This may be tested for in the way described by Strasburger, *Practical Botany*, p. 48.

MODIFIED STEMS.

I. Make a thorough study of the common potato, obtaining for the purpose a number of different varieties. What reasons are there for considering it a stem rather than a root? What are the "eyes"? Where are they most abundant? Are they all alike? Find where the potato was attached. Draw an outline and indicate by a dotted line the direction of growth in length. Does it ever branch? Cut a transverse section so that it will pass through a bud. Indicate in an outline sketch the position of pith, wood, and bark. Notice that the wood has been reduced to a minimum. It appears to the naked eye as a faint circular line.

Write a complete description, and discuss the morphology of the potato. See Gray, *Structural Botany*, p. 59.

II. Study a collection of other modified stems in the same way, endeavoring in each case to satisfy yourself as

[1] This is really a root, but on account of its convenience it is selected instead of a stem.

to every morphological feature. The following and a considerable number of additional species can usually be obtained, — some at the florist's, others at the grocery, and still others at the drug store: ginger, iris, geranium, onion, crocus, Solomon's seal, aconite, calamus. Fresh indigenous plants will furnish many more.

III. Examine specimens of as many of the following genera as are procurable, and discuss their morphology: Muhlenbeckia, Myrsiphyllum, Ruscus, Asparagus.

In such exercises, a hasty examination of external features is by no means sufficient. Every species taken in hand should be subjected to patient and thorough study. Some of those named present difficulties that are not likely to be overcome by a student who is unwilling to think.

GROWTH OF STEMS FROM BUDS.

I. Obtain, before they have opened in spring, well-developed buds of lilac, maple, hickory, horse-chestnut, Austrian pine, and other trees. Study them carefully with regard to protective arrangements, taking account of the structure and position of the bud-scales (imbricated like the shingles of a roof), waterproofing, hairs; in short, whatever appears to contribute to the protection of the parts within. What part of the bud is best protected?

II. Study next the arrangement of the parts composing the bud, taking first the buds of the lilac, and following with those of the horse-chestnut and other trees. Remove the bud-scales and undeveloped leaves in succession, and lay them in radiating rows, following the order in which they are placed in the bud.

Is the arrangement of the parts of the bud advantageous as regards economy of space? Does it present any other advantages?

Compare the last year's growth of the stem with the terminal bud, bearing in mind that "a bud is an undeveloped branch."

III. Examine all the marks on a horse-chestnut branch. Three kinds of scars are to be seen; namely, those left by the foliage leaves, by bud-scales, and by flower-clusters. Compare all these with each other and with what is seen in the terminal bud, until you are thoroughly familiar with the characters of the branch as they appear in the bud. Carry out a similar study with the buds and branches of other trees.[1]

IV. Place the cut ends of shoots of lilac, horse-chestnut, apple, etc., in water, the latter part of winter; keep them in a warm room, changing the water frequently, and observe the unfolding of the buds. Notice the first observable changes as well as those occurring in later stages. Record your observations in detail.

V. Compare the terminal buds of plants belonging to different genera, *e.g.* Acer, Carya, and Pinus, and determine whether each presents distinctive marks. Next, compare the buds of the red, and sugar maple, noting carefully all the differences. In the same way, compare the buds of Austrian, Scotch, and white pine, of the black walnut and butternut.

As opportunity offers, practice the identification of trees in winter by means of buds and other parts.[2]

[1] For an admirable study of the buds and branches of common trees, see Newell, *Outlines of Lessons in Botany*, Part I. Ginn & Co.

[2] Cf. Foerste, *Bot. Gaz.*, XVII (1892), p. 180.

REVIEW AND SUMMARY.

The stems of plants exhibit certain inherited peculiarities of form, structure, and habit. In some large families, the mints, for example, the stem is square; while in others, as the true sedges, it is triangular. The cylindrical form, however, which has important mechanical advantages in its favor, is most common. Characteristic habits, manifested in mode of growth or choice of surroundings, are also frequently met with. Thus, the family to which the morning-glory belongs is particularly distinguished by its climbing habit, the members of the water-lily family by their aquatic habits, and so on. Structural peculiarities are still more distinctive and far-reaching; so that, as a rule, we readily determine the class to which a plant belongs by ascertaining the arrangement of the tissues composing the stem.

Form, structure, and habit.

The texture of the stem, as determined by the nature of its elements, is often characteristic. Various families of plants, as those to which the maple, oak, and willow belong, have woody stems; while others, as the pink and violet families and many others, are herbaceous. The duration of the plant corresponds rather closely to the nature of the stem. Woody plants are perennial, living for an indefinite period, while herbaceous ones are commonly annual or biennial. These distinctions, however, are not to be pressed too far, since the texture of the stem is subject to much variation, even in the same species, and duration is greatly influenced by climatic conditions.

Texture and duration.

While typical stems are distinguished by the various characters already referred to, there are many others that have taken modified forms corresponding to special functions that they have assumed. Thus many stems, a large proportion of which are subterranean, serve chiefly as reservoirs of reserve materials, and in the course of time have undergone striking modifications both of form and structure. The tuber of the common potato shows all the essential characters of a dicotyledonous stem in the formation of buds, the concentric arrangement of pith, wood, and bark, and in still other respects, but the fibrous tissue has almost wholly disappeared, while the cellular tissue has increased to such an extent as to give the tuber the appearance of a monstrosity compared with the ordinary branches of the same plant. Quite as striking changes are seen in branches that have taken the form of spines and assumed the function of protection. Good examples of these are the spines of the hawthorn and other familiar plants. Even more remarkable modifications are presented in the leaf-like organs known as cladophylls. In the case of the so-called smilax of the greenhouses, the true leaves are inconspicuous scales, while the cladophylls so perfectly simulate foliage leaves as to deceive an inexperienced eye. Much caution is necessary in studying the morphology of these and other modified branches. Their position on the stem, structure, and mode of growth, and any tendency they may exhibit to become ordinary leaf-bearing shoots, are all to be taken into account.

Modified or derived forms.

In their anatomical structure and mode of growth, stems present well marked peculiarities, which, as already stated, are sufficiently characteristic to admit of the ready determination of the great class to which a plant belongs. The stems of a large proportion of monocotyledons are well represented by that of

Anatomical structure and mode of growth.

Indian corn. In this the fibro-vascular bundles are scattered through the fundamental tissue so that there is no manifest distinction of pith, wood, and bark, and both here and in other members of the same class certain mechanical arrangements of much interest present themselves. In the stem of Indian corn a strong cylindrical band of sclerenchyma is placed just beneath the epidermis, a disposition of the mechanical elements adapted to secure the greatest strength with the least amount of material; and the same principle is carried out in the bundles themselves, the sheaths of which are much thickened radially, thus aiding materially in preventing bending of the stem, and also protecting the vessels and other conducting elements.

Monocotyledons.

The stem of dicotyledons presents a rather more complicated structure. As seen in the apple shoot, which may be taken as a representative, the pith, wood, and bark are arranged concentrically. In the bark, as a rule, three layers may be distinguished, viz., outer bark or cork, middle bark or green layer, consisting chiefly of large cells containing chlorophyll and other materials, and inner bark or bast, characterized by the presence of sieve-tubes, usually with bast fibers and some parenchyma. Between the inner bark and wood is the cambium zone, which during the growing season is a layer of delicate cells, by the multiplication of which new wood and bark are produced. The wood consists of the large vessels, the openings of which are conspicuous on transverse section, wood fibers which constitute the greater part of its substance and give the wood its rigidity, and the medullary rays, to which in many species are added the wood-parenchyma cells. The pith consists of large cells which commonly present no distinctive

Dicotyledons.

peculiarities. Since each year, in temperate regions, the stems of dicotyledons add a new zone of wood, it is possible to determine the age of a tree by counting the number of annual rings. Not infrequently the record is obscured by irregular growth, due to drought and other causes, but in general these rings are clearly defined.

Gymnosperms.

In their mode of growth the stems of gymnosperms agree with those of dicotyledons, but their wood elements are peculiar, the wood being composed mainly of elongated cells called tracheids, the radial sides of which have numerous bordered pits, by means of which they communicate with each other and with the medullary rays.

Functions.

The structure of stems corresponds with a number of very important functions performed by the elements that compose them. Thus the epidermis, afterwards replaced by cork, is protective, as is also the bark, which on the trunks of most trees becomes greatly thickened with advancing age. The medullary rays and other parenchyma cells of wood and bark serve for storage of various food products, and are also employed to a considerable extent in conducting them from one part of the plant to another. Bast and wood fibers serve a special purpose as mechanical elements by which the stem is maintained in its position, and enabled to resist forces that tend to strain or fracture it. Finally the vessels and tracheids are chiefly concerned in conducting water containing mineral substances and air from the roots to the upper parts of the plant, while the sieve-tubes of the inner bark store up nitrogeneous food materials, and convey them to the points where they are needed.

It will, of course, be understood that an adequate account of the physiology of stems cannot possibly be condensed into such a summary statement as the foregoing; but it will at least serve to point out the important parts played by the various elements of the stem as they contribute, each its share, to the work of the whole. The mechanical system is treated at length by Haberlandt, *Physiologische Pflanzenanatomie*, pp. 96–143, and an extended review of the theories regarding the ascent of water in the trunks of tall trees is given by H. Marshall Ward, *Timber and Some of its Diseases*, Chap. IV.

V. THE LEAF.

MATERIAL REQUIRED.

Leaves of as many kinds as are procurable. See suggestions under "Systematic Description." Branches of basswood, elm, maple, and horse-chestnut. Leafy plants of primrose, fuchsia, dandelion, and geranium.

Leaves of hyacinth and English ivy.

Leaves of various hairy plants and of conifers, rushes and sedges, etc.

Leaves of different ferns and flowering plants called for under "Mechanical and Conducting System."

Specimens of *Elodea Canadensis* growing in water, and of Mnium or other common moss.

Tropæolum and other convenient plants growing in pots

A collection of modified leaves.

SYSTEMATIC DESCRIPTION.

Write a careful and complete description of the leaves of ten or a dozen different plants, following, as far as it proves serviceable, the schedule given below.

Some one has said that "there is no part of botany so overwhelmed with cumbrous terminology as that which relates to leaves." Nevertheless the really necessary terms are easily learned, and the peculiarities expressed by them are far from accidental. The form of the leaf, its position on the stem, the venation and other structural features are generally such as to secure the greatest efficiency, and in studying these it is desirable to be able to express one's self with exactness. The greenhouse or window garden, the drug store, collections of preceding years, and seedlings raised in the laboratory will, even in winter, furnish abundant material. The following may be suggested as a partial list: English ivy, geranium, primrose, verbena, rose, oxalis, maurandia, nasturtium, oak, maple, elm, lily, Indian corn, hyacinth, amaryllis, arbor vitæ, hemlock, juniper, and different species of pines.

Schedule for Leaf Description.[1]

1. *Position.* Radical[2] or cauline.
2. *Arrangement.* Opposite, alternate, whorled, fasciculate.
3. *Relation to Stem.* Petiolate, sessile, perfoliate, sheathing, connate, decurrent, etc.
4. *Stipules.* Described as leaves. If absent, the leaf is said to be exstipulate.
5. *Form.* Acicular, awl-shaped, linear, oblong, elliptical, oval, rotund, ovate, lanceolate, reniform, obovate, oblanceolate, etc.
6. *Apex and Base.* For special terms see dictionary and text-books.
7. *Margin.* Entire, serrate, dentate, crenate, sinuate, irregular, lobed, cleft, parted, divided, etc.
8. *Venation.* Pinnate, palmate, parallel.
9. *Surface.* Glabrous, glaucous, pubescent, wooly, villose, hirsute, prickly, etc. (These terms apply also to the surface of other organs.)
10. *Compound Leaves.* Pinnate, bi-pinnate, tri-pinnate, palmate, bi-palmate, tri-palmate, pinnately or palmately decompound, etc.

[1] Gray's *Lessons*, Section 7, and illustrations of botanical terms in Webster's *International Dictionary* should be consulted.

[2] A misleading term, but fixed in the language.

LEAF ARRANGEMENT.

I. Take branches of basswood, elm, maple, and horse-chestnut, and study the leaf arrangement. In winter the position of the leaves of preceding years may be determined by the leaf-scars.

Are the leaves placed advantageously as regards exposure to light? Cf. Lubbock, *Flowers, Fruits, and Leaves*, pp. 103–114.

II. Compare other plants, *e.g.* primrose and fuchsia, dandelion and geranium, with regard to this principle.

III. Try the effect of putting the leaves of one species on the branches of another, without changing the leaf arrangement.

MINUTE ANATOMY.

I. With a pair of fine forceps strip off a portion of the epidermis of a hyacinth leaf. Mount in water and examine under the high power of a compound microscope. Observe

1. The elongated **epidermal cells** destitute of chlorophyll.
2. The **stomata,** each with two reniform guard-cells containing chlorophyll bodies. Draw.

II. Place a small portion of a leaf of the English ivy between two pieces of pith, and, with a keen razor, cut a number of transverse sections. Examine under the compound microscope. Select a section that shows all the structural details and draw accurately. Beginning with the upper surface the section shows

1. The upper epidermis, consisting of a single layer of thick-walled cells, destitute of chlorophyll.

2. A layer or two of closely packed cells, with their long diameter perpendicular to the surface of the leaf, containing many chlorophyll bodies. These constitute the **palisade** tissue.
3. Other chlorophyll-bearing cells essentially the same as the preceding, but less regular in shape and more loosely arranged, so that toward the lower surface of the leaf large openings, intercellular passages, occur. Some of these cells contain large stellate crystals of oxalate of lime.
4. About midway between the upper and lower surface, the veins, **fibro-vascular bundles,** cut either transversely or at an angle, according to their direction at the place where the section is made. The thick-walled mechanical elements constitute the bundle-sheath. The bundle itself is divided into two adjacent parts, the **xylem** lying towards the upper surface of the leaf, and the **phloëm** towards its lower surface. The **tracheids** of the xylem, elongated tube-like structures, are easily recognized.
5. The lower epidermis, similar to the upper, but with stomata at frequent intervals. These are placed so that each one forms an entrance to one of the intercellular passages. (Sections of the stomata are best studied in a hyacinth leaf.)

NOTE.—The different sections should be studied until the general structure of the leaf is thoroughly understood. Every fact is of physiological significance, and it is of the utmost importance that the student should have a complete and clear knowledge of the minute anatomy based on direct observation.

PHYSIOLOGY OF LEAVES.

Protection.

Leaves require protection against

1. Changes of temperature.
2. Drying.
3. Attacks of animals, fungi, etc.
4. Injury by wind and other meteorological agencies.

Cf. Lubbock, *Flowers, Fruits, and Leaves*, Chap. VI; Kerner, *Flowers and their Unbidden Guests*.

Some of the following observations are to be carried out in the laboratory, while others are best conducted out of doors.

I. Remove the epidermis from a portion of a hyacinth leaf, or the leaf of some other fleshy plant. Notice its texture, strength, and elasticity. After a time observe any changes that have taken place in the part from which the epidermis has been removed.

II. Examine the hairy covering of leaves of common mullein. Compare other hairy plants. Examine microscopically the hairs of mullein, verbena, rose geranium, and other common species. Make a series of drawings illustrating the epidermal appendages of various leaves.

III. Study the leaves of the Austrian pine, common juniper, and other conifers. Enumerate the protective arrangements exhibited by them.

IV. Compare very young leaves of the oak, apple, or other common tree, with older ones.

V. Many plants are protected by disagreeable or poisonous substances stored in their foliage. Name any of these that you know.

VI. Some leaves exhibit remarkable "sleep movements." What are these for? Cf. Darwin, *Power of Movement in Plants*, Chap. VII.

VII. Other leaves exhibit equally remarkable "hot sun positions." Of what use are these to the plant? Cf. Wilson, *Contributions from the Bot. Lab. Univ. of Pa.*, Vol. I, No. 1.

Mechanical and Conducting System.

The skeleton or framework of the leaf serves to support the delicate green tissue, holding it so as to expose the largest possible surface to the sun, and, at the same time, giving the whole structure sufficient rigidity, strength, and elasticity to resist mechanical violence. It also serves to conduct a constant supply of water and mineral substances to every part of the leaf, and to convey away elaborated food materials. It is only by keeping these principles in mind that an intelligent study of venation can be made. Cf. Sachs, *Physiology of Plants*, pp. 48–53.

I. Obtain the leaves of several ferns, *e.g. Adiantum pedatum*, *Aspidium cristatum*, *Osmunda Claytoniana.* Draw an enlarged outline of a leaflet of one or more species, showing the exact position of the veins.

II. Compare the venation of a number of monocotyledons, *e.g.* Tradescantia, Alisma, Sagittaria, Pontederia, Calla, Arisæma, Smilax. Draw accurately one or more leaves.

III. Examine the venation of the leaves of Catalpa, Liriodendron, Fuchsia, and Nymphæa. How does it compare from a mechanical standpoint with that of the leaves previously studied?

IV. Study critically the structure of the leaf of a black oak or red oak. Measure the widest space you can find that is free from veinlets. Do these end freely or anastomose? Is there any apparent advantage in this?

Assimilation.

The chief and characteristic function of green leaves is assimilation, that is, the production of organized food substances.

I. Examine the leaves of *Elodea Canadensis* under the compound microscope. Study the form and position of the chlorophyll bodies contained in the cells. Are they equally numerous in all parts of the leaf? Draw two or more cells showing the chlorophyll bodies in place. Compare with these the chlorophyll bodies of Mnium or other common moss.

II. Take fresh leaves of the Elodea that has been growing in a jar of water exposed to sunlight. Place them in strong alcohol and allow them to remain until they have lost their color and the alcohol has turned green. Mount for microscopic study and test with iodine solution. Starch should be found in the chlorophyll bodies. It may be demonstrated still more easily in the chlorophyll bands of Spirogyra and other filamentous algæ.

III. By an experiment best performed by the teacher or by a pupil specially appointed, the necessity of light for the production of starch, and the local nature of the process of assimilation is demonstrated. Take a healthy Tropæolum ("nasturtium") growing in a flower pot, and place it in the dark for two or three days. Test one of the leaves for starch, which by this time should have disappeared. Now place the plant where it will be exposed to the bright sunlight, having previously covered a part of one or more of the leaves so as to exclude the light by pinning flat pieces of cork closely on opposite sides. After the plant has been in the light for a day or more, proper tests show that starch has been formed in the parts of the leaves exposed to light but is absent where they were covered (except in the fibro-vascular bundles). Further details are given by Detmer, *Das pflanzenphysiologische Praktikum*, pp. 33–34 and 37–38.

IV. Place an inverted funnel over a lot of Elodea, growing in a glass jar, and push it down until the small end of the funnel is beneath the surface of the water. Fill a test-tube with water, stop it with the thumb, invert, and (under water) bring the small end of the funnel into it. Set the apparatus where it will be in bright sunlight. Observe the bubbles of gas given off by the plant. After enough has been collected in the tube, test for oxygen. This may be done by lighting a match and blowing it out, and then inserting it, while still glowing, into the test-tube.

V. The preceding observations show that starch is formed in the chlorophyll bodies in the presence of sunlight, and that during the process oxygen is given off. By means of a simple experiment it may also be shown that starch is not thus produced unless carbon dioxide is supplied to the plant. The teacher will find the apparatus figured and described by Detmer, *Praktikum*, p. 38, easily made and entirely satisfactory.

Transpiration.

I. Take a quantity of green leaves and place them in a wide-mouthed bottle. After a time observe the moisture that has collected on its inner surface. Where has it come from?

II. Cut off a strong, well-developed leaf of a primrose, immerse the blade of the leaf in water, and placing the cut end of the petiole in the mouth, inhale forcibly. Do you obtain any proof that the inside of the leaf is in communication with the atmosphere?

III. Take any leafy plant of convenient size that is growing in a flower pot, cover the pot with a piece of dentists' rubber, bringing it up around the stem of the plant and tying it so that no water can be given off except through the plant itself. Weigh the whole, and at the end of twenty-four hours weigh again. To what is the loss of weight due?

IV. Vary the last experiment by employing different kinds of plants, as, for example, some with leathery and others with soft leaves; also by placing some in the sunlight and others in the shade, in the open air and in a closed room. What are some of the conditions affecting transpiration?

Respiration.

Respiration is a function of every living cell. Hence leaves are to be thought of as organs of respiration in so far as they expose a very large number of active cells to the atmosphere, although they do not really "correspond to the lungs of animals." We may therefore employ leaves to demonstrate the process of respiration, or we may use flowers or germinating seeds.

Take three wide-mouthed bottles and fill each two-thirds full, the first of fresh leaves, the second of germinating peas, and the third of flowers. Cork and allow to stand a few hours. Test the air in the bottles at the beginning and close of the experiment by introducing a homœopathic vial containing limewater, also by inserting a lighted match. What is the result?

NOTE. — The student should carefully consider what is taking place in the cells of green leaves, inasmuch as a great deal of confusion has arisen through lack of clear conception and expression. Since they respire like other parts of the plant, leaves absorb oxygen and give off carbon dioxide both day and night. On the other hand, as organs of assimilation, they decompose carbon dioxide in the sunlight, giving off oxygen and employing the carbon in the production of starch. A complete discussion of the subject would require much space, but the fundamental facts are as stated above, and should be firmly fixed in mind.

MODIFIED LEAVES.

When some other function than that of assimilation becomes predominant, leaves exhibit marked, and in some cases extremely peculiar, modifications.

I. Examine shoots of the common barberry. Determine the morphology of the spines and give reasons. Compare the spines of the common locust. Are they the same morphologically as those of the barberry? Examine different species of cacti and determine the morphology of the parts.

II. Study the tendrils of such of the following plants as can be obtained and ascertain which of them are to be classed as leaves or parts of leaves: *Smilax rotundifolia*, *Cobœa scandens*, *Adlumia cirrhosa*, *Echinocystis lobata*, grape-vine, pea, cucumber, etc. Note particularly any cases in which only partial modification has taken place. Cf. Darwin, *Climbing Plants*, Chaps. III, IV.

III. Leaves of insectivorous plants. See Special Studies.

SPECIAL STUDIES.

I. Correlation of the forms of leaves with their position on the stem. See Lubbock, *Flowers, Fruits, and Leaves.*

II. Extent of leaf surface. Measure accurately the superficial area of an average leaf of a geranium or other common plant, and estimate its entire leaf surface.

III. Generic and specific characters drawn from leaves.

IV. Variability. Compare the leaves of any individual plant, a rose bush, for example, and observe their different forms.

V. Leaves of insectivorous plants. *Drosera rotundifolia* is widely distributed and is easily cultivated in the laboratory. It is a most valuable plant for prolonged observation and experiment. Cf. Darwin, *Insectivorous Plants*.

REVIEW AND SUMMARY.

A characteristic part of the plant.

The leaf is the most characteristic, and, in some respects, the most important part of the plant. The venation and various peculiarities of form and structure are usually sufficient to indicate at once the class, and not infrequently the genus or species to which a plant belongs. Even those who have had no special botanical training readily distinguish the oak, willow, maple, and various other plants by the leaf alone. Hence in determining relationships special attention is given to characters drawn from leaves, and it becomes necessary to define these with care and precision. Physiologically, too, the leaf is engaged in work peculiar to plants, work of a nature that cannot be performed by animals, and upon which they are dependent for their continued existence on the globe. A clear conception, therefore, of the general facts of leaf structure and physiology is essential to an understanding of some of the most fundamental facts of biological science.

Form and position.

Beginning with form and position, we have seen that, as a rule, leaves are so constructed and placed as to secure the exposure of a large surface to the air and light. The blade of the leaf is raised on a petiole whenever this is necessary to more readily accomplish the end to be attained. Furthermore, the position of leaves on the stem is such as to aid in securing the greatest exposure. If we inspect a large tree in full foliage, such as a maple or basswood, it will be seen that the leaves are placed so as to result in a minimum of interference with each other. It will also be noticed, as Sir John Lubbock points out, that there is a manifest correlation between the form of the leaves and their arrangement on the branch, so that in many cases it would be a decided disadvantage to replace the leaves of one species by those of another unless the leaf arrangement were changed. Further, an examination of buds that have not yet opened shows that the leaf arrangement is such as to economize space. These two principles, compact disposition in the bud, and a position on the stem that will secure full exposure of leaf surface, are the determining factors in the arrangement of leaves.[1]

An examination of the anatomical structure of an ordi-

[1] Incidentally it results that the leaf arrangement of many plants is so definitely fixed that it may be expressed by a mathematical formula. Phyllotaxis, however, as usually presented, is a curious rather than a fruitful study. "We must now acknowledge that there is no general law which can be formulated for the arrangement of the organs on a parent axis; that, on the contrary, according to circumstances in each case, special causes determine whether the relations of position turn out to be this or that." — SACHS, *Physiology of Plants*, pp. 500, 501.

nary foliage leaf shows that both surfaces are protected by an external layer of cells constituting the epidermis. The outer wall of the epidermal cells is commonly thickened, and by taking on a layer of cutin or wax becomes nearly or quite impervious to water. The leaves of some plants, particularly of species growing in tropical regions, have more than one layer of cells composing the epidermis, thus securing more efficient protection. The cells of the epidermis are, for the most part, destitute of chlorophyll, but contain a large quantity of water which is absorbed as required by the delicate cells in the interior of the leaf. Additional protection is often afforded by hairs which thickly cover the leaves of many species, particularly those growing on the steppes and other parts of the globe where vegetation is subject to sudden and extreme changes of temperature. Finally, protection is not infrequently secured by diminishing the amount of leaf surface, as seen in many shrubs, and in desert grasses and sedges with cylindrical leaves.

Anatomical structure. Epidermis.

Stomata.

Communication with the interior of the leaf is secured by means of numerous openings called stomata. These are provided with guard-cells, commonly of the same general form as those of the hyacinth leaf, which act as a valve, opening in sunlight while the leaf is at work and closing, or partially closing, at night. The mechanism, apparently simple, is, in reality, rather difficult of complete explanation.[1] The essential fact is that by means of the stomata a free interchange of watery vapor and gases between the interior of the leaf and the surrounding atmosphere is effected, and that by means of the guard-cells this interchange is obstructed when the external conditions are unfavorable.

[1] Cf. Sachs, *Physiology of Plants*, pp. 248–251.

The internal structure of the great majority of leaves is essentially the same as we have seen in the English ivy. The midrib and veins, composed of fibers and tracheids, present a strong frame-work by means of which all the parts are supported, and which also serves as the conducting system of the leaf. The green parts consist of chlorophyll-bearing, parenchyma cells, the chief function of which is the manufacture of organized food substances. An extended comparison of the leaves of many species of plants shows several interesting arrangements for bringing the assimilating cells into an advantageous position as regards the light. In the first place, the leaf itself "turns towards the light," *i.e.* places itself so that the upper surface is perpendicular to the incident rays. In the second place, the palisade cells are themselves nearly perpendicular to the leaf surface, a position in which their contents are brought into relation with the light, without, however, cutting it off entirely from the cells below. Finally, the chlorophyll bodies vary their position in the cells according to the intensity of the light, ranging themselves so as to expose as large a surface as possible when the illumination is feeble, and a less surface when it is too intense.[1] In addition to these arrangements with reference to light, the assimilating cells are grouped in such a manner as to facilitate the conveyance of water to them by the fibro-vascular bundles, and the removal of elaborated food substances through the same channels.[2]

Fibro-vascular bundles.

Assimilating cells.

It is thus seen that the leaf is an extremely delicate organ, adapted to the performance of certain important functions. Their first and most characteristic function

[1] Sachs, *l.c.*, p. 617 *et seq.*

[2] Haberlandt, *Physiologische Pflanzenanatomie,* p. 184 *et seq.*

is the formation of organic food products out of the crude substances taken in from the atmosphere and soil. In the presence of sunlight starch is produced in the chlorophyll bodies. The materials from which it is formed are carbon dioxide, obtained from the atmosphere, and water brought up from the roots. The starch accumulates in the daytime in the cells where it is formed, and afterwards is conveyed away in a soluble form to the various reservoirs of reserve materials. Simple experiments have shown the conditions under which the formation of starch takes place and the attendant phenomena. The rapid evolution of oxygen seen when a water plant is allowed to stand in bright sunlight is at once checked when the vessel containing it is brought into the shade. The oxygen is given off in the formation of starch and this process ceases when light is wanting. Again, if the water in which the plant is growing is boiled so as to expel the carbon dioxide, it is observed that the evolution of oxygen ceases as in the preceding experiment, but for a different reason. The carbon dioxide being wanting, the leaves are deprived of the carbon necessary to the production of starch.

Functions. Assimilation.

Water in relatively large quantities is required to carry to the leaf, and to the other parts of the plant, the substances used in the formation of starch and other products. The surplus water is evaporated by the leaves. By simply weighing at stated intervals a plant arranged so that evaporation can take place from no other part, it is found that large amounts of watery vapor are given off through the leaves. Transpiration, then, or the evaporation of water, is another important function of leaves, since the water thus given off is the vehicle of transportation of the various substances used by the plant.

Transpiration.

Still another function which the leaf shares with other living parts of the plant, and which is characteristic of all living cells whether plant or animal, is that of respiration. As we have seen, one of the products of respiration, carbon dioxide, is easily demonstrated by testing with limewater the air within a bottle containing a quantity of green leaves. The abundant precipitate of carbonate of lime shows that the leaves are giving off carbon dioxide in considerable quantity, and as this is true whether the experiment is performed in the daytime or at night, we infer that respiration is going on continually. It should be said, however, that, contrary to a widely spread popular belief, the quantity of carbon dioxide exhaled by plants is so small in comparison with what is given off in animal respiration that it may be disregarded in connection with the question of keeping house plants. They are a decided advantage in the home from a sanitary, as well as æsthetic, point of view.

Respiration.

The chief functions of the leaf, then, are

1. Assimilation, or the production of organized material.
2. Transpiration, or the evaporation of water that has served as a vehicle for the transportation of crude substances.
3. Respiration, a process common to all living things.

The first of these takes place in sunlight, or its equivalent; the second is most active in the daytime, but is not limited to it; and the last continues both day and night, as long as the leaf is alive.

We have learned in our study of the barberry and a number of other familiar plants, that leaves are subject to various modifications corresponding to other than their ordinary functions. These modifications are not infrequently so profound that it becomes a matter of no little difficulty to pronounce upon the morphological character of a particular structure. Spines and tendrils, for example, may represent either leaves or branches. The morphological character of bud-scales, on the other hand, is usually recognized at once from their position, structure, and especially from the various transitional forms by which they are connected with ordinary leaves. Though often puzzling, the morphology of modified leaves is always an exceedingly interesting and profitable study.[1]

Modified leaves.

[1] Cf. Gray, *Structural Botany*, pp. 110–118.

VI. THE FLOWER.

MATERIAL REQUIRED.

Flowers of white Trillium, *T. grandiflorum*, Salisb. Other species may be used.

Cultivated Fuchsia. Specimens must be selected that have not become double.

Several pots of cultivated primroses in flower, some specimens with long- and others with short-styled flowers.

Various wild flowers, or cultivated kinds that have not undergone modification, may be substituted for the preceding.

TRILLIUM. *T. grandiflorum*, Salisb.

I. Study first the morphological characters.[1]

1. Is the flower complete, that is, are the **calyx**, **corolla**, **stamens**, and **pistil** all present?
2. What is the **numerical plan** as indicated by the number of **sepals**, **petals**, **stamens**, and **carpels**?
3. Is the flower **regular**?
4. Is **coalescence** to be observed in the members of any whorl?
5. Describe in detail each part of the flower, noting shape, color, and other features.

II. Make a transverse section of the **ovary**. Draw it sufficiently enlarged to show all the parts clearly. Note particularly the form, position, and place of attachment

[1] Read Gray, *Lessons*, pp. 79–117.

of the **ovules**, and make out as much of their structure as possible.

III. Construct a diagram of the flower.[1]

Note. — A correct diagram necessitates a careful study of the relation of every part of the flower to every other part. It should be drawn with geometrical precision, representing the parts of each whorl so as to show their number, arrangement, relation to other whorls, and to some extent their union or separation. Properly constructed, such diagrams serve an important purpose by facilitating the comparison of the permanent morphological features of flowers of the same and different families.

IV. Ascertain whether the flower manifests any physiological adaptations.

1. Is there anything protective in its form, position, or structure?
2. Enumerate its attractive features.
3. Is there anything to indicate whether cross- or self-fertilization takes place?

Note. — A satisfactory answer to this question may require more experience than the pupil has yet attained. It involves close observation of any peculiarities that seem to favor the visits of insects or other agents of fertilization, such as grooves, guiding lines, the presence of nectar, and so on.[2]

FUCHSIA. *Fuchsia coccinea, etc.*

I. Note carefully all external features, such as

1. Position of the flower and its direction, erect or drooping. Compare with the flower buds.
2. Color of different whorls.
3. Union of parts
   a. Of the same whorl.
   b. Of different whorls.

[1] Cf. Gray, *Lessons*, p. 82, footnote; also Eichler, *Blüthendiagramme.*
[2] Cf. Müller, *Fertilization of Flowers.*

4. The extremely long **style**.
5. Relative position of **anthers** and **stigma**.
6. Numerical plan.

II. Make a clean transverse section of the ovary. Examine under the dissecting microscope. How many carpels are there?

III. Draw the section, taking care to represent accurately

1. The position of **septa** and **placentæ**.
2. Attachment and form of **ovules**.

IV. Make an exact longitudinal section and draw it in outline. Note particularly

1. The conspicuous **nectary**.
2. Presence or absence of nectar.
3. The insertion of the **filaments** and their direction, so placed as to bar out unwelcome visitors.

V. Measure the length of the calyx tube. Is the nectar accessible to bees and similar insects?

VI. Construct a diagram.

VII. Review the whole and describe in detail.

PRIMROSE. *Primula veris, etc.*

I. Study the morphological characters, such as

1. The numerical plan.
2. Regularity.
3. Symmetry.
4. Coalescence of parts.
5. Structure of ovary.

II. Construct a diagram.

III. Note all protective and attractive arrangements.

IV. Compare flowers of a number of different plants with regard to the position of the essential organs. Notice

1. The length and insertion of the stamens.
2. Length of style.
3. Form and structure of the stigma.
4. Any other particulars in which the long- and short-styled forms differ.

V. Make longitudinal sections of the two forms and sketch in outline. Read Darwin, *Different Forms of Flowers on Plants of the Same Species*, Chap. I.

NOTE. — It will, of course, be understood that an acquaintance with many more species will be necessary in order to obtain a general conception of the morphology of the flower, and an adequate knowledge of its physiological adaptations. Accordingly, similar studies of other flowers may be made before proceeding farther, or this may be postponed until the families of flowering plants are taken up. In any case the student should now read carefully Gray, *Lessons*, pp. 79–109, or the equivalent part of the *Structural Botany*, by the same author. He should also make a constant practice of referring to Müller, *Fertilization of Flowers*.

POLLEN, OVULES, EMBRYO.

I. Examine with the compound microscope the **pollen** of a number of different plants, such as pine, lily, pumpkin, mallow, and others. Compare the grains as to size, shape, and surface. Notice whether those disseminated by the wind are characterized by different features from those that are carried by insects or birds. Draw and describe.

II. Sow various kinds of pollen in watch glasses containing sugar solution (3 to 20 per cent). At intervals of a day or less transfer a few grains to the glass slide with a camel's-hair brush and examine microscopically. Some of them will soon show formation of **pollen-tubes.** Draw them in different stages of development.[1]

III. Cut transverse sections of the ovary of Trillium at the time the flower is fading and at subsequent periods. Under the compound microscope study the **ovules** in different stages of growth. Notice

1. The **anatropous** form of the ovule.
2. Its two **coats** distinctly marked at the apex.
3. The **nucellus,** or mass of tissue making up the body of the ovule.
4. The **micropyle,** a canal leading from the apex of the ovule to the nucellus.

Draw and describe.

IV. Prepare similar sections of the ovary of Fuchsia, Begonia, and various other plants, studying carefully, as before, the structure of the ovule. Some of these will show, lying within the nucellus, the outlines of the **embryo-sac,** a large cell in which the embryo is subsequently formed. Clearing with potash solution facilitates the observation. Indian-pipe, *Monotropa uniflora*, L., when it can be obtained, is an extremely favorable species for the study of the embryo-sac and the structures contained in it.[2]

V. Take a flower-bud of shepherd's-purse, *Capsella Bursa-pastoris*, Mœnch, and under a lens remove the floral envelopes. Open the ovary and dissect out the ovules. Treat on the slide with dilute potash solution and apply light pressure to the cover glass. If a series of younger

[1] For further hints as to culture methods, cf. Strasburger and Hillhouse, *Practical Botany*, p. 320 *c*; Halsted, *Bot. Gaz.* XII (1887), p. 287.

[2] Cf. Strasburger and Hillhouse, *l.c.*, pp. 327–337.

and older specimens are prepared in this way, the **embryo** in various stages of development can be satisfactorily studied. Make a series of sketches showing as many of these stages as practicable. Compare your own figures with those of Hanstein.[1] Write a brief account of the development of the embryo of this plant as far as you have observed it.

SPECIAL STUDIES.[2]

I. Morphology of stamens.
II. Morphology of the pistil.
III. Protection against unbidden guests.
IV. Dimorphism.
V. Mechanical devices favoring cross-fertilization.
VI. Changes in the ovule after fertilization.

REVIEW AND SUMMARY.[3]

Parts of the flower.

In the preceding study we have found that a flower is commonly made up of four distinct whorls, or circles, calyx, corolla, stamens, and pistil. The parts of the calyx are called sepals, those of the corolla, petals. The stamens are spoken of collectively as the andrœcium, and the pistil (or pistils) as the gynæcium. While in most flowers all the parts are present, there are

[1] Goebel, *Outlines of Classification and Special Morphology*, p. 397.

[2] Gray, *Structural Botany*, pp. 215–240, 251–268; Kerner, *Flowers and their Unbidden Guests*; Darwin, *Different Forms of Flowers on Plants of the Same Species*; Strasburger and Hillhouse, *Practical Botany*, pp. 311–337.

[3] It will probably be better to postpone the review until the flowers of a considerable number of families have been carefully studied. After this has been done the pupil may profitably devote some little time to the *résumé* and references here given.

many species in which one or more of the whorls are absent, and each is subject to more or less modification of form and structure.

Its morphology.

Morphologically the flower is to be regarded as a modified branch, the members of its different whorls corresponding to so many leaves. The most obvious reasons for this view are that the flower has the position of a branch; that the arrangement of its parts follows more or less strictly that of the leaves on the stem; that the anatomy of leaves and floral structures is essentially the same; that transitions from ordinary leaves to floral envelopes are of frequent occurrence; and finally that reversions of parts of the flower to a more primitive or leaf-like form often take place.

Typical flower.

It is convenient, and at the same time in accordance with the views now held regarding the actual evolution of plant life, to take some such flower as that of the Trillium as a pattern or "typical" flower with which to compare others. The Trillium, as we have seen, has three distinct green sepals, three petals, two whorls of stamens of three each, and a pistil composed of three parts, each part called a carpel. We may characterize our pattern flower, then, as having all the parts present, these parts distinct from each other, of the same form and size in each whorl, and presenting throughout the same numerical plan, most frequently three or five. In other words, it exhibits completeness, distinctness of parts, regularity, and symmetry.[1]

The flowers of most plants differ in one or more respects from such a typical flower as has been described. Never-

[1] The flower of Trillium departs slightly from the ideal typical flower in the coalescence of the three carpels to form the compound ovary. Cf. Gray, *Structural Botany*, pp. 176–178.

theless a comparison of the flower of a given species as we actually find it, is, as a rule, readily made with the assumed type, and this comparison is a necessary part of the morphological study of any flower.

Modifications.

In carrying out such a study it is found that flowers may vary from the type in any one (or in more than one) of its characteristic features. In the first place, members of the same whorl, instead of being separate, may be more or less completely united. The calyx of the primrose, the bell-shaped corolla of the campanula, the united filaments of various members of the pea family, and the compound ovary of the lily, are familiar examples. Coalescence of parts is held by botanists to indicate a higher development than has been attained by flowers in which the parts remain free.

Coalescence.

A still further step in the same direction is seen in the union of contiguous parts of different circles. Thus the flower of the Fuchsia has the calyx-tube so united with the ovary as to make it appear as if inserted on its summit, and both petals and stamens are inserted on the calyx, the filaments showing very plainly their union with the calyx-tube. The various degrees of adnation furnish important characters that are constantly employed in descriptive botany.[1]

Adnation.

Again, while the typical flower is regular, having all the parts of a given whorl alike in size and shape, the flowers of the more highly developed species, as a rule, show marked irregularity. The spurred corolla of the violet, and the curiously irregular flowers of the sweet pea, salvia, and snapdragon are striking cases. It is believed that these are descendants of much simpler forms

Irregularity.

[1] Cf. Gray, *Structural Botany*, pp. 182–184.

that in the course of an indefinite period of time have gradually taken on shapes manifestly correlated with the visits of insects or other agents by which pollen is carried from one flower to another.

Suppression. Many flowers have undergone the suppression of one or more parts. In some cases a whole whorl is wanting, as in the anemone, which is destitute of a corolla; or several whorls may be lacking, as in the willows, the flowers of which are reduced to a single whorl. Frequently, however, a part of a whorl only is wanting, and in such cases it often happens that a rudiment, or trace, of the missing parts remains to indicate a former condition. In the common toad-flax, for example, there are four perfect stamens and a trace of the fifth; some of the mints now have but two stamens, although five was the original number; and many plants, as the lupine and its allies, otherwise on the plan of five, have the ovary reduced to a single carpel.

Multiplication. The symmetry of the flower is interfered with, not only by the suppression, but also by the multiplication of parts, so that it not infrequently happens that the original plan, in some one whorl at least, is no longer recognizable. The very numerous stamens of the cacti will serve as an illustration.

The changes described are of great interest as indicating actual steps in the developmental history of flowers. They help us to see, if not fully yet in part, how such extraordinary structures as those of a milkweed flower or an orchid have come to be what they are.[1]

[1] Lack of space renders it necessary to refer the student to a much more extended discussion of the subject than can here be undertaken. Cf. Gray, *Structural Botany*, pp. 179–209, which has been followed in the main in the brief *résumé* just given.

As already intimated, the parts of the flower exhibit the same general structure as that of the leaf, but with modifications corresponding to the special functions that each part fulfills.

Structure and functions of the several parts.

The calyx and corolla are protective, serving to guard the parts within from frost and rain and the intrusion of unwelcome visitors. They are also attractive, particularly the corolla, which is usually colored so as to attract bees and other color-loving insects. They form, too, a part of the mechanism, often very peculiar and interesting, by which pollination is effected.

Floral envelopes.

The stamens are usually far more modified than the floral envelopes. The thickened anther, corresponding to the blade of the leaf, produces pollen, the active agent of fertilization. The pollen consists of rounded cells, the walls of which are variously thickened, frequently beset with spines, and, in some instances, winged, thus facilitating their conveyance by insects or by the wind. The cell contents are protoplasm, with one or more nuclei, and a considerable quantity of food material, such as starch, oil, and sugar.

Stamens.

The pistil is simple or compound according as it is made up of one or more than one carpellary leaf.[1] The ovules, which afterwards become the seeds, originate as cellular outgrowths from the margins of the carpel. An ovule, when fully formed, consists of a central mass of cells, called the nucellus, around which one, or commonly two, protective coats are formed, and within which a cell, called the embryo-sac, arises. It is in the embryo-sac that the young embryo is developed. An opening between the coats, called the micropyle, leads down to the nucellus. The parts as described at once

Pistil.

[1] Cf. Gray, *Structural Botany*, p. 260 *et seq.*

recall the seed, which is simply a fertilized and matured ovule.

Fertilization.

When pollen-grains have been brought by any agency to the moist and receptive stigma of a flower of the same species, they begin after a short interval to germinate. In germination pollen-tubes are produced, which rapidly elongate, growing through the loose tissue of the stigma and downwards through the style until they enter the ovary. Here they find their way to the ovules, which they enter, one pollen-tube going to each ovule and pushing its way through the micropyle, until its end comes in contact with the nucellus and finally with the embryo-sac. A portion of the contents of the pollen-tube, including nuclear material, now passes into the embryo-sac and unites with a cell in it, called the oösphere. The oösphere now takes on a cell-membrane, increases in size, undergoes division, and, as a result of still further division and growth, produces the embryo. Other cells are formed in the embryo-sac which rapidly multiply and become the endosperm, a tissue often absorbed afterwards by the growing embryo prior to germination. Meantime the embryo-sac becomes many times its former size, while the nucellus is crowded to the walls of the ovule and is commonly absorbed, but sometimes remains as the perisperm. The coats of the ovule are extended to keep up with this increase in size, the testa takes on its characteristic hard and usually colored condition, a further store of food is deposited around or in the growing embryo, and with the completion of these various processes the ovule has become a mature seed.

The changes just described, together with some others that chiefly affect the ovary, take place whether pollen from the same flower or from another flower of the same species is applied to the stigma; but it has been proved that, as a general rule, there are great advantages in having the pollen brought from another flower.[1] Accordingly, while self-fertilization is possible in most plants, various arrangements exist by which cross-fertilization is favored.

Pollination.

A number of external agents serve as efficient means of pollination. The wind carries the light pollen of pine and other trees to great distances, sometimes even hundreds of miles, insects of many different kinds are actively engaged in carrying pollen from one flower to another, and humming birds visit a considerable number of species. In comparatively few cases pollen is conveyed to the stigma by the agency of water.

External agents.

Flowers themselves show many remarkable adaptations that favor cross-fertilization. The most important of these, as discussed at length by Darwin and other writers, are the following:

Adaptations of flowers.

1. Diclinism, or the separation of stamens and pistils. These are borne in different flowers, either on the same plant, as in the hazel, oak, etc., or on different individuals, as in the willows and poplars. In some families, as the maples, both conditions prevail. Plants with staminate and pistillate flowers on the same individual are said to be monœcious, those in which the separated flowers are on different individuals are diœcious, and those in which either condition exists together with the production of some perfect flowers are called polygamous. Of those in which the separation is most complete, namely, perfectly diœcious species, Darwin says, "About the origin of such

[1] Cf. Darwin, *Cross- and Self-fertilization in the Vegetable Kingdom;* Müller, *Fertilization of Flowers.*

plants nothing is known."[1] This arrangement practically necessitates cross-fertilization.

2. Dichogamy, or the maturing of stamens before or after the period of receptivity of the stigma. When the stamens shed their pollen before the stigma is receptive, the dichogamy is proterandrous; if, on the other hand, the stigma is receptive before the pollen is shed, it is proterogynous. The former condition is far more common than the latter.[2]

3. Prepotency of pollen from other flowers. It has been found by experiment that pollen from another individual is often decidedly prepotent over that produced by the same flower. This is best shown by placing its own pollen on the stigma of a flower, and after some hours applying pollen of a different colored variety of the same species. The plants raised from seeds of flowers thus fertilized show by the color of their flowers whether crossing has taken place. Darwin found in a number of cases that pollen of another individual was prepotent after twenty-three or twenty-four hours.[3]

4. Heteromorphism. A considerable number of species produce flowers of different forms. In various species of Primula and Houstonia, certain individuals have long stamens and short styles, while others have long styles and short stamens. Such flowers are said to be dimorphic, while those of loosestrife, *Lythrum Salicaria*, L., which have stamens and styles of three different lengths, are trimorphic. Both conditions involve the same principle and favor cross-fertilization in a remarkable way.[4]

[1] *Different Forms of Flowers on Plants of the Same Species*, p. 278.

[2] Cf. Gray, *Structural Botany*, p. 219, *et seq.*

[3] *Cross- and Self-fertilization*, pp. 395, 396.

[4] Cf. Darwin, *Different Forms of Flowers on Plants of the Same Species.*

5. Special mechanisms. Such peculiarly shaped flowers as those of the lupine, sage, lady's-slipper, milkweed, and many other plants exhibit special contrivances, often in the form of an exquisitely arranged mechanism, by which the flower is adapted to some particular visitor or class of visitors, through whose agency it is fertilized. These are described at length in various works, and we shall have occasion to study some of them in detail as we take up different families of plants.[1]

[1] The student is given distinctly to understand that the foregoing account is necessarily incomplete, and must be supplemented by careful and intelligent reading of the references given, if even a fairly complete comprehension of the subject is to be attained. It is by no means the part of these exercises, with their brief summaries, to cover the subject of botany, but *to show the beginner how to go to work.*

VII. FRUITS.

MATERIAL REQUIRED.

Mature fruits of sugar maple. Pods of common locust.
Capsules of opium poppy and of *Linaria vulgaris*, Mill.
Fruits of climbing bitter-sweet, *Celastrus scandens*, L. Cranberries.
A miscellaneous collection of fruits from the market and elsewhere. Among the most easily procurable are the following: Peanut, acorn, common plantain, coriander, colocynth, milkweed, black pepper, juniper berries, raisins, sumac "berries," rose hip, fig, date, banana, star anise, cardamom, cocoanut, apple, plum, mulberry, catalpa, spiræa, evening primrose, and mullein.

COMMON LOCUST. *Robinia Pseudacacia*, L.

I. Taking dry, unopened specimens, note all the external features, as form, surface, color, and texture. Are there any remains of floral structures?

II. Open the pod and draw in outline the inner surface of one of the halves, showing the position, attachment, and form of the seeds. Locate the **funiculus** and **micropyle**, and indicate their position by letters and dotted lines.

III. Describe the structure and mode of **dehiscence** of the fruit and classify it. How many **carpels** are there?

POPPY. *Papaver somniferum*, L.

I. With uninjured commercial specimens note

1. The general external characters.
2. The peculiar stigma. Count the number of divisions.
3. Mode of dehiscence.

II. Make a transverse section and examine the internal structure. Ascertain

1. Where the seeds are attached.
2. Number and position of the **placentæ.**
3. Number of carpels.

SUGAR MAPLE. *Acer saccharinum*, Wang.

I. Taking dried specimens, gathered the preceding fall, notice

1. The form of the wings.
2. Their size as compared with the rest of the fruit.
3. The lightness and strength of the whole structure. What do you infer as to the mode of dissemination?

II. Make an outline sketch of one of the two halves, **mericarps**, into which the fruit separates.

III. Soak some of the fruits in water, and after an hour notice what changes have taken place. With a sharp knife or scalpel remove the **pericarp**. How does its outer part differ from the inner in texture? Has the seed become wet? Describe the means of protection of the embryo.

IV. Taking a mericarp that has soaked a longer time, or better, one that has lain on the moist ground from the time of its fall, remove the pericarp so as to expose the seed in its natural position. Next remove carefully the seed-coats and examine the embryo. Observe the way it is folded together and the form of the radicle and cotyledons.

V. Classify the fruit.[1]

[1] Cf. Goebel, *Outlines of Classification and Special Morphology*, p. 428; Gray, *Structural Botany*, Chap. VII.

BUTTER-AND-EGGS. *Linaria vulgaris*, Mill.

I. Place some of the dry capsules in water and watch them for a few minutes. Observe and record any changes that take place.

II. Ascertain the following facts:

1. Number of carpels.
2. Position of placentæ.
3. Mode of dehiscence.

CLIMBING BITTER-SWEET. *Celastrus scandens*, L.

I. Examine the dry fruits, noting the number, shape, and position of the reflexed valves.

II. Compare specimens that have been soaked in water an hour or more and note differences.

III. Ascertain the number of seeds and describe them. They are surrounded by a brightly colored **aril**.[1]

IV. Classify the fruit and describe the mode of dehiscence.

CRANBERRY. *Vaccinium macrocarpon*, Ait.

I. Note critically the external features, including the presence or absence of floral envelopes. Can you determine by inspection of the fruit whether the ovary should be described as *superior* or *inferior?*

II. Prepare transverse and longitudinal sections. Determine

1. The number of carpels.
2. Position and direction of seeds. Draw and describe.

[1] Cf. Gray, *Structural Botany*, pp. 308, 309.

CLASSIFICATION OF FRUITS.

After a thorough study of a few such fruits as the foregoing, examine and classify a large number of easily procurable sorts, selected so as to secure as great a variety as possible. See list given above. Careful attention should be given at the same time to their morphology. Endeavor to ascertain in each case how many carpels there are, and what modifications the parts forming the fruit have undergone. It is desirable to adopt some one classification and adhere to it. That of Gray is, on the whole, the most satisfactory.

SPECIAL STUDIES.[1]

I. Projection of seeds.
II. Arrangements for burying seeds.
III. Colors of fruits.
IV. Relationships indicated by fruits.
V. Variation as seen in cultivated fruits.
VI. Minute anatomy of the cherry.
VII. Development of the apple or some other common fruit.

This last may be made an extremely interesting and profitable study. Beginning with the flower of the apple, cherry, or any of the common fruits, watch day by day the changes that take place, keeping a full record of them until the fruit is formed.

[1] *Botanical Gazette*, Vol. VII (1882), pp. 125, 137 ; Vol. XII (1887), p. 225 ; Lubbock, *Flowers, Fruits, and Leaves*, Chap. III ; Wallace, *Darwinism*, pp. 305–308 ; Darwin, *Animals and Plants under Domestication*, Vol. I, Chap. XI ; Strasburger and Hillhouse, *Practical Botany*, p. 347 *et seq.*

REVIEW AND SUMMARY.

After the process of fertilization has taken place, remarkable changes occur aside from those of the ovule already described. The corolla withers, and the ovary increases in size, finally becoming the fruit, which in ordinary cases is to be thought of simply as the ripened ovary. In some species, however, the calyx-tube forms a part of the fruit, and still other exceptional forms of developmental history occur. The wall of the ovary, which becomes the pericarp, generally changes in texture, becoming firm and leathery as in the bean, or fleshy as in the cucumber, or partly fleshy and partly bony as in the cherry, and so on. The pericarp often shows three fairly distinct layers corresponding to the upper and lower epidermis and intervening parenchyma of the carpellary leaf, the outer layer being known as the exocarp, the middle, mesocarp, and the inner, endocarp. Thus, in the peach, the skin is the exocarp, the fleshy part the mesocarp, and the stone the endocarp. In the pod of a bean or pea, the correspondence between the parts of the pericarp and those of the carpellary leaf is still more manifest. In many other fruits the changes that have occurred render this relation less easily observed, and are frequently still more fundamental in character. In some cases in which the ovary is composed of several carpels, only one develops, the rest becoming abortive; in others the ovary becomes divided by one or more septa, which give the fruit the appearance of having arisen from a compound pistil with more than the actual number of carpels. These and other important features of the developmental history of fruits are best understood by a careful comparison of their structure in different stages of growth from the pistil to the mature condition.

Development of the fruit.

Many of the peculiarities just referred to find their explanation in physiological adaptations, chiefly those connected with protection and the dissemination of seeds. Physiological adaptations. Attention has already been directed to these in our study of seeds, but they may now be briefly noticed with more direct reference to the fruit. Fleshy fruits, particularly if brightly colored, are attractive to animals, and are carried away by them in great numbers, often to very remote places. One has only to recall the habits of birds in distributing seeds of cherries, strawberries, and many other fruits, to realize the importance of these common and familiar but nicely adjusted relations. Other fruits, such as nuts of various kinds, though less attractive externally, are carried away by squirrels and other animals for the sake of the abundant food stored up in them. Still other fruits, such as the samara of the hop-tree and maple, have the pericarp greatly modified in adaptation to dissemination by the wind, and a considerable number of dehiscent fruits exhibit mechanical arrangements by which their seeds are forcibly thrown to a considerable distance. Frequently, too, the structure of the fruit is manifestly adapted to secure the protection of the seed. The thick and bitter outer covering of the walnut and its extremely hard shell, the rind of the orange with its pungent, aromatic oil, the extraordinarily multiplied and thickened coverings of the cocoanut, and other arrangements of similar character, are so many means of protection against attacks of animals, the penetration of water and fungous germs, and injury from other destructive agents.

In systematic botany it becomes necessary, for the sake of intelligible description, to employ some one of the various classifications of fruits. At the same time, it must be understood that such classifications are more or less artificial, and that their value is rather that of convenience than as an expression of relationship. Nevertheless it is the case many times that in a given group of plants a certain kind of fruit prevails, not infrequently to the exclusion of all other kinds. Thus the pĕpo is the fruit of the gourd family, the achenium of the composites, and so on, so that by means of the fruit alone it is often possible to determine the relationship of the plant from which it came. Accordingly the student is advised to familiarize himself with the various kinds of fruits by a careful study and classification of such a collection as that of the list in this exercise, and in his subsequent study of special groups of plants to observe how far the kind of fruit is characteristic. Such a mode of procedure will give interest and meaning to what otherwise is likely to be nothing more than a *bête noire* to the beginner.

Classification. Relationships indicated by fruits.

In closing our study of fruits we come back again to the seed, with which we started, and it must already have occurred to those who are in the habit of stopping to think, that the same plant appears at different periods of its life under widely different forms. The seed represents the plant in its period of rest, but it is as truly the plant in this state as in its period of highest activity. We may even hold, perhaps more accurately, that a part of the seed — the embryo — strictly represents the entire plant, the parts around the embryo being merely protective or food-supplying accessories that belong in reality to the preceding generation.[1] We have found it best to study parts of many different species in order to

Cycle of development of flowering plants.

[1] The theory of the alternation of generations and the details of the reproductive process cannot well be discussed until the student is acquainted with flowerless plants.

obtain a general conception of the structure and cycle of development of flowering plants, but if we were to take a single seed, and watch its germination and every detail of its subsequent life and growth, we should find its developmental history a connected synopsis of what we have learned from so many sources. This may be stated briefly as follows: In the spermaphytes, or higher plants, the embryo arises from a single cell, the oösphere, contained in the embryo-sac. The embryo has all the essential vegetative parts of the mature plant, and in germination these are unfolded, finally developing into root, stem, and leaf. Certain buds of the plant in this later stage of its development become ordinary branches, while others undergo extraordinary modifications and become reproductive branches or flowers. In due course of time the oösphere is formed in the embryo-sac of the various ovules, and after fertilization the same history is repeated in a subsequent generation. Later on in our work we shall see that plants lower in the scale of life exhibit similar, though not identical, phases of developmental history. Before proceeding to these, however, we have first to study certain relationships of the higher plants among themselves.

VIII. SEAWEEDS AND THEIR ALLIES. ALGÆ.

MATERIAL REQUIRED.

Green algæ gathered in a fresh condition from different places. Pains should be taken to secure the coarser, branching sorts, common in running water, the fine, silky kinds that grow abundantly in stagnant water, and the dull green felt that forms on the damp ground and in pots in conservatories.

Note to the Teacher. — The arrangement of families and higher groups in the following pages is believed to indicate, as well as a lineal arrangement can, their natural succession, and is that adopted by modern botanical writers. In most preparatory schools, however, certainly in those not fully equipped for microscopic work, the best results will be attained by following a somewhat different order. After studying the organs of flowering plants, it will be found advantageous to pass at once to the Coniferæ, then to the early flowering families of phanerogams, taking them in the order that is most convenient, which will be determined chiefly by time of flowering and abundance of material. As a rule, the cryptogams should be studied later, although in schools provided with a full laboratory outfit the order followed in the book may be the best.

No attempt is made to treat all families alike. The aim is simply to help the student in every case to ascertain existing facts and their meaning. Observation should constantly be directed to the differences and resemblances by which various degrees of relationship are determined. The exercises on the Coniferæ and Ranunculaceæ will serve to indicate the prominence that may properly be given to this idea, which forms the basis of vegetable morphology. On the other hand, observations of distribution and physiological adaptations, too much neglected hitherto, should receive their full share of attention. It is essential that careful descriptions of the plants examined should be written, and that these should be accompanied by sketches. The number of these will vary according to circumstances and the judgment of the teacher, but they are by no means to be omitted.

SPIROGYRA. *S. longata, quinina, etc.*

General Characters.

The soft, green material called "pond scum," growing on the surface of still water, is usually made up largely of Spirogyra, not infrequently several species together. Notice

I. The color, varying according to conditions, so that specimens from different places, or gathered at different times of year, may present a wide range of shades.

II. The delicate and slippery feeling, reminding one of silk when taken between the fingers.

III. The remarkable difference in size of the filaments when examined with a hand lens, or even with the naked eye, if specimens of extreme sizes are compared.

Microscopic Structure.

Mount in water and examine with the compound microscope.

I. Observe that each filament is composed of a single row of cells. Follow one of the filaments to the end. Are the cells composing it of uniform diameter? Of uniform length? How does the terminal cell differ from the others?

II. Study critically the cell structure.

1. Focus slowly and compare one cell with another until you are satisfied as to their geometrical form. Are they "rectangular" or cylindrical?
2. Separate the cell-contents from the cell-membrane by applying a plasmolyzing agent. Two per cent

salt solution is suitable for this purpose. Watch the process of plasmolysis (contraction of the protoplasm and its separation from the cell-membrane).
Sketch one or two of the cells showing the cell-membrane in its place and the contracted protoplasmic contents.

3. Preparing a fresh slide, so as to have the cells in their natural condition, study the cell-contents. How many green bands, **chlorophyll bodies**, are there in each cell? Change the focus slowly, and follow a band from one end of the cell to the other. What is its shape? Is its edge even or irregular? Notice the rounded, highly refractive bodies, **pyrenoids**, contained in it.

4. Treat with iodine solution, and ascertain whether starch occurs in the cells. If so, does it stand in any relation to the pyrenoids?

5. Look for a **nucleus**. This is sometimes brought out very plainly by the action of iodine. In some species it may be seen with perfect clearness without any treatment. Compare different specimens until you know definitely
   a. The position of the nucleus in the cell.
   b. Its shape.
   c. Whether it is connected in any way with other parts of the protoplasmic contents. This is a very interesting point, difficult to determine in some species, but very obvious in others.
   d. Its structure. A **nucleolus** will readily be found. (The finer details of structure require special methods not provided for in this course.)

III. Draw one of the cells with great care large enough to show its complete structure. This will require close attention to details. Repeat, if necessary, until you are satisfied that your drawing represents truthfully a Spirogyra cell.

Describe fully what you have seen so far.

Note. — Possibly some things have escaped notice. The septa between adjacent cells differ widely in different species. There are still other points not likely to be observed except by comparing different forms.

Reproduction.

Spirogyra is reproduced sexually by **zygospores** and non-sexually by **cell-division**.

I. By zygospores. These may be found in the summer time in specimens that look faded or discolored. They are not to be looked for in bright green material.

1. Observe the marked contrast presented by the **conjugating filaments** to those in the vegetative condition. The filaments occur in pairs, one with empty cells, the other containing in each of its cells a large, commonly oval zygospore.
2. Notice the structure of the zygospore, with its heavy wall and dense contents.
3. Compare different specimens, and try to make out the way in which the zygospores have been produced. Notice the **connecting-tube** by which the cells of the empty filament are connected with those of the one containing zygospores. See if there are any cases in which it contains protoplasm. Look for specimens in which instead of a complete tube there are protuberances from the opposite cells of the

two filaments. If the material is favorable, you will be able by continuing such a comparison to observe for yourself the successive stages in the development of the zygospores.[1]

II. By cell-division. The nucleus undergoes a remarkable series of changes, ending in its separating into two new nuclei and the formation of a septum between them. In this way a cell becomes divided into two "daughter cells" which after attaining their full development divide in the same way, the process continuing through a series of generations.[2]

Spirogyra is one of the most abundant and widely distributed of the green algæ. It is always to be had, and is one of the most satisfactory plants with which to begin the study of the plant cell. Zygnema, recognized by its stellate chlorophyll bodies, and Mesocarpus, in which a flat plate takes the place of a spiral band, are both often found with it. All of these, particularly Spirogyra and Mesocarpus, are capable of almost unlimited use in the demonstration of fundamental facts of vegetable physiology. The student will do well to read carefully what is said of Spirogyra in the laboratory manuals, and consult the references in Arthur, Barnes, and Coulter's *Plant Dissection*, and the recent periodical literature.

[1] Cf. Strasburger, *Practical Botany*, p. 247; Sachs, *Physiology of Plants*, pp. 727, 728.

[2] For details of the process, including nuclear changes, see Strasburger's admirable monograph, *Ueber Kern- und Zelltheilung*. Jena, 1888.

VAUCHERIA. *V. sessilis*, Vauch.

General Characters.

Examine with a good hand lens the specimens that have been gathered, some from fresh water, others from moist soil in greenhouses. Notice

I. The coarsely filamentous appearance, and the matting together to form a thick felt, when growing on the soil in flower-pots.

II. The color. Compare with the bright green of some of the finely filamentous sorts growing in water.

Microscopic Structure.

Mount some of the filaments and examine with the compound microscope. Observe

I. The very large size of the cells, a filament, as a rule, consisting of a single cell. Try to find the end of one. Ascertain whether branches are formed.

II. The thick cell-wall. Run two per cent salt solution under the cover glass, and see if the wall becomes more plainly defined.

III. The cell-contents. These present considerable differences, depending on the age of the plant, and the conditions under which it grew. Good specimens show in the thicker protoplasm next to the cell-wall

1. Chlorophyll bodies. Observe their shape.
2. Drops of oil. Apply iodine solution, and determine whether starch also is present.
3. Nuclei. These require special treatment to be brought out satisfactorily.[1]

[1] Cf. Bower and Vines, *Practical Botany*, II, p. 76.

Reproduction.

Vaucheria is reproduced by **oöspores** and also by **swarm-spores.**[1]

I. By oöspores. These are easily obtained from specimens growing on damp earth, and may be satisfactorily studied both in living and alcoholic material. Using first the low power of the compound microscope, observe

1. The organs of reproduction generally growing close together.
   a. The cylindrical **antheridium.**
   b. The obliquely oval **oögonia**, commonly two with each antheridium. Draw.
2. The structure of both antheridium and oögonium. Examine this more in detail, using the high power, and, if practicable, having fresh material.
   a. Early stages of development may be found. If these are met with, make a series of sketches, showing both oögonia and antheridia at different periods.
   b. The process of fertilization should be observed, if possible. It will probably involve the outlay of considerable time, yet there are few plants in which the process can be more satisfactorily followed. It is even more striking in Œdogonium, a plant closely related to Vaucheria, on account of the large size of the antherozoids.[2]

II. By swarm-spores. These cannot always be had when wanted, but are unusually large, and on account of

[1] For other forms of vegetative reproduction, cf. Goebel, *Outlines of Classification and Special Morphology*, p. 32.

[2] For an account of the process and further directions, cf. Strasburger, *Practical Botany*, pp. 252–254.

their peculiarities are worth taking pains to secure. Strasburger recommends[1] that vigorous specimens of Vaucheria, growing in running water, be obtained the day before, placed in shallow vessels, and fresh water poured over them. The swarm-spores are formed the following morning, and, on account of their large size, both their structure and development are readily observed.

No further special directions will be needed beyond those in the manuals referred to, which should be carefully read. As complete a study as possible should be made of this plant, since it stands as a representative of those algæ in which the sexual reproduction has proceeded a step farther than in Spirogyra, male and female cells being distinctly differentiated. Many of these are also reproduced by swarm-spores. These two modes of reproduction are so common that we expect, as a general rule, to find the algæ reproducing themselves both sexually and non-sexually, a fact that continually presents itself in studying other groups of plants, but not often in quite so striking a way as here. The non-sexual process is a means of rapid reproduction; sexual reproduction, on the other hand, commonly results, in the lower plants at least, in the formation of a resting-spore by which the plant is carried through various vicissitudes and dangers, and in which by a mingling of the male and female elements in the process of fertilization, certain other advantages, not yet fully understood, are attained.

The brown and red algæ grow in salt water in nearly all cases, and are seaweeds properly so called. They present many forms no less interesting than the green algæ, but as they will not be accessible to the great majority of those

[1] *Practical Botany*, p. 250. See also Bower and Vines, *Practical Botany*, II, pp. 78–80.

who are likely to use this book their study has not been introduced. The various text-books and manuals give the necessary help for beginning their study.[1]

[1] No provision is made in this work for the study of fungi, not because they are unimportant, but because it is better on the whole that the student should complete his preparatory course with the definite understanding that he knows nothing whatever about this vast and heterogeneous group. Their introduction, moreover, would break the natural succession that the beginner especially should keep continually in view.

IX. MOSSES AND LIVERWORTS. MUSCINEÆ.

MATERIAL REQUIRED.

A collection of common mosses of different genera, *e.g.* Bryum, Climacium, Mnium, Polytrichum, Cylindrothecium, Sphagnum, and others. With care in selecting, and by gathering material at different times, some specimens will be obtained in fruit, others in the vegetative condition, and still others with archegonia and antheridia.

A similar collection of liverworts, including representatives of the genera Conocephalus, Lunularia, Riccia, Porella, etc.

MOSSES. *Musci.*

General Characters.

Without selecting one species for exclusive study, compare the different kinds of mosses in the collection that has been made, and ascertain what general characters they have in common. Notice

I. Their choice of locality. By what does it appear to be determined? Are the habits of the different species alike in this respect?

II. Whether they grow separately or in tufts.

III. The differentiation of vegetative organs. Is there a plain distinction of root, stem, and leaf? If so, is it equally marked in the different species?

IV. Differences of size, color, and other specific characters.

V. The fructification, — when fully developed a very conspicuous part of the plant.

Rhizoids.

I. Examine the different species with reference to the occurrence of roots. They are found to have the form of hair-like bodies, **root-hairs**, or **rhizoids**. Where do they arise? Are they limited to any one part of the plant?

II. Remove some of the rhizoids, mount in the usual way, and examine under the compound microscope. Prepare several slides, taking the root-hairs from different species, and from different parts of the same plant for comparison.

1. Notice first the color, mode of branching, and other external features.
2. Study more closely the minute structure, observing the form of the cells composing the rhizoids, the character of their contents, and position of the septa.[1]
3. Notice whether the younger cells of the rhizoids differ from the older ones, and if so how. Also whether exposure to different conditions, as a greater or less amount of light, has any effect on the character of the cells or their contents.

Stem.

I. Compare the stems of the different mosses, and observe their differences of size and habit, contrasting the erect, rigid stem of Climacium with the delicate, spreading branches of Mnium, the minute forms of Barbula with the coarse Polytrichum, and so on.

[1] Cf. Sachs, *Physiology of Plants*, p. 30.

II. Cut thin transverse sections of the stems of two or three different species, and study them under the compound microscope. Beginning with the outside, notice

1. The **epidermis**, consisting of a single layer of peripheral cells. Underneath this, in some of the species, are similar, thick-walled cells, the whole forming a cylindrical band of mechanical tissue.
2. The **cortex**, consisting of rounded cells, often containing starch and oil.
3. The **axial cylinder**, an extremely simple form of fibro-vascular bundle, occupying the center of the stem, and made up of much narrower elements than those composing the cortex. Longitudinal sections show that these are also much more elongated than the cortical cells are. Observe also whether they differ from the latter in the color of their walls and the character of their contents.

Leaf.

I. Examine next the ordinary **foliage leaves** of the different species, observing

1. Their differences of size, form, and other external features.
2. Their relation to the stem. Are they stalked or sessile? Is their arrangement on the stem alike in the different species?
3. The structure of an individual leaf, as far as this can be observed under a good lens. Notice particularly the margins and midrib.

II. Study fresh and well-developed leaves, such as those of new shoots of Mnium, with the compound microscope. The cellular structure will be found beautifully distinct, the cells containing large and clearly defined chlorophyll bodies. Notice their position in the cells; does it appear to be constant?

A little attention will show that the leaf is not a simple plate of cells throughout. Examine the midrib and compare with the axial cylinder of the stem.

III. Look for other kinds of leaves, **scale leaves,** of frequent occurrence, especially on the lower part of the stem, and **perichætial leaves,** forming a rosette, usually at the apex of fruiting stems.[1]

Fructification.

I. Taking any of the mosses in the collection that are in fruit — several species if possible — observe

1. The slender stalk, **seta,** on which is borne
2. The **capsule,** containing spores.
   Compare the capsules of different species as to size, form, color, and other features.

II. Make a thorough study of the parts composing the capsule, using the compound microscope when needed.

1. The **calyptra,** commonly a thin membrane covering the apical part of the capsule; rarely, as in Polytrichum, a thick hairy cap. Notice the form, differing in different genera.
2. The **operculum,** in most genera a conical lid, fitting closely to the end of the capsule, but thrown off when the latter is fully ripe, thus permitting the scattering of the spores.
3. Lightly covered by the operculum when it is in place, but showing conspicuously when it is re-

[1] For further suggestions cf. Arthur, Barnes, and Coulter, *Plant Dissection*, p. 84 *et seq.*

moved, the **peristome**, or circle of teeth surrounding the opening of the capsule. The peristome presents a widely different appearance in the different genera, and its structure requires careful study. It consists of four, eight, sixteen, thirty-two, or sixty-four teeth, plain, or variously cut and ribbed, and often very hygroscopic. In a few genera the peristome is wanting.

4. Within the capsule, the **spores** filling a cylindrical space which surrounds a central mass of tissue called the **columella**.

5. In some mosses, besides the parts already named, there are to be observed the **epiphragm**, a thin, membranaceous structure, stretching across the mouth of the capsule; and at the base of the capsule a swelling called the **apophysis**.

NOTE. — The structure of the capsule should be studied in detail in a number of different mosses, and descriptions accompanied by careful drawings should be written. The peristome, especially, is very characteristic and furnishes important features for the systematic study of the group.

Protonema.

If ripe spores are sown on moist soil, or on a compact clump of moss, and kept under a bell-jar at the temperature of an ordinary living room, the early stages of development of the **protonema** are easily observed. The spore swells and pushes out a papilla which elongates into a tubular cell. This increases in length, becomes septate, and branches are formed.

The later stages of development may be followed out with the same material; but there are some advantages in obtaining vigorous specimens by the simple expedient of turning a clump of moss bottom side up, and keeping it in a moist atmosphere for a week or two. By this means the relation of rhizoids and protonema is made clear. It is seen that they are the same thing, the filamentous growth taking the appearance and structure of protonema or rhizoids according to the conditions under which it grows. It is also seen that the protonema may originate from other parts of the plant, as well as from the spore.

On the protonema, whether it has its origin in the spore, or from some other part of the plant, buds arise, from which new plants are formed.

Archegonia and Antheridia.

Among the specimens, if these have been gathered at different times of year, some will be likely to show "**flowering heads,**" most frequently terminating the stem, and surrounded by a more or less conspicuous rosette of leaves, the **perichætium.** The antheridia and archegonia may occur together in the same "flower," or in separate flowers, on the same or on different individuals.

The whole structure is best studied by means of longitudinal sections, which are easily made with a razor, after a little practice, without any previous preparation of the specimen. Examining such sections under the microscope, if we chance to have selected a male specimen we shall find antheridia in great numbers growing at the apex of the axis, and with them slender, filamentous bodies, **paraphyses,** while outside of both is the circle of perichætial leaves. The antheridia are sacs, usually oblong in shape, with a wall consisting of a single layer of cells, the interior being composed of the mother cells of the antherozoids. The latter are ciliated, protoplasmic bodies, closely resembling those of the ferns. In the examination of a female specimen the paraphyses are seen as before, but archegonia take the place of antheridia. A fully formed archegonium is a flask-shaped body with an elongated **neck**, and an enlarged **ventral portion**, within which is the **oösphere.**

Fertilization takes place by the mingling of the substance of an antherozoid with that of the oösphere, after the antherozoid has forced it way down through the long canal of the neck. The fertilized oösphere, now called the **oöspore**, becomes septate, and by still further cell-division and growth the capsule with its seta, spores, and various parts already described, is formed.

With suitable material and sufficient time the student can readily verify most of the facts here given.

Cycle of Development.

It will be observed that in the mosses **alternation of generations** takes place. The **sporophyte**, or non-sexual generation, begins with the formation of the oöspore and closes with the spore, while the **oöphyte**, or sexual generation, begins with the germination of the spore, and includes both protonema and leafy plant.

Note. — It is important that this should be perfectly clear. The student must see for himself the various stages of development of the mosses as far as this is practicable. He may now consult the various text-books and manuals, particularly those of Goebel, Arthur, Barnes, and Coulter, Bower and Vines, and the references given by them. See further on this subject under Ferns.

The peat mosses, Sphagnaceæ, are easily obtained in many parts of the country, and afford an opportunity for extended and profitable comparative study. Their habits, structure of the vegetative organs, and fructification, all present interesting points of difference from the true mosses.

LIVERWORTS. *Hepaticæ.*

The liverworts are closely allied to the mosses, their cycle of development being essentially identical with that of the latter group. Accordingly our work will be restricted to a comparison of the general characters of some of the most easily procurable liverworts. Representatives of the genera named at the beginning of this section are widely distributed and easily obtained through a considerable part of the year. Lunularia is of almost universal occurrence in greenhouses, and while seldom if ever found in fruit, almost always has gemmæ in different stages of development. Conocephalus is common and abundant in moist, shady places. The floating species of Riccia have a wide range, as do also some of the species of Porella. These and other genera will furnish a full supply of material for comparative study.

The student is advised to proceed with his preliminary observations as he did with the mosses, comparing a number of different kinds, instead of confining his attention to a single species. Differences of habit between these and the mosses, the bilateral and dorsi-ventral frond of the liverworts, their texture and anatomical structure, and peculiarities of fructification should all be noted. If the mosses have already been studied as directed, there will be little difficulty, with suitable material and the help of the various manuals, in obtaining a corresponding general view of the structure and habits of the liverworts.

Many interesting subjects for more extended investigation present themselves; among them the following are suggested as

SPECIAL STUDIES.

I. Development of the gemmæ. Lunularia offers excellent and abundant material for this, and its gemmæ, on account of their simplicity, are among the best objects with which to begin studies of developmental history.

II. Comparison of the anatomy of Conocephalus with that of Marchantia. The latter is selected because of its being so fully described in the books. For the former, Lunularia or some other genus may be substituted if more convenient.

III. Rhizoids of liverworts compared with those of mosses.

IV. Structure of the mature sporocarp in the different families of liverworts.

V. Comparison of the archegonia and antheridia of liverworts and mosses.

VI. Alternation of generations as seen in mosses and liverworts compared with the ferns and other vascular cryptogams. This will naturally be postponed until after the study of the latter groups. It will be found that in the ferns the oöphytic generation is reduced to a green prothallium, and in the club-mosses and their allies a still further reduction takes place.

VII. Origin of the calyptra of mosses.

X. FERNS. **FILICINEÆ.**

MATERIAL REQUIRED.

Shield-fern, *Aspidium cristatum*, Swartz, gathered in summer when the fructification is fully developed.

Similar specimens of maidenhair, *Adiantum pedatum*, L., brake, *Pteris aquilina*, L., spleenwort, *Asplenium Filix-fœmina*, Bernh.

Representatives of other genera of ferns that are procurable, such as Cystopteris, Woodwardia, Osmunda, Dicksonia, etc.

SHIELD-FERN. *Aspidium cristatum*, Swartz.

General Characters.

I. Record first what you have observed as to the habits and habitat of the plant. Does it grow in moist or dry ground? in shady places or in the open? How do its habits compare with those of other ferns, as regards choice of soil and surroundings?[1]

II. Notice the parts of the plant.

1. The underground stem, from which arise
2. Large, compound leaves, **fronds**, and
3. Roots. Observe their origin, form, and structure.

Leaf.

The leaf is the most characteristic part of the fern, and is to be studied in detail. Notice

[1] Cf. Underwood, *Our Native Ferns and their Allies*.

I. The leaf-stalk, **stipe**, with many thin, brown scales. Are these persistent or deciduous?

II. The outline of the frond and the form of its main divisions, **pinnæ**.

III. How the pinnæ are divided. Compare the description of this species in Gray's *Manual*, p. 688.

IV. The **venation**. Select one of the pinnæ in which this is well defined, and draw it carefully in outline, taking pains to represent accurately the exact position of the veins, tracing them to the end of their ultimate divisions.

Fructification.

I. The conspicuous bodies on the under side of the pinnæ are the **sori**, or fruit-dots. Observe

1. Their position. Are they situated on the back or alongside of the veinlet?
2. The thin, scale-like covering, **indusium**, protecting the spores.

II. Taking specimens nearly or quite mature, remove the indusium, and with a good lens look at the spore-cases, **sporangia**. Mount in water in the usual way, and examine under a low power of the compound microscope. Observe

1. The general form and structure of the sporangium,—a flattened sac, the walls of which are composed of distinct cells.
2. The **annulus**, a row of thick-walled cells, forming a continuation of the **stalk**. Does the annulus extend completely around the sporangium?

III. Examine the sporangia under a high power, observing them in different positions. Compare different specimens and draw a perfect one.

IV. Using material that has been kept in alcohol, mount some of the sporangia in water as before, and examine microscopically. Run a drop of glycerine under the cover glass and notice the result. Repeat the experiment until you are satisfied as to the way the spores are discharged from the sporangium.

Note. — This is by no means an easy problem. Notice where the sporangium ruptures, the form of the cells composing the annulus, and the changes they undergo with its change of position. Try the use of different media, such as strong salt solution, etc. Compare the sporangia of different ferns, and see whether all have the same structure and behave alike.

V. Under the highest power, study the form and structure of the **spores**. Draw one or more of them.

VI. Taking almost any sorus except the oldest ones, study the **development of the sporangium** by carefully comparing the structure at different ages. A series of drawings should be made illustrating as many stages as possible.[1]

Prothallium.

If fern spores are sown on soil, or on pieces of decayed wood, and are kept in a moist atmosphere, they will germinate, and give rise to a structure known as the **prothallium**.

I. The early stages of development of the prothallium are easily observed by examining the spores at intervals during the first few days after they have been sown. Microscopic examination shows that the spore swells, the outer coat, **exospore**, ruptures, and the inner coat, **endospore**, protrudes in the form of a papilla, which rapidly elongates into a delicate, tube-like structure, the first **root-hair**. The

[1] Cf. Goebel, *Outlines of Classification and Special Morphology*, p. 217 *et seq.*

spore itself elongates at the same time and becomes septate, the septa at first arising at right angles to its direction of growth. By further growth, and a series of divisions in different directions, the mature prothallium is finally produced. While the prothallium is in the early, or filamentous stage of its development, the form and contents of its cells and other structural details are easily observed. Full descriptions, accompanied by careful drawings, should be made.[1]

II. The mature prothallium may be raised successfully by taking care of the specimens that have been started as directed above; but since they require weeks, or even months, to attain their full development, it is more convenient to obtain prothallia from conservatories where ferns are cultivated. In the pots containing ferns, or on the surface of the moist earth near by, one can frequently find excellent specimens. They are generally heart-shaped, a few millimeters to a centimeter in diameter, of a delicate green color, and so much like small liverworts as sometimes to deceive experienced collectors.

An uninjured specimen that has been carefully washed, so as to remove the adherent particles of earth, shows under the microscope a deep anterior depression, **sinus**, and back of this a thickened portion of the prothallium, sometimes called the **cushion**. The latter is several layers of cells in thickness, while the parts nearer the margin are but one layer thick. **Rhizoids** in great numbers arise from the lower surface. The **growing point** is at the base of the depression. The arrangement of the cells at this point indicates their order of development, which is readily

[1] For a model cf. Campbell, *Development of the Ostrich Fern*. Memoirs, Boston Soc. Nat. Hist., Vol. IV, No. II (1887).

made out if younger specimens of different ages are compared.

After the points named have been observed, drawings of the mature prothallium should be made and compared with those of earlier stages. If the material is suitable for the purpose, intermediate stages of development also may be studied.

III. On the lower side of the mature prothallium **archegonia** and **antheridia** are produced. These are organs of reproduction, corresponding in function to the "essential organs" of flowering plants. The archegonia are usually situated near the sinus. They are flask-shaped bodies, the lower portion of which is sunk in the tissue of the prothallium, while the **neck** projects above the surface. The neck consists of a wall made up of four longitudinal rows of cells, surrounding a single row of **canal-cells** which lead down to the **oösphere.** The latter is the cell from which, after fertilization, the embryo, *i.e.* the young frond, arises.

The antheridia are, as a rule, more remote from the sinus, and present the appearance of small, hemispherical protuberances, consisting of a wall one layer of cells thick, which encloses the **mother-cells** of the **antherozoids.** The latter are minute, ciliated, protoplasmic bodies, and are the active agents of fertilization. They are best observed by placing in water on a slide prothallia that have been kept rather dry for some time. After the water has been absorbed by the antheridium the latter ruptures, and the antherozoids in great numbers are seen in active motion, swarming in the field of the microscope like so many animalcules. Under favorable circumstances they have been seen to move towards an archegonium and enter it, passing down through the canal-cells which have now become mucilaginous. The union of an antherozoid with the oösphere is necessary in order to the subsequent development of the latter.[1]

Developmental History and Minute Anatomy.[2]

The oösphere after fertilization becomes surrounded by a cell-membrane, and is now known as the **oöspore.** It is afterwards divided into two cells by a septum nearly parallel with the axis of the archegonium. This is followed by the formation of two additional septa at right angles with the first and with each other, the oöspore being thus divided into eight parts or octants. Further cell-division takes place, and the embryo soon shows a differentiation into a **foot**, or absorptive organ, by which it draws nutriment from the prothallium, a **first root, leaf,** and **stem.** The first leaf, root, and foot are temporary structures, all of them serving the needs of the plant for a comparatively short period. The stem, on the other hand, is of slow growth, but is permanent, and finally attains the size and structure that it exhibits in the mature plant; roots and leaves arise from it, the prothallium finally disappears, and the so-called **sporophyte** takes the place of the preceding or **oöphyte** generation.

[1] Only a bare outline is given above. For further details the student should consult Strasburger, *Practical Botany*, pp. 290–296; Bennett and Murray, *Cryptogamic Botany*, p. 64 *et seq.*; Goebel, *Outlines of Classification and Special Morphology*, p. 198 *et seq.*, and references given by the authors just named. For some of the most recent and valuable contributions see Campbell, *Development of the Ostrich Fern*, and various papers by the same author in the *Botanical Gazette*, *Annals of Botany,* and other periodicals.

[2] A practical study of the developmental history of ferns requires more time than can possibly be given to it in a preparatory course, and accordingly it is thought best to omit altogether directions for laboratory work, merely giving a *résumé* of the cycle of development as it has been worked out by different botanists. Cf. Goebel, *l.c.*, p. 204 *et seq.*

The **alternation of generations** just referred to appears very clearly in the ferns. The oöphyte, or sexual generation, includes the stage beginning with the germination of the spore and closing with the fertilization of the oösphere. The sporophyte, or non-sexual generation, begins with the formation of the oöspore and closes with the mature spore. The prothallium is, therefore, the characteristic feature of the oöphytic generation, and the leafy plant, in this case the "fern," of the sporophytic generation.[1]

Full instruction for the study of the minute anatomy of ferns is given in a number of accessible manuals, and need not be repeated here. A quite full and satisfactory account of Pteris is given by Sedgwick and Wilson in their *General Biology;* Adiantum is well treated by Arthur, Barnes, and Coulter in the *Plant Dissection;* and Bower and Vines give sufficient help for a thorough microscopic study of Aspidium. It appears to the writer better, if the time is limited, to undertake complete examination of only one part, preferably the stem, since the leaf repeats in its general structure much of what has already been seen in the flowering plants. In studying the stem, most of the time should be given to the fibro-vascular bundle, including a comparison of its structure with that of the bundle of Indian corn and the apple tree. The investigation may well be extended to various other plants; but its success will depend on the preparation and judgment of the teacher, and the previous training of the student. On the whole, a comprehensive study of the fibro-vascular

[1] So much depends on a correct conception of the alternation of generations, that the teacher is advised to review, illustrate, and, in short, use all means to make it clear. It stands as a prominent developmental character, common to all the groups of plants from mosses to phanerogams. Cf. Sachs, *History of Botany*, pp. 200, 201.

bundle hardly falls within the scope of an elementary course.

RELATIONSHIP.

A careful comparative study of a number of prominent genera of ferns should be made. Those named above are widely distributed, and, in general, easily procurable. For this part of the work, dried specimens are nearly or quite as satisfactory as fresh ones. The comparison, while including a study of external characters, should be directed primarily to the fructification, which presents the really distinctive features of the different genera. It is necessary in each of the genera studied, to observe particularly the form of the sorus and indusium, and the way in which the latter is attached to the leaf. If ten or a dozen different kinds of ferns are studied in this way, with accompanying drawings and descriptions, the student will have learned from his own observation the salient characters of the ferns as a group, the marks that distinguish the more prominent genera, and the features by which the species belonging to them are recognized.[1]

The ferns include three thousand or more species, varying widely among themselves in habits and external features. With leaves of extraordinary variety and beauty; their texture delicate or coriaceous, or extremely thin and translucent, as in the filmy ferns; of various habits, creeping, climbing, erect, or tree-like; growing in every quarter of the globe, and yet exhibiting marked preferences of soil and surroundings; a dominant group in earlier geological time, and still holding a manifest supremacy among the higher cryptogams, — they present themselves as one of the most varied and attractive, and at the same time most easily

[1] For further hints see Underwood, *Our Native Ferns and their Allies.*

studied groups of plants. They are of special interest as representatives of the higher flowerless plants, the **vascular cryptogams,** since they share with them certain developmental features that are wanting or are imperfectly seen in phanerogams. The alternation of generations is far more easily recognized here than in flowering plants, since both generations are characterized by structures of considerable size. The oöphyte, or sexual generation, presents us with the prothallium, which is a relatively conspicuous, leaf-like body, bearing archegonia and antheridia, structures that do not occur in the same form in phanerogams.[1] The systematic literature is extended and rather expensive. Eaton's *Ferns of North America* is the best for this country, and the works of Hooker and Baker give the most help on foreign species; but with Gray's *Manual* or Underwood's little book, the student will be able to identify without difficulty the ferns indigenous to the region where he lives, and this is suggested to him as an interesting and instructive piece of systematic work.

[1] On the homologies of these organs as they exist in higher plants cf. Bennett and Murray, *Cryptogamic Botany*, p. 11 *et seq.;* Goebel, *Outlines of Classification and Special Morphology;* Macmillan, *Metaspermæ of the Minnesota Valley*, and recent periodical literature.

XI. HORSETAILS. EQUISETINEÆ.

MATERIAL REQUIRED.

Common horsetail, *Equisetum arvense*, L. The fertile fronds must be gathered in the spring when the spores are mature. These are preferably examined fresh, but may be preserved in alcohol. Sterile fronds in the early stages of development may be gathered at the same time, but fully formed ones will have to be obtained later in the season, unless they are pressed or put up in alcohol the preceding year. Underground stems, with fronds attached, should be collected.

Other species of the same genus, such as the scouring-rush, *Equisetum hiemale*, L., and others.

COMMON HORSETAIL. *Equisetum arvense*, L.

General Characters.

I. Note first the habits of the plant, the places in which it grows best, and the time of year when it appears above ground.

II. Compare the two forms that arise from the same rootstock, the **fertile** and **sterile fronds**, noting points of likeness and difference.

III. Examine the underground stem, observing its peculiarities of form, size, and structure as compared with the aërial stems.

Fertile Frond.

I. Examine the fertile frond throughout, and describe in detail its characteristic features. Notice

1. The succession of **nodes** and **internodes**. Are there any branches?
2. The whorls of **modified leaves** arising at the nodes. How many leaves are there at each node? Are they separate or united? Do they differ in either texture or color from the stem? If so, how?
3. Surface, form, and structure of the stem. Cut a transverse section of an internode and examine under a dissecting microscope. Is it solid or hollow? Notice the openings, **lacunæ**, and their number and position. Are these constant in different specimens? Is there any mechanical advantage in such a disposition of material?

   Make an outline sketch of the section, using, if necessary, a higher magnifying power.

II. Study next the **spike** terminating the stem and bearing the fructification. It will be seen that it is a modified portion of the stem, showing a succession of nodes and internodes, and exhibiting more or less perfectly the same structural features as other parts of the stem.

1. With a pair of fine forceps remove one or more of the leaves, here called **scales**, and examine them carefully. Their study will be facilitated by making transverse and longitudinal sections of the spike, so as to expose the scales more fully. Are they stalked or sessile? Draw one in outline.
2. Examine under a lens the spore-cases, **sporangia**, borne on the under surface of each scale. How many are there? What is their shape? Make an outline sketch.

III. Remove carefully one of the sporangia, mount in water, and examine with the compound microscope. Be sure to have a well-formed and uninjured specimen. Observe the peculiar structure of the cells that compose the sporangium wall. Ascertain, if you can, how the sporangium opens.[1] Draw carefully a few of the cells, using the high power.

IV. Examine the spores under the high power of the compound microscope, mounting some of them in water and others dry. How do the dry ones differ from those in water? Breathe gently on them, and see if any changes take place. Draw one or more of the spores with their slender, hygroscopic appendages, **elaters.**

V. Sow some of the spores in water and others on moist soil, and at intervals examine with the microscope. Germination of the spores and the early stages of development of the prothallium are easily observed, and should be figured and described.

Sterile Frond.

I. Examine specimens of the sterile frond throughout, comparing them in detail with the fertile ones. How do they differ from the latter in size, color, texture, formation of branches, and structure on transverse section? Is there a "division of labor"? If so, point out what you conceive to be the most important function of the fertile frond; of the sterile frond.

II. Study the **fibro-vascular bundles**, and compare with those of the fertile frond. Verify the details of structure as given by Goebel, *Outlines of Classification and Special Morphology*, pp. 270–272.

[1] Cf. Newcombe, *Spore-dissemination of Equisetum*, Bot. Gaz., Vol. XIII (1888), p. 173.

RELATIONSHIP.

With the species already studied compare others of the same genus, such as *Equisetum hiemale*, L., *E. limosum*, L., etc. Do these species show the same general structure? Do they present the same differentiation into fertile and sterile fronds?

Comparison with still other species of the single genus now composing this family[1] shows that the Equisetineæ possess very marked and characteristic features by which they are distinguished from all other families of plants. At the same time their close relationship with the ferns is evident when their developmental history is followed out. If the spores of the common horsetail are sown as directed above, the development of the prothallium, including the formation of archegonia and antheridia, can be observed in detail in the course of a few weeks, and affords a most instructive study.[2] If this study is carried far enough to include the formation of the embryo and growth of the young plant, it is seen that the cycle of development is essentially identical with that of the ferns.

[1] The horsetails are remnants of a family which once flourished luxuriantly, reaching its highest development in the Carboniferous period, when there were several genera, including a number of tree-like species.

[2] Cf. Campbell, *Male Prothallium of the Common Horsetail*, Amer. Nat., 1883, p. 10.

XII. CLUB-MOSSES AND THEIR ALLIES.

LYCOPODINEÆ.

MATERIAL REQUIRED.

Fresh specimens of Selaginella from the conservatory. A number of species are common in cultivation, and any of them may be used.

Club-moss, *Lycopodium clavatum*, L., with spore-bearing spikes. Similar specimens of other species of the same genus, *e.g. L. lucidulum*, Michx., *L. complanatum*, L., etc.

Any other vascular cryptogams that are procurable, as Marsilia or Isoëtes.

SELAGINELLA. *S. stolonifera, denticulata, etc.*

General Characters.

I. Record your observations of the plant as a whole. Where did it grow, and under what conditions? Point out any peculiarities of form, texture, or habit, by which it would readily be distinguished from ferns.

II. Examine carefully the mode of branching. Draw a diagram to represent it. Is it **dichotomous** or **monopodial**?[1] The plant is said to be **bilateral** and **dorsi-ventral**; show how this is true. How do you distinguish between the **dorsal** and **ventral** aspect of the plant?[2]

III. Describe the form and arrangement of the leaves. Are they all alike? How many rows are there?

IV. On well-developed specimens, slender, root-like organs, **rhizophores**, are to be found. Notice where these

[1] Cf. Bower and Vines, *Practical Botany*, I, p. 162.

[2] Cf. Strasburger, *Practical Botany*, p. 296.

arise, whether from the lower (ventral), or upper (dorsal) side of the stem. Where their ends come in contact with the soil, roots are produced. Observe their peculiar mode of branching, unusual for roots.

Fructification.

The **fertile branches** are not particularly conspicuous and may be overlooked; they are readily recognized, however, by their rigid, erect habit and quadrangular outline, in contrast with the flattened and spreading sterile branches.

I. Notice the form and arrangement of the leaves. How do they differ from those of other parts of the plant?

II. The spore-cases, **sporangia**, arise singly in the axils of the leaves. They are of two kinds, **microsporangia** in the axils of the upper leaves, and **macrosporangia**, few in number, in the axils of the lower leaves of the fertile branch. Examine different specimens, under a good lens, until you are satisfied as to the position of the two kinds of sporangia and their external differences.

III. With a pair of fine forceps remove the upper part of a fertile branch with its microsporangia. Dissect carefully on a slide, and examine with the low power of the compound microscope. Compare the sporangia as they lie in various positions and notice

1. The exact relation of the sporangium to the stem and leaf, and whether it is stalked or sessile.
2. Its form and mode of dehiscence.

   NOTE.— The *cause* of the opening of the sporangium may not be obvious, but there is no difficulty in finding the line of dehiscence and observing the escape of the spores.

3. The structure of the sporangium wall.
4. The spores, set free in great numbers when the spo-

rangium opens. From their small size, as compared with those produced in the macrosporangia, these are called **microspores**. With the high power, observe

a. The form of the microspores. Are they strictly spherical?

b. Their structure, particularly the spiny exospore and granular contents.

IV. Remove a macrosporangium from the lower part of a fertile branch and examine on the slide, using first a good lens, and afterwards the compound microscope. Observe

1. The obvious external differences by which this is distinguished from the microsporangium.
2. The number of spores contained in the sporangium. From their relatively large size, these are called **macrospores.**
3. The structure of the macrospores. This is readily made out by simply treating with potash solution, and dissecting away the hard external coat, as recommended by Bower and Vines.[1] After removal of the exospore, the smooth, light-colored endospore is found, and the contents of the spore, chiefly oil and aleurone grains, with the mass of cells composing the prothallium, are plainly seen. Sectioning must be resorted to, if these are shown accurately in position; but all of them can be recognized easily and satisfactorily by following the treatment suggested.

NOTE.— It is important that these parts should be clearly seen and understood. In Selaginella the prothallium is formed before

[1] *Practical Botany*, I, p. 173.

the spore has left the mother plant, and it is still for some time enclosed in the macrospore, which also contains a large amount of food materials. The whole structure shows a likeness on the one hand to the spores of other vascular cryptogams, and on the other to the embryo-sac of flowering plants.

Developmental History and Minute Anatomy.

As in the case of the fern, a laboratory study of the developmental history requires a special investigation extending through some weeks or months. The following important features of the cycle of development may be mentioned: Selaginella, as well as the ferns and horsetails, is characterized by alternation of the oöphyte, or sexual generation, with the sporophyte, or non-sexual generation. The latter differs widely from that of the ferns, in that instead of one kind of spore, giving rise to prothallia which bear both antheridia and archegonia, there are two kinds, macrospores, or female (archegonia-bearing) spores, and microspores, or male (antheridia-bearing) spores, are produced, — a distinct foreshadowing of what is seen in flowering plants, — the microspores corresponding to pollen-grains, and the macrospores to the embryo-sac of the ovule. The oöphyte, again, as compared with that of the ferns, is reduced in size, and all its early stages of development are completed *within* the spore, reminding us of similar facts in the developmental history of phanerogams. The prothallium of the microspore, in particular, is reduced to the lowest terms, and should be compared with the two or more vegetative cells (rudimentary prothallium) in the pollen-grain of certain gymnosperms. The archegonia, produced only on the prothallium of the macrospore, are essentially like those of ferns, though somewhat simpler, but after fertilization the first septum of the oöspore is formed at right angles to the axis of the archegonium, and the upper of the two cells thus formed develops into a **suspensor**, a structure characteristic of flowering plants, but occurring in few cryptogams.

RELATIONSHIP.

It is desirable that at least the external characters and fructification of one or more additional genera of vascular cryptogams should be studied in connection with the preceding ones; but specific directions are omitted, partly because of uncertainty as to material likely to be procurable, and partly because it is understood that by this time the student should be in a position to make an intelligent comparative study of at least the general characters of any group to which he has already given special attention. Club-mosses are as likely to be available as any of the Lycopodineæ, since they are pretty widely distributed, and besides are extensively used for Christmas decorations. As they appear in market in the middle of winter they are frequently in fruit. Marsilia and Isoëtes are of great interest, and when they can be obtained may well claim a considerable share of the time given to this group. Aside from the manuals and text-books, the references given below will be found serviceable to those who undertake a further study of the vascular cryptogams.[1]

[1] Campbell, *Development of Pilularia globulifera*, L., Annals of Botany, Vol. II, p. 233; *Contributions to the Life-History of Isoëtes*, Annals of Botany, Vol. V, p. 231; *On the Prothallium and Embryo of Osmunda Claytoniana*, L., and *O. cinnamomea*, L., Annals of Botany, Vol. VI, p. 49; *On the Affinities of the Filicineæ*, Botanical Gazette, Vol. XV (1890), p. 1; *On the Relationships of the Archegoniata*, Botanical Gazette, Vol. XVI (1891), p. 323. Frequent references to other important literature are given by the author in the papers cited.

XIII. THE PINE FAMILY. CONIFERÆ.

MATERIAL REQUIRED.

Twigs of the following species: White pine, *Pinus Strobus*, L.; Austrian pine, *Pinus Austriaca*, Hœss; Norway spruce, *Picea excelsa*, Lk.; Hemlock, *Tsuga Canadensis*, Carr.; Juniper, *Juniperus communis*, L.; Red cedar, *Juniperus Virginiana*, L.; Arbor Vitæ, *Thuja occidentalis*, L.

Mature fruits of the preceding, and flowers, both staminate and pistillate, as far as these can be procured.

Substitutions, such as Scotch in place of Austrian pine, may be made as occasion requires.

WHITE AND AUSTRIAN PINE.

I. Compare branches of the two species as to **surface markings** and other external characters.

II. Compare the **foliage leaves.**

1. How many are produced in a fascicle? Examine specimens enough of both species to determine the general rule, since exceptions frequently occur.
2. How do those of the two species differ in length, thickness, rigidity, and color?
3. With a sharp knife make a transverse section of a leaf of each kind. Examine with a lens and note difference of outline.

III. Examine next the different sorts of **scale-like leaves.** Notice

1. Differences of size and texture.

2. Whether they are **deciduous** or **persistent**. Do the two species agree in this respect?

IV. Study **cones** of the two species, and note the points in which they agree or differ.

V. Extend the comparison, if practicable, to the standing trees, observing their mode of branching and other characteristic features.

VI. Finally, passing in review all the points to which attention has been called, summarize your observations in a brief written description, taking care to bring out clearly the distinctive characteristics of each species.

NORWAY SPRUCE. HEMLOCK.

Determine in what respects the Norway spruce differs from the pines. Is the arrangement of the branches the same? How do the leaves compare in size, form, and mode of insertion with those of the pines? Compare the terminal buds. Is there anything common to the cones of the two species of pines not belonging to those of the Norway spruce? Do the seeds of the latter differ in any structural particular from those of the former?

In the same way compare the hemlock with the different species already studied, noting arrangement of branches, position, form, and size of leaves, peculiarities of terminal buds, structure of cones, and other characteristic features.

JUNIPER AND RED CEDAR.

I. Compare the two species and note all points of difference and resemblance.

1. What is the form of the leaves of the juniper? Number of leaves in a **whorl**? How do those of the red cedar compare in size, shape, and arrange-

ment with those of the juniper? Are the leaves of the red cedar all alike? Do they all exhibit the same arrangement?

2. If the fruits are to be had, study their structure and points of resemblance and difference.
3. If living specimens are accessible, compare the habits of the two species. Which assumes the size and habits of a tree? Is this difference constant?

II. Next compare these with the conifers previously studied. What characters are common to the juniper and red cedar that do not belong to the pine, spruce, and hemlock?

ARBOR VITÆ.

I. Observe the form of the leaves and their arrangement on the branches. Are the leaves all alike? Do they exhibit any structural peculiarity not observed in those of the other conifers?

II. Compare the cones with those of other genera. Is the arrangement of the scales the same? How does it compare with the leaf arrangement?

When the pollen of the different species begins to be shed in May, compare the structure of the flowers, both staminate and pistillate, of as many different conifers as can be obtained.

I. How do the staminate flowers of the hemlock differ from those of the Norway spruce? From those of the pines? What peculiarities are presented by those of the red cedar?

II. Make a similar comparison of the pistillate flowers?

III. Of all the species studied which are **monœcious?** Are any of them **diœcious?**

Write a brief summary of the particulars in which all the species thus far examined agree. These, with certain features that you have not yet observed, constitute the family characters of the Coniferæ.

RELATIONSHIP.

From the preceding study it will be easy to understand something of the relationship of plants and the way this is determined by botanists.

1. Plants that are related to each other show a mutual resemblance. This may be observed in
   - *a.* External features and habits, including form, direction of growth, etc.
   - *b.* Structure.
   - *c.* Reproduction.
   - *d.* Developmental history.
   - *e.* To some extent, physiological peculiarities. But in this respect closely related plants often show great differences.

In our study of the conifers we have directed our attention chiefly to external features.

2. Plants exhibit degrees of relationship, those most closely related being most alike, while those remotely related are less alike.
3. Plants that are related as parents and offspring, forming a succession of individuals not to be distinguished from each other by any constant differences, constitute a **species**. The white pine is one species, the Austrian pine another, and so on.
4. Closely related species constitute a **genus**. Thus the various species of pines together make up the

genus Pinus, and the different species of juniper, the genus Juniperus. We have thus far studied one or more representatives of each of the genera Pinus, Juniperus, Picea, Tsuga, Thuja.

5. Closely related genera constitute a **family**. The genera just named, with a number of others, make up the Coniferæ, or Pine family.
6. Closely related families constitute higher groups, sometimes designated as **orders**, though the usage is not uniform. Finally, orders (of flowering plants) are grouped together in the great **classes** gymnosperms, monocotyledons, and dicotyledons.

The relationships here pointed out are those of descent. It is believed that just as all individuals of a species are descendants of a common ancestor, so all the species of a genus and all the genera of a family have a common, though remote origin.

We shall have constant opportunity in our further study of plants to become acquainted with specific, generic, and family characters. Their recognition is frequently attended with some difficulty, and in all cases the exercise of careful judgment is required. In fact botanical work consists very largely in accumulating evidence by which degrees of relationship are determined.

XIV. THE GRASS FAMILY. GRAMINEÆ.[1]

MATERIAL REQUIRED.

Entire plants of cultivated wheat, soon after it has headed out.

Similar specimens of the following grasses: Chess, *Bromus secalinus*, L.; Quick-grass, *Agropyrum repens*, Beauv.; Orchard-grass, *Dactylis glomerata*, L.; Fowl meadow-grass, *Glyceria nervata*, Trin.; Barn-yard-grass, *Panicum Crus-galli*, L.; Indian rice, *Zizania aquatica*, L.; Bur-grass, *Cenchrus tribuloides*, L.; Beard-grass, *Andropogon furcatus*, Muhl.; Timothy, *Phleum pratense*, L.; June grass, *Poa pratensis*, L.

Some of these can be obtained in a suitable condition for study early in June in the northern States, and at a still earlier date farther south; others are best examined in late summer or autumn. Rye may be used instead of wheat, and other substitutions may be made if necessary.

WHEAT. *Triticum vulgare*, Villars.

General Characters.

I. Taking a number of entire and uninjured specimens, determine first the relation of the stem and root system. Is there anything to show whether more than one culm is produced from a grain of wheat? "By the process of tillering, or multiplication of stems from one root . . . over fifteen hundred grains have been obtained from a single seed." The beginnings of this process may be observed in seedlings of wheat started in the laboratory.

II. Examine the stem, **culm**, and note all peculiarities of

[1] The Gramineæ will be studied to better advantage after some other families of monocotyledons, such, for example, as the Liliaceæ.

form and structure. Is any mechanical principle involved in the disposition of material? Observe the number and position of the **nodes** (parts of the stem to which the leaves are attached). Do they contribute in any way to the strength of the structure?

Bend the culm through several degrees, after stripping off the leaves. Where are the weakest parts? Is there any special protection or support for these parts?

Taken as a whole, is the stem satisfactorily constructed to sustain the weight of the head and resist the stress of winds?

NOTE.— Microscopic examination shows a simple but effective arrangement of the mechanical elements of the culm, by which great strength is secured with a minimum of material.[1]

III. Take up next the relation of leaves and stem. How are the leaves attached? Are their sheaths entire or slit? What is the leaf arrangement?

IV. Note the form and structure of the leaves, and the manner in which they twist in drying.[2]

Notice the appendage of the leaf at the angle made by the blade and culm. What is it morphologically, and what is it called?[3]

Inflorescence and Flowers.

I. Notice first the general features of the inflorescence. It has the form of a thickened **spike**, composed of many **spikelets**. The latter are arranged alternately on each side of a "zigzag, jointed, channelled rachis." Remove half a dozen or more of the lower spikelets to make this more obvious.

II. Study next the structure of one of the spikelets. Each spikelet includes several flowers and is subtended by

[1] Cf. Haberlandt, *Physiologische Pflanzenanatomie*, p. 114 *et seq.*

[2] Cf. Beal, *Grasses of North America*, p. 29 *et seq.*

[3] Cf. Gray, *Structural Botany*, p. 106.

two **glumes**. Observe the form and texture of the glumes. Are they symmetrical or one-sided? Is their surface smooth or hairy? Are there any longitudinal ribs or "nerves"?

III. Ascertain how many flowers there are in a spikelet. Each of the fully developed flowers is subtended by a **floral glume** and a **palet**. The former, in the bearded varieties of wheat, bears at its apex a long, barbed **awn**.

IV. Compare carefully the floral glume and palet, noting their differences of form, position, and structure.

V. Separate the floral glume and palet so as to expose the parts of the flower within. Examine flowers of different ages until the essential organs are found in good condition. How many stamens are there? How many stigmas? Look for some minute, scale-like bodies, **lodicules**. How many are there, and where are they placed?

VI. Construct a diagram of the flower, showing the position of the floral glume, palet, lodicules, stamens, and pistil.[1]

VII. Open different flowers of the same head, and continue the examination until the relations of anther and stigma are ascertained. Does it appear that the flowers of wheat are cross- or self-fertilized.[2]

RELATIONSHIP.

Obtain good specimens of any of the genera named above, and compare them with wheat throughout, noting all points of difference and agreement. Chess is excellent

[1] Cf. Eichler, *Blüthendiagramme*, p. 119 *et seq.* Some interesting suggestions are given by Allen, *Flowers and their Pedigrees*, p. 160 *et seq.*

[2] Cf. Beal, *l.c.*, p. 37 *et seq.*

to begin with, on account of the simplicity and distinctness of its floral structures. Many of the other genera are likely to prove rather troublesome until the student has had some experience.

After careful comparison of as many different kinds of grasses as practicable, summarize your observations in a general account of the characters of the Gramineæ.

This family includes some four thousand species and is of great economical importance, since it furnishes, directly or indirectly, by far the larger part of the food of the human race. Botanically it presents many points of interest. While there are many species of grasses within the tropics, they form a characteristic "sod" only in the cooler parts of the world. Some depart so widely from the habits of those we have studied as to be properly reckoned among climbing plants. Although giving evidence of very considerable modification, the flowers are, with few exceptions, destitute of odor and attractive colors, and are either self-fertilized or depend for fertilization on the agency of the wind. The seeds are disseminated in a variety of ways, some passing undigested through the alimentary canal of herbivorous animals, others, as Cenchrus, bearing hooked or spiny appendages, and still others, as Stipa, provided with a twisting awn that attaches itself to the coats of animals or buries the grain in the earth. In Tripsacum the joints of the spike break apart and are often floated away by water, while species of Panicum and Eragrostis are blown about by the wind as "tumble-weeds." The cultivation of the most important grains is prehistoric and their origin uncertain.[1]

[1] Cf. De Candolle, *Origin of Cultivated Plants*, p. 354 *et. seq.;* Hackel, *The True Grasses;* Beal, *Grasses of North America.*

XV. THE SEDGE FAMILY. CYPERACEÆ.

The study of this family involves no little difficulty, and its various genera present such wide differences that it is impossible to select one that may be taken strictly as a "type." Nevertheless, it is desirable that at least the conspicuous and widely distributed genus Carex should be familiarly known.

As a convenient representative, we select one of the most common species.

CAREX. *C. hystricina*, Muhl.

General Characters.

Note the locality and choice of surroundings, the habit of growth, whether in clumps or scattered, the height to which the plant grows, and general resemblance, if any, to other plants already studied.

Stem and Leaves.

I. Notice the form and structure of the **culm.** How does it differ from that of wheat and other grasses?

II. Note the relation of stem and leaves. In how many ranks are the latter disposed? How do their sheaths differ from those of the grasses? Is there a **ligule?**

III. Describe the leaves as to form and surface. Observe their behavior in drying.

Inflorescence and Flowers.

I. How many inflorescences are there? Are they sessile or stalked?

II. Beginning with the lowest inflorescence, study carefully the individual flowers. Note first that each flower is borne in the axil of a bract or **scale.** Describe the latter as to form, color, and structure.

III. Each flower is further protected by a sac called the **perigynium.** Examine this, observing critically its form and surface, venation, and the long beak terminating above in two sharp teeth.

IV. Open the perigynium and examine the pistillate flower. It consists of a single pistil, which in some species of Carex has two stigmas with a lenticular ovary, **caryopsis,** while in others the caryopsis is triangular, and the stigmas are three in number. Which do you find to be the case in this species?

V. Taking younger specimens, examine the uppermost (staminate) spikes. How do they differ in external features from the pistillate ones? Is each flower subtended by a scale? Does it have a perigynium? How many stamens are there?

VI. From the observed facts, what do you infer as to the mode of fertilization?

RELATIONSHIP.

A number of other species should, if possible, be compared with the one just studied. *Carex lupulina*, *utriculata*, *stricta*, *gracillima*, *laxiflora*, *Pennsylvanica*, *rosea*, etc., are of common occurrence and suitable for such a comparison. The beginner will do well to heed Professor Bailey's remark to the effect that this is "an exceedingly critical genus, the study of which should be attempted only with complete and fully mature specimens." After becoming familiar with several representatives of the genus Carex, some time may be given to a few other genera of Cyperaceæ, as, for example, Cyperus, Eleocharis, Scirpus, and Eriophorum. An intelligent comparison of a limited number of well-developed and well-chosen forms will place the student in a position to continue his work satisfactorily; but the study of sedges demands clear judgment and unlimited patience, and will never prove attractive to any one who is not possessed of these qualities. For classification, Gray's *Manual*, sixth edition, will serve a good purpose. Professor L. H. Bailey's *Types of the Genus Carex*, Memoirs of the Torrey Botanical Club, Vol. I, No. I, is the most important contribution that has yet been made to our knowledge of North American species.

XVI. THE ARUM FAMILY. **ARACEÆ.**

MATERIAL REQUIRED.

Entire plants of Indian turnip, *Arisæma triphyllum*, Torr., in flower.
Similar specimens of skunk-cabbage, *Symplocarpus fœtidus*, Salisb.
Flowers of cultivated calla, *Richardia Africana*, Kunth.
Other plants of this order that are procurable, such as sweet-flag, *Acorus Calamus*, L., and any of the cultivated aroids.

INDIAN TURNIP. *Arisæma triphyllum*, Torr.

General Characters.

Examine entire specimens in a fresh condition. Note

I. The thick, rounded, underground stem, **corm**, more or less wrinkled externally.

II. Long fibrous roots growing out from its upper part.

III. Above ground, the smooth, cylindrical stem with membranaceous, sheath-like leaves below, and one or two large, compound, foliage leaves above. Describe the latter in detail.

IV. The peculiar venation, differing from that of a majority of monocotyledons. Sketch one of the leaflets in outline, and point out the mechanical advantages.

V. Note the acrid taste due to the mechanical effect of the raphides (crystals) on the tongue and throat.

Inflorescence and Flowers.

I. The inflorescence is covered by a peculiarly shaped, arched **spathe**. Compare this in a number of specimens, and note variations.

II. Open a spathe so as to explore the parts within. Observe

1. The elongated, club-shaped, sterile portion of the **spadix.**
2. The lower, fertile part, on which the naked flowers are borne.

III. Examine the flowers of a number of different individuals. It will be seen that, as a rule, some have only pistillate flowers and others only staminate ones. Notice

1. The very simple structure of the staminate flowers and the mode of dehiscence of their anthers.
2. The closely packed pistillate flowers, each with a sessile, white stigma. Make sections and ascertain the structure of the ovary, and the number and position of the ovules.

IV. Ascertain by a further comparison of specimens whether this species is strictly **diœcious.**

V. If *Arisæma Dracontium*, Schott., can be obtained, compare it throughout with the species just studied, noting carefully all points of likeness and difference.

SKUNK-CABBAGE. *Symplocarpus fœtidus*, Salisb.

General Characters.

The skunk-cabbage is in flower very early in the season. Its striking features at once attract attention. The disagreeable odor, suggesting its common name, the thick, shell-like spathe enclosing the large, rounded spadix, the ample leaves, and numerous long, fleshy roots, arising from the thickened rootstock, mark this as an exceedingly well-defined species. Record what you have observed regarding the habitat and duration of the plant, and any other characters not mentioned above. Do its habits indicate that it is indigenous?

Inflorescence and Flowers.

I. In studying the plant, remove the spathe, observing meantime whether any special devices exist for the attraction of visitors.

II. Examine the spadix carefully, comparing it in plants of different ages. The flowers are said to be **proterogynous.** Is the statement confirmed by your observation?

III. Satisfy yourself by a further comparison of specimens whether self-fertilization is possible.[1]

IV. Examine the individual flowers, making sections for this purpose that will show their structure and relation to the axis of inflorescence. Are all the flowers perfect? How do the stamens of older flowers differ from those less developed?

V. Construct a diagram showing the plan of the flower.

CALLA. *Richardia Africana*, Kunth.

Compare the inflorescence and flowers of the cultivated calla with those of the preceding species. Note

I. The color and form of the spathe.

II. The structure of the flowers. Are they perfect? Are there any floral envelopes?

III. How do those of the upper part of the spadix compare with those of the lower portion?

[1] Cf. Trelease, *Am. Nat.*, September, 1879.

A comparative study should be made of such other aroids as can be procured, *e.g.* sweet-flag, water-arum, etc. Aside from the peculiarities of their inflorescence, which mark them as a unique group, the acrid properties of many members of this family constitute a marked feature.[1]

[1] Müller, *Fertilization of Flowers*, pp. 562–565, should be consulted. Some interesting facts and suggestions are given by Allen, *Flowers and their Pedigrees*, pp. 236–266. Certain peculiarities of fruits and seeds may be looked for as different genera are examined, such as

1. The gelatinous outer surface of the fruit of Peltandra.
2. The seeds, — albuminous in some genera and exalbuminous in others.
3. The embryo, — green in a number of genera.

XVII. THE LILY FAMILY. LILIACEÆ.

MATERIAL REQUIRED.

Yellow adder's-tongue, *Erythronium Americanum*, Ker., in flower.
Representatives of other conspicuous genera of this family, as for example: Convallaria, Ornithogalum, Smilacina, Uvularia, Lilium, etc.

Taking any of the plants named above, when in full bloom, examine the structure of the flower, studying it whorl by whorl, as directed in the case of Trillium, Section VI.

Comparison of even a few genera of Liliaceæ is sufficient to show very wide differences of external features. At the same time the regularity and fixed plan of the flower afford constant and distinctive characters by which the immediate recognition of the family is assured. The student, however, should compare the flowers of a number of different species until their morphology is perfectly familiar. This is the more important, inasmuch as the flower of the Liliaceæ serves as a type with which to compare the modified flowers of a number of related families of monocotyledons.

The family includes about sixteen hundred species, inhabiting chiefly the temperate and warmer regions of the globe. Many of the most pleasing and widely cultivated ornamental plants, among them the tulip, lily, hyacinth, and lily-of-the-valley, belong to this family. With them are also included such medicinal plants as aloe, sarsaparilla, etc., and, among vegetables, the onion, asparagus, and some others. The extraordinary extent to which the vegetative organs have been modified, as illustrated by the cladophylls of asparagus and Ruscus, indicate a comparatively remote origin, notwithstanding the relative simplicity of the flowers, some of which, however, as the Yucca, exhibit very remarkable relations to insects.

The student is advised to extend his acquaintance to as many genera as possible, and to follow as far as opportunity offers, the transitional stages through which it is believed that the more highly developed ones have passed.[1] See Müller's admirable review of the Liliaceæ, *Fertilization of Flowers*, pp. 558, 559, and the papers of Riley and Trelease, third and fourth annual reports of the Missouri Botanical Garden, 1892 and 1893.

[1] A number of interesting points for comparison will present themselves as the family is studied, *e.g.*

1. The nectaries which vary much in different genera.

2. Bulblets produced in the axils of the leaves of Lilium.

3. Wide differences of underground stems. Contrast the creeping rootstock of Smilacina, Medeola, etc., with the bulb of Lilium and Scilla.

XVIII. AMARYLLIS FAMILY.

AMARYLLIDACEÆ.

MATERIAL REQUIRED.

Flowers of the cultivated Amaryllis in various stages of development. Specimens should be selected that have just opened, others more advanced, and still others that have been open a longer time. In addition to these a single entire plant.

Other representatives of the family that are procurable, such as Hypoxis, Galanthus, or Narcissus, in flower.

I. In what particular does the flower of the Amaryllis differ from that of the lily? From that of the Iris?

II. How does the plant as a whole differ from those of the Iridaceæ that you have studied?

III. Compare a number of flowers of Amaryllis, in different stages of development. What arrangements do you find for cross-fertilization? To what class of visitors are many of the plants of this family adapted?[1]

IV. Having examined as many plants of the Amaryllidaceæ as are to be had, enumerate the essential features that they possess in common.

V. Finally point out the characters in which all three families, Amaryllidaceæ, Iridaceæ, and Liliaceæ, agree.

The close relationship of these three families of plants is obvious upon acquaintance with even a few species. The

[1] Cf. Müller, *Fertilization of Flowers*, p. 560.

first "differs from the Liliaceæ in the inferior ovary," and approaches the simple forms of the Iridaceæ, which, however, are distinguished by having three stamens instead of six.

Note.—Exercises of this kind should be introduced and frequently repeated, as soon as the pupil is in possession of a sufficient number of observations to make intelligent comparisons. By this means the important fact will become impressed on the mind, that groups of related families may be recognized by their common characters, precisely as groups of related genera are.

XIX. THE IRIS FAMILY. **IRIDACEÆ.**

MATERIAL REQUIRED.

Blue flag, *Iris versicolor*, L., in flower.
Blue-eyed grass, *Sisyrinchium angustifolium*, Mill.
Cultivated Iris, Gladiolus, and Crocus.

BLUE FLAG. *Iris versicolor*, L.

Distribution and General Characters.

I. Does the plant manifest a decided choice of locality? Is there anything to indicate whether it is an indigenous species?

II. Notice the form and arrangement of the leaves. They are described as **equitant**. When studying other species recall this peculiarity, and observe whether it is characteristic of the family. How do the **bracts** that subtend the flowers compare with the stem leaves?

III. Write a description of the plant as a whole, including rootstock, stem, and leaves.

Flower.

I. Study first the morphological characters.

1. Look over the flower, whorl by whorl, and see whether you recognize each part.
2. Determine the plan. How many divisions of the perianth are there? How many stamens and styles? Does the plan of the flower differ in any particular from that of the lily (or Trillium)?

3. Study carefully the modifications exhibited by this flower, as compared with the lily taken as a type. Have any parts been suppressed? Does adnation occur? What are some of the most striking peculiarities of form and structure?

II. Examine each part in detail with reference to the arrangements for cross-fertilization.

1. Enumerate the attractive features.
2. Ascertain whether there is a store of nectar, and if so whether there are any path-pointers to direct visiting insects towards it.
3. Observe particularly the position of stamens and stigma.
    a. Position of the anther and its mode of dehiscence.
    b. Location of the stigmatic surface. Examine under a good lens.

"The curved style-branches have at their tip a small deltoid crest which turns slightly backward. Under this there is a thin shelf, the upper surface of which is covered with minute hairs, and is moistened with a sticky secretion. This shelf is the true stigma." Verify this description as given by Dr. Goodale, *Wild Flowers of America*, p. 34.

What do all these peculiarities of structure, color, and arrangement suggest? Do you regard self-fertilization as possible in this species? If you infer that cross-fertilization takes place, show how this is probably brought about.[1]

BLUE-EYED GRASS. *Sisyrinchium angustifolium*, Mill.

This species is widely distributed, and continues to flower for some weeks, so that it can usually be obtained for comparison.

[1] Cf. Gray, *How Plants Behave*, pp. 21, 25; Müller, *Fertilization of Flowers*, p. 543 *et seq.*

I. With entire specimens make a careful study of the blue-eyed grass, noting all the points in which it agrees with the Iris or differs from it.

1. Compare the essential organs as to number, position, and structure.
2. How does the perianth differ from that of the Iris?
3. Compare leaves, stem, and roots.

II. Record concisely the results of your comparative study of the two genera, taking care to bring out the really essential features that indicate their relationship.

In like manner compare with the two preceding species any other plants of this family that can be procured, as the cultivated Gladiolus or Crocus. Some of the latter open early in the spring, and the study of the Iridaceæ may begin with them if more convenient. After studying as many representatives of the family as practicable, summarize your observations in a brief synopsis of the characters common to them all. As a subject of special investigation, a comparative study of the arrangements for fertilization in the Iridaceæ is suggested.

XX. THE ORCHIS FAMILY. ORCHIDACEÆ.

MATERIAL REQUIRED.

Yellow lady's-slipper, *Cypripedium pubescens*, Willd., and Arethusa, *Arethusa bulbosa*, L., in flower. Other species of Cypripedium may be substituted for the former, and Calopogon or Pogonia for the latter. If it is impossible to obtain indigenous species, various tropical orchids can be procured through florists in the larger cities, who will deliver them safely at a distance. The expense is of small moment compared with what is gained by having a familiar acquaintance with at least two or three representatives of a family of plants in which mechanical contrivances for securing cross-fertilization have been carried to the highest degree of perfection.

YELLOW LADY'S-SLIPPER. *Cypripedium pubescens*, Willd.

Flower.

Our study will be restricted to the flower, which, though greatly modified, has departed from the type less than those of other genera, and remains "as a record of a former and more simple state" of the great family to which it belongs.[1]

I. Notice first the most conspicuous external features.

1. The nodding flower, generally single, terminating the leafy stem.
2. The floral envelopes.
   a. Three sepals, of which the upper one is the largest, the two lower united into one, but showing at the apex a trace of their original separation.

[1] Darwin, *Fertilization of Orchids*, p. 226.

b. The petals, of which the two lateral ones resemble the sepals, but are narrower and more or less twisted, while the lower[1] is developed into a large sac, the lip or **labellum.**

3. The essential organs. These have been greatly modified, and are united above into an organ called the **column.** Note

a. The three stamens, the single sterile one forming a broadly triangular body, the apex of which projects slightly into the opening of the labellum, and the two lateral fertile ones, each with a large anther on the under side.

b. The fleshy stigma, arching under the sterile stamen, the stigmatic surface covered with minute papillæ. This is seen to better advantage after the removal of the floral envelopes.

II. Having learned the parts of the flower, endeavor next to understand their homologies. Such a study is extremely interesting, showing as it does "how curiously a flower may be moulded out of many separate organs, — how perfect the cohesion of primordially distinct parts may become, — how organs may be used for purposes widely different from their proper uses, — how other organs may be entirely suppressed, or leave mere useless emblems of their former existence, — and finally . . . how enormous has been the amount of change which these flowers have undergone from their parental or typical form."[2]

[1] "The lip (in the Orchidaceæ) is really the upper petal, *i.e.* the one next to the axis, but by a twist of the ovary of half a turn it is more commonly directed forward, and brought next to the bract."

[2] Darwin, *l.c.*, p. 234.

1. Compare the flower throughout with that of the lily (or Trillium) previously studied, endeavoring to ascertain the character and extent of its modifications.
    a. How does the ovary compare with that of the lily as regards adnation of the floral envelopes?
    b. In what parts of the flower has coalescence occurred?
    c. Has suppression of any parts taken place?
    d. Point out the most striking modifications of form.[1]
2. Construct a diagram and compare with that of the lily.[2]

NOTE. — The student cannot hope to understand all of this at once. The distance between the lily and the lady's-slipper is too great to be bridged by a single effort of the imagination. Let him do his best with the flower itself, then read the references, then lay the whole matter aside, and return to it again after other representatives of the family have been studied.

III. The striking modifications of the flower of Cypripedium are correlated with the visits of insects on which it is dependent for fertilization.

1. There are certain peculiarities likely to prove attractive to insect visitors. Enumerate these.
2. Assuming that an insect, a bee for example, is about to pass into the interior of the labellum, where would it be likely to enter? Would it probably pass out by the same opening?
3. Examine carefully the structural peculiarities of the lip. Find where the tissue is thinnest, and accord-

[1] Cf. Gray, *Structural Botany*, p. 179 *et seq.*

[2] Cf. Goodale, *Wild Flowers of America*, p. 86; Darwin, *Fertilization of Orchids*, pp. 234–246.

ingly where the most light is admitted. If the insect crawling on the floor of the labellum moves towards the part that is best lighted, which direction will it take? Are there any path-pointers?

4. Examine more closely the pollen masses. Notice particularly their adhesive inner surface. Observe the form and structure of the stigma, and see how the pollen is retained when applied to its surface.
5. Endeavor to interpret these peculiar arrangements. If practicable, observe the action of visiting insects.[1]

ARETHUSA. *Arethusa bulbosa*, L.

Study the flower as directed in the case of Cypripedium, with reference to

I. External features, such as form and position of parts, color, odor, etc.

II. Morphological characters.

Examine each whorl critically. Determine the plan of the flower and note modifications. In what important particular does the androecium differ from that of Cypripedium?

Construct a diagram, and compare with that of the flower of Cypripedium.[2]

III. Physiological adaptations.

While plainly dependent on insects for fertilization, the flower of Arethusa presents a very different mechanism from that of Cypripedium. Examine carefully the rela-

[1] Cf. Müller, *Fertilization of Flowers*, pp. 539–542; Gray, *Am. Jour. Sci.*, XXXIV (1862), pp. 420–429; Darwin, *l.c.*, p. 230.

[2] Cf. Goodale, *l.c.*

tive position of anther and stigma, and endeavor to make out for yourself how this arrangement prevents the application of its own pollen to the stigma of a given flower, and at the same time favors cross-fertilization.[1]

RELATIONSHIP.

This large family of plants includes about three thousand species, widely distributed in both hemispheres, and showing the highest specialization of the flower yet attained in the vegetable kingdom. Many of the most conspicuous and curious kinds are tropical epiphytes, and are frequently cultivated in conservatories. As Müller points out, the family is remarkable for the great differences of habit exhibited by the different species, the extraordinary modifications of its flowers, and the great number of seeds produced in a single fruit. The differences of habit, some being epiphytic, others saprophytic, and so on, indicate great capacity of the vegetative organs for variation, and the modifications of the flowers are manifestly correlated with the visits of insects. Cross-fertilization is the rule, but here again "orchids show the greatest possible differences, all of which, however, are linked together by intermediate conditions. We find in this order, cleistogamic flowers and open flowers; flowers regularly or occasionally self-fertilized; others never self-fertilized, though quite fertile to their own pollen if it be applied artificially; flowers absolutely sterile to their own pollen, though fertile not only to the pollen of their own species but even to that of other species of their own genus; finally, species in which pollinia and stigma of the same individual act as fatal poisons to one another."[2]

[1] Cf. Gray, *How Plants Behave.*

[2] Müller, *l.c.*, pp. 527, 528.

The homologies of the flowers of orchids have been discussed at length by Darwin and others. The following may be given as a brief *résumé* of the most essential facts: Comparing the flower of an orchid with a simpler one, such as a lily, the several whorls are seen to have undergone varying degrees of modification. The three sepals are readily identified, although they are usually petal-like in structure, and two, or sometimes all three, may have undergone coalescence. Of the three petals, the two lateral ones are alike, while the third, called the lip, is enlarged and differs widely in form from the other two. The essential organs are consolidated into a single body, the column. In the genus Cypripedium one stamen has become abortive, while the two remaining ones produce pollen; in the other genera of the family only one stamen, as a rule, is perfect. The ovary shows its origin in three carpels; but it is one-celled, and the three placentæ are parietal.

Theoretically it is held that originally the stamens were in two whorls of three each, and that in Cypripedium the staminode (abortive stamen) belongs to the outer whorl and the two fertile ones to the inner, while in other genera, in the great majority of cases, this relation is reversed. For a brief but satisfactory statement of this, with good diagrams, see Luerssen, *Botanik*, p. 469.

XXI. THE WILLOW FAMILY. SALICACEÆ.

MATERIAL REQUIRED.

Branches of the earliest flowering willow, *Salix discolor*, Muhl., gathered in the early spring before the leaves appear. Specimens with both staminate and pistillate flowers are wanted. (*Salix cordata*, or other species may be substituted.) Similar branches of different kinds of poplar, *Populus tremuloides*, Michx., and other species.

WILLOWS.

General Characters.

Beginning with the willows, observe the various external characters, such as

1. Form and structure of buds.
2. Color of the bark. Is it smooth or rough?
3. Texture of the twigs. Are they lithe or brittle?

Note. — Such characters are frequently of much more importance than they appear to be at first sight. The twigs of some species of willows are extremely brittle at the base, and being easily detached serve as a means of propagation; while their color and surface are sometimes so characteristic as to become an important factor in classification.

Flowers.

I. Examine first the **staminate catkins.**

1. Ascertain what constitutes the individual flower. (Each flower is subtended by a small hairy **scale.**) Under a lens determine
   a. The shape of the scale.
   b. Whether the margin is cut or entire.

c. Where the numerous silky hairs are attached.

2. Study the flower itself.

 a. How many stamens are there?

 b. Is a **nectary** (organ that secretes nectar) present?

II. Examine next the **pistillate catkins**.

1. In what respects do they differ from the staminate ones? Are the scales alike in both?

2. Note the peculiarities of the pistil.

 a. Its form.

 b. Stalked or sessile?

 c. Number and form of stigmas.

 d. How many carpels compose the ovary?

 e. Is there a nectary?

III. Are the flowers visited by insects? Enumerate the attractions adapted to secure insect visits.[1]

Fruits.

When the fruits are ripe, observe their structure and mode of dehiscence, the attachment of the seeds and their peculiarities, particularly their means of dissemination.

Comparison with Other Species.

Some days later, as soon as they are in proper condition for examination, study the catkins of other kinds of willows (*Salix cordata*, Muhl., *S. lucida*, Muhl., or other available species), and note all the characters in which they agree with the species already studied.

POPLARS.

In the same manner make a careful study of one or more common species of poplar and compare them with the willows.

[1] Cf. Müller, *Fertilization of Flowers*, p. 524.

I. Note first their external characters and habits, and notice in what respects they differ from those of the willows. Compare

1. Bark.
2. Buds, particularly the surface of the bud-scales.
3. Leaves.
4. Branches, as to size, texture, and surface marking.

II. Carry out, step by step, a thorough comparison of the inflorescence and flowers.

1. How do the scales of the poplar catkin differ from those of the willows?
2. Do the flowers of the poplar have any structure that is wanting to those of the willows?
3. Compare the number of stamens in the two genera.
4. Are their fruits and seeds essentially alike?

III. Finally, after several species of each have been studied, record all the characters in which willows and poplars agree. The characters exhibited by all of them in common are those of the willow family (Salicaceæ).

SPECIAL STUDIES.

I. Determination of species of poplar, by means of winter buds.

II. Recognition of different species of willow by size, habit, and other external features.

NOTE. — The identification of willows and poplars is attended with some difficulty, requiring long practice and the exercise of critical judgment; but it is desirable that even beginners should observe how readily the large-toothed aspen, *Populus grandidentata*, may be distinguished from *Populus tremuloides* by its bud-scales, how *Salix lucida* is at once recognized by its leaves, and how *Salix alba* and *Salix nigra* are distinguishable from other species by their size and from each other by their habit, even at a distance. Simple exercises of this sort may be introduced occasionally with great advantage.

XXII. THE CROWFOOT FAMILY.

RANUNCULACEÆ.

MATERIAL REQUIRED.

Specimens of the early crowfoot, *Ranunculus fascicularis*, Muhl., some in flower, others in fruit.

Similar specimens, as they can be obtained, of *Anemone nemorosa*, L., and *Caltha palustris*, L.

Representatives of other genera, such as Hepatica, Clematis, Aquilegia, Actæa, Hydrastis, etc.

EARLY CROWFOOT. *Rununculus fascicularis*, Muhl.

Distribution.

Record what you have observed as to the habitat of this species. For the use of the term habitat cf. Gray, *Structural Botany*, p. 366. Do you regard it as indigenous or introduced?

Note. — This is often a difficult question to settle. We have to depend partly on recorded observations and partly on what we now see of the habits of the plant, the places where it grows, the direction in which it spreads, and so on. Trustworthy evidence is attained when competent botanists actually observe for a period of years and record the stations occupied by the species in question.

Observations of this kind are of much interest, and if properly conducted may be made of great scientific value. Constant changes in the vegetation of a given locality are taking place, due either to the introduction of foreign species or to the disappearance of indigenous plants, as the result of changed climatic and other conditions. Some introduced plants have so taken possession of territory invaded by them as to become formidable rivals of the native species, and even to crowd them out. The Canada thistle, prickly lettuce, butter-and-eggs, hound's tongue, and many others are among the undesirable accessions to our native flora, some of them extending over wide areas in the course of a few years..

In collecting data regarding the distribution of a species, you should first of all record where you have seen the plant growing. To this add any observations you may have made as to its choiçe of locality, behavior from year to year, increase in number, liability to extermination, etc. To be accepted as trustworthy, notes of this kind must be accompanied by specimens.

With perfect specimens at hand examine the parts of the plant in order.

Roots.

Describe their shape. What direction do they take? How do those of last year differ from those of the present year? Are there any fine, fibrous roots? if so, where do they arise?

NOTE.—A comparison of different specimens shows an interesting division of labor.

The smaller fibrous roots absorb from the soil water and crude materials that are passed on to the leaves. In the latter, starch and other reserve substances are produced, and are then carried down to the spindle-shaped roots where they are stored until the next year. At the time of flowering the roots of last year have already become exhausted, and look old and wrinkled, while the new ones that are to take their place have not nearly attained their full size. There are, then, three different sets of roots performing as many different functions. One set is absorbing, another is feeding the rapidly growing plant, and the third set is developing into a storehouse in which will be laid up during the summer a supply of food for future use.

Leaves.

Most of the leaves arise from a very short stem, and appear as if they grew directly from the roots; accordingly they are described as "radical." One or more leaves are borne on the flowering stems and are spoken of as "cauline."

I. Describe first the radical leaves. Compare specimens and see whether the same description will answer for all of them.

II. Examine the cauline leaves of a number of different individuals and note the various forms.

III. Are there any means of protection?

NOTE. — Do not answer the question hastily. Hairs on delicate plants sometimes protect their tissues against cold, sometimes against small, soft-bodied animals that might devour them or climb up to the flowers and steal the nectar, and again, the presence of acrid juice may render them distasteful to grazing animals. See, if you can, whether this plant is protected in any or all of these ways.

Flower.

Study first the plan of the flower. Are all the parts present? Is it a "regular" flower? Has any consolidation of parts taken place, or are they all free and distinct? Describe by a single word the insertion of the floral envelopes.

Next, examine and describe in detail the successive whorls.

I. **Calyx.** How many sepals are there? Is this number constant? Describe their shape, color, and surface. How does their position on the flower bud correspond with that taken when the flowers are fully expanded? From its earlier condition do you infer anything as to the function of the calyx?

II. **Corolla.** Does the number of petals correspond with the number of sepals? Remove two or three and examine them under a lens. Draw one in outline, taking care to represent the little scale near the point of insertion.

Examine the scale carefully. Lift up the free edge with the point of a needle. Frequently a small drop of nectar can be found at its base. The whole arrangement constitutes a simple and efficient device for protecting the nectar, and, at the same time, leaving it accessible to visiting insects.

III. **Stamens.** How many? Are they all alike? In what order do they ripen? Study under a lens the mode of dehiscence of the anthers. It will usually be found that such facts, apparently trivial, are really important. In the present case, after the oldest stamens begin to shed their pollen, some little time elapses before the youngest ones are mature, thus ensuring a supply of pollen for visiting insects several days in succession, and insects climbing over the flowers can hardly fail to carry pollen from one to another.

IV. **Pistils.** Study these in flowers of different ages. It will be an advantage to make longitudinal sections of the flower. Notice

1. The elongated axis, **receptacle**, on which the pistils are inserted.
2. The shape of the pistils. Draw an enlarged outline of one.
3. In those that have been properly sectioned the single ovule. Examine the latter in still older specimens and satisfy yourself regarding its form, point of attachment, and direction taken in the ovary. Compare mature fruits and seeds if they are to be had.

Read Müller, *Fertilization of Flowers*, p. 74 *et seq.*

RELATIONSHIP.

We have next to study some of the immediate relatives of the early crowfoot. This may be done at the same time, if specimens are procurable, otherwise comparisons should be deferred until a full supply of material is at hand.

I. We take first the wood anemone, *Anemone nemorosa*, L.

The anemone rises from a creeping rhizome that gives off fine, fibrous roots. The simple stem bears a three-leaved involucre and a single conspicuous flower. Each leaf of the involucre is petiolate, without stipules, and divided into three leaflets that are variously cut and toothed, the lateral ones often divided nearly or quite to the base. Similar radical leaves arise from the rhizome. The flower has a calyx consisting of five or six (frequently more) white sepals, that are often tinged with pink, many distinct stamens, and a less number of carpels (15–20).

See if your specimens agree throughout with the description just given. Name all the points in which the anemone and early crowfoot agree and those in which they differ. Incidentally observe the arrangements for securing fertilization.[1]

II. Continuing our comparative study, we next take the marsh marigold, *Caltha palustris*, L., and in the same way compare it throughout with the anemone and early crowfoot, noting as before all points of difference and resemblance. Widely as the vegetative parts differ, it is obvious that the flowers of all three species are almost identical in their essential structural features.

The marsh marigold presents several attractive features, and cross-fertilization is effected through the agency of insects, but self-fertilization may also take place. Cf. Müller, pp. 79, 80.

[1] Cf. Müller, *Fertilization of Flowers*, pp. 72, 73.

III. If practicable, the comparison should be extended to a number of other species belonging to different genèra, as, for example, *Hepatica triloba*, Chaix, *Anemonella thalictroides*, Spach, *Clematis Virginiana*, L., *Aquilegia Canadensis*, L., *Actœa alba*, Bigel, *Hydrastis Canadensis*, L., and any other plants of this family, wild or cultivated, that may be available.

CHARACTERS OF THE RANUNCULACEÆ.

After such a comparative study, embracing as many species as possible, we may sum up the characters that distinguish members of this family as follows:

1. Chiefly herbaceous plants.
2. Juice watery, in many species acrid and poisonous.
3. Leaves generally compound or variously cut and divided, without true stipules, but frequently dilated at the base.
4. All parts of the flower free and distinct. Corolla often wanting. Floral envelopes and numerous stamens hypogynous.
5. Carpels numerous or few, forming achenia, berries, or follicles in fruit.[1]

This family of plants is of interest in many ways. Owing to their active properties many of the species such as gold-thread, black hellebore, aconite, larkspur, and Hydrastis are employed medicinally. In fact these active properties constitute an important feature of their relationship. The order furnishes a number of ornamental plants common in cultivation, such as Clematis, columbine, monkshood, and others. The color of the flowers, yellow and white in many of the simpler species, passing into red and

[1] Cf. Gray, *Manual*, p. 34.

blue in the more highly developed ones, taken in connection with the striking modifications of form by which the latter have become more and more perfectly adapted to the visits of insects, gives some support to the theory called the Law of Progressive Coloration.[1]

SPECIAL STUDIES.

I. Colors of flowers belonging to the Ranunculaceæ.

II. Various degrees of adaptation to fertilization by the agency of insects in this family. Is self-fertilization possible in the majority of cases? Is it impossible in any species?

III. Fruits of the Ranunculaceæ.

IV. Dissemination of seeds. Special arrangements in Clematis and other genera.

[1] Cf. Grant Allen, *Colors of Flowers*, pp. 17–60; Müller, *Fertilization of Flowers*, pp. 88, 89.

XXIII. THE MUSTARD FAMILY. **CRUCIFERÆ.**

MATERIAL REQUIRED.

Entire plants of Shepherd's-purse, *Capsella Bursa-pastoris*, Mœnch, with both flowers and fruit.

Specimens of any of the following species that can be obtained: Spring Cress, *Cardamine rhomboidea*, DC.; Pepper-root, *Dentaria diphylla*, L.; Water Cress, *Nasturtium officinale*, R. Br.; Sweet Alyssum, *Alyssum maritimum*, Lam.; Rocket, *Hesperis matronalis*, L.; Peppergrass, *Lepidium Virginicum*, L.; Hedge Mustard, *Sisymbrium officinale*, Scop.; Wild Mustard, *Brassica Sinapistrum*, Boiss.

SHEPHERD'S-PURSE. *Capsella Bursa-pastoris*, Mœnch.

Distribution.

Record your own observations as to the occurrence and habits of this plant. Does it manifest a preference for any particular soil or locality?

General Characters.

Write an accurate description of the root, stem, leaves, and inflorescence.

Flower and Fruit.

I. Study the plan of the flower, noting the number and arrangement of sepals, petals, and essential organs. Show the application of the word "cruciform" as used to describe the corolla. Are the stamens all alike?

II. Examine the structure of the ovary. Compare it as it appears in the flower, with partially and fully developed fruits. How many carpels are there? Attachment, direction, and form of ovules? Mode of dehiscence? How is the fruit to be classified?

III. Construct a diagram of the flower.

IV. Compare the views of different writers regarding the morphology of the flower of Cruciferæ.[1]

RELATIONSHIP.

I. Compare with shepherd's-purse such of the species named above as can be procured, and determine what characters they exhibit in common. Do they all have a pungent juice? Are they all herbaceous? Are the flowers on the same plan? How far do the fruits and seeds agree in structure?

II. Summarize the results of your observations in a brief general description of cruciferous plants.

NOTE.—To complete this comparative study at all satisfactorily will require much time and patience. In studying the seeds it will be best to obtain those of different genera from the seed store, sow a part of them in moist sawdust, and dissect carefully from day to day. If the time is short, it may be best to limit the comparison to a very few species, but if even two or three genera are thoroughly studied, and the descriptions accompanied by floral diagrams and sketches of the structure of fruits and seeds, the student cannot fail to be impressed, as in no other way, with the persistent and marked features of this remarkable group of plants.

The flowers of the Cruciferæ, notwithstanding their great uniformity of structure, exhibit striking physiological differences. The number and position of the nectaries is extremely variable. Some have a strong odor, and in at least one species this is associated with evening expansion

[1] Cf. Gray, *Structural Botany*, pp. 206, 207; Arthur, Barnes, and Coulter, *Plant Dissection*, p. 238 (references in footnote).

of the flower. One has become distinctly anemophilous, although giving plain evidence of having descended from entomophilous ancestors.[1]

[1] Cf. Müller, *Fertilization of Flowers,* pp. 100–114; Hooker, *Nature,* Vol. X, p. 134; Eichler, *Blüthendiagramme,* pp. 200, 206.

XXIV. THE ROSE FAMILY. **ROSACEÆ.**

MATERIAL REQUIRED.

Flowering shoots of the cultivated cherry, and, as soon as they are in full bloom, those of the peach, plum, apple, and pear.

Representatives of the following genera, as far as they can be obtained in flower or fruit; Fragaria, Physocarpus, Potentilla, Geum, Rubus, Rosa, Cratægus.

THE CHERRY. *Prunus Cerasus*, L.

Distribution.

The cultivated cherry is familiarly known in the north temperate zone of both hemispheres. For the evidence regarding the region to which it is indigenous, see De Candolle, *Origin of Cultivated Plants*, pp. 206–210.

Flower and Fruit.

I. Study the parts of the flower in succession, noting their form and insertion, the union of parts, and other modifications if such exist.

II. Make a longitudinal section and draw it accurately. Is any nectar to be found? If so, are there any arrangements for its protection?

III. Make longitudinal sections of a number of ovaries and transverse ones of others. Determine the number of ovules, their form and place of attachment. Draw. Compare the number of ovules in flowers just opened and in those that are fading or have lost their corolla.

IV. Construct a diagram of the flower.

V. Does the structure of the flower present any adaptations to the visits of insects?

VI. How is the dissemination of seeds provided for?

RELATIONSHIP.

I. With the cherry compare first the cultivated plum, in flower about the same time.

1. Note every point of difference between the two species, giving special attention to the structure of the flower.
2. Observe the points in which they agree.

II. Compare the flowers of the peach with those of the cherry and plum, noting the features in which all agree and those in which they differ.

III. Examine next the flowers of the pear or apple. Make a longitudinal section, draw it and compare with that of the cherry flower. Make successive cross-sections of the ovary till one is found that shows the ovules clearly. Draw and compare with similar sections of the ovary of the cherry.

IV. Make a similar study of the flowers of the strawberry. Indicate all the points in which they differ from those of the cherry and apple. Compare longitudinal sections of all three.

V. Having made a further comparative study of as many of the plants of this family as are available, summarize the characters that you have found to be general, taking leaves, fruit, etc., into account as well as the flowers.

If enough species have been examined the characters thus derived will be those of the Rosaceæ or Rose Family, a large and important natural order, furnishing a large proportion of the fruits of the north temperate zone, numerous ornamental species, among them the rose, spiræa, hawthorn, and mountain-ash, and some medicinal plants, including the wild cherry and others.

The flowers of the various genera exhibit interesting peculiarities of color and structure corresponding to the different degrees of adaptation to insect visitors.[1]

SPECIAL STUDIES.

I. Development of a cherry. This involves a study of the ovary and its changes during the entire period of the formation of the fruit. Sections of different specimens should be made at frequent intervals, and a series of drawings kept with their accompanying dates.

II. A similar study of the development of the apple.

III. How far the production of our domestic fruits is dependent on the agency of insects.

IV. Evidence regarding the "law of progressive coloration" drawn from the flowers of this family.[2]

V. Collection and classification of the indigenous rosaceous plants of the region in which the study is carried on.

VI. Origin and varieties of the cultivated strawberry.

VII. Extra-floral nectaries and their use.

[1] Cf. Müller, *Fertilization of Flowers*, pp. 242, 243.

[2] Allen, *Colors of Flowers*, p. 25 *et seq.*

XXV. THE PEA FAMILY. LEGUMINOSÆ.

MATERIAL REQUIRED.

Entire specimens of the wild lupine, *Lupinus perennis*, L., in flower. Flowers, leaves, and fruits of some or all of the following species: *Robinia Pseudacacia*, L.; *Vicia Caroliniana*, Walt.; *Trifolium pratense*, L.; *Melilotus alba*, Lam.; *Lathyrus palustris*, L.; *Lathyrus odoratus*, L.

WILD LUPINE. *Lupinus perennis*, L.

Distribution and General Characters.

Note locality and habits. Is this species indigenous or introduced? Describe in detail stem, leaf, and inflorescence.

Flower.

I. How many divisions has the calyx? Is its surface smooth or hairy?

II. With a number of good specimens at hand, observe in their natural position the parts of the corolla, their form, color, and relations to each other. They have received special names that must be made familiar. The conspicuous upper petal is called the standard, **vexillum**, the two lateral ones are the wings, **alæ**, while the two lower ones are united to form the keel, **carina**.

III. Examine critically each of these parts.

1. Are there any grooves or ridges on the standard? If so notice their form and direction. See if there

are any lines or dots likely to serve as path pointers. Compare the color of the standard of a number of flowers.

2. Observe the form and structure of the wings. Remove one and sketch its outline. In an uninjured flower, notice particularly how the wings are fitted to the keel and standard.

IV. With a pencil, or other instrument, push the wings downward with some force, imitating the action of a heavy insect. Repeat the operation on different specimens until its result is clearly seen.

V. See if you can understand how it is that the wings and keel return to their position when the pressure is removed, and whether there is any advantage in this.

VI. Examine next the structure and mechanism of the essential organs.

1. Remove the floral envelopes from the side of the flower, leaving the other parts undisturbed. The stamens and pistil can now be studied to advantage in their natural position.
2. Count the stamens. Are they monadelphous or diadelphous? Are they all alike? Compare those of flowers about to open with younger and older ones.
3. Look at the end of the keel of uninjured flowers. Where is the pollen stored after the dehiscence of the anthers? Examine and describe the mechanism by which it is pushed out when the keel is opened.
4. Observe next the shape of the pistil, the direction taken by the style, and the surface of the latter as seen under a lens.

5. Finally, with a number of perfect specimens of different ages, study the whole mechanism. Write a complete account of the structure of the flower and the mechanical arrangements favoring cross-fertilization, making outline sketches whenever it is necessary to render the description more intelligible.[1]

RELATIONSHIP.

As the flowers of different plants belonging to the pea family are to be had, compare their structure and mechanism with those of the lupine. Any of the species named above, the common locust for example, in flower a little later than the lupine, will present interesting points for comparison.

1. Do corresponding whorls of the flowers of different species agree as to position, form, and number of parts?

2. Is the mechanism by which fertilization is accomplished essentially the same as in the lupine?

3. In specimens that are past flowering, study the fruit in early and later stages of development.

4. Observe the position and form of the ovules, and, in older specimens, the mode of dehiscence of the fruit.

5. Aside from characters drawn from flowers and fruit, determine whether leaves of the different species present any common features.

6. Summarize the results of your comparative study in a brief statement of the characters common to those members of the Leguminosæ that you have become acquainted with.

[1] Cf. Müller's account of *Lupinus luteus*, the structure of which is much like that of *Lupinus perennis*, *Fertilization of Flowers,* p. 187.

The Leguminosæ constitute a large and remarkable family of plants, including between six and seven thousand species, distributed throughout the world, but most abundant in tropical regions. Many of the species are of economical interest. The various kinds of clover furnish important forage crops, and peas, beans, and lentils form an almost indispensable constituent of the food plants of the world. Dye woods and drugs are yielded by a considerable number. Some are exceedingly poisonous, among them the famous ordeal bean of Calabar. Botanically they are of special interest for the peculiarities of the mechanism by which their flowers are adapted to cross-fertilization. A large proportion, too, of plants whose leaves exhibit "sleep movements" belong to this family.

SPECIAL STUDIES.

I. Arrangements for cross-fertilization in the Leguminosæ.

II. Extent to which the production of seeds of red clover is dependent on the agency of insects.

III. Capacity of the common pea for self-fertilization.

IV. Occurrence of modified leaves, such as tendrils, phyllodes, etc., among the Leguminosæ.

V. Morphology of protective structures of various leguminous plants, *e.g.* spines of locust and honey locust, prickles of Schrankia, and hairs of Desmodium.

VI. Sleep movements of clover, lupine, and other plants of this family.

VII. Affinities of the Leguminosæ.

VIII. Causes of the wide distribution of this family.

IX. Varieties of cultivated peas and beans.

XXVI. GERANIUM FAMILY. **GERANIACEÆ.**

MATERIAL REQUIRED.

Specimens of horseshoe geranium, *Pelargonium zonale*, L., in flower.
Wild cranesbill, *Geranium maculatum*, L.; Nasturtium, *Tropæolum majus*, L.; Touch-me-not, *Impatiens fulva*, Nutt., or cultivated balsams that have not become double.

HORSESHOE GERANIUM. *Pelargonium zonale*, L.

Distribution.

The "horseshoe geranium" is universally cultivated. In common with various other cultivated species of the same genus, it is indigenous to southern Africa. Very many varieties have been produced.

General Characters.

With good specimens, observe and describe the various external features, such as

I. Mode of branching.
II. Leaf arrangement.
III. Presence or absence of stipules.
IV. Form of leaves.

Inflorescence.

Taking care to select plants the flowers of which have not become double, compare inflorescences of different ages, and ascertain the order of development of the flowers.

Note. — Like many other facts usually treated as morphological, the character of the inflorescence is of much physiological importance. The successive opening of the flowers in regular order, instead of simultaneously, insures a much longer period of time during which fertilization may take place, and their position and aspect when ready for pollination are most frequently such as to render them conspicuous and easily accessible to insect visitors. The latter, while gathering honey, are often observed to proceed in a methodical manner corresponding to the order of development of the flowers.

Flower.

I. Study the structure and plan of the flower. Is it perfectly regular?

Note. — Give special attention to this point. The beginnings of irregularity are of great interest, since they give us a clue to the way in which some of the most efficient mechanical contrivances in the vegetable kingdom have originated.

II. Study next the ovary.

1. Cut transverse and longitudinal sections of ovaries of various ages.
2. Make out the form and place of attachment of the ovules.
3. In the partially developed fruit examine the immature seeds, and note the form and position of the embryo, easily recognized by its green color.
4. Construct a diagram of the flower.

Physiological adaptations.

I. Examine with a good lens the surface of stem, leaves, flower-stalk, and calyx. Are there any distinctively protective arrangements?

II. In what ways is the inflorescence adapted to cross-fertilization? Notice the position of the open flowers as contrasted with that of the flower buds. Effect of "massing."

III. Study the flower itself with reference to the same question. Compare the color of different specimens and varieties. Is there anything to indicate to a visiting insect the way to the nectar? Find the nectar-tube and explore with a bristle.

Note. — Some specimens have a nectar-tube united with the pedicel and easily recognizable on the outside, either by its color or by its forming a longitudinal ridge. In others it is not readily found. Even flowers of the same inflorescence differ in this respect.

IV. Compare the stigmas of older flowers with those in which the anthers are just shedding their pollen. Are the flowers **proterandrous** or **proterogynous**? [1]

V. Study the structure of the mature fruit, and ascertain how the seeds are disseminated.

Note. — The geranium lends itself readily to experiments in cross-fertilization, and the student who has opportunity is advised to cross two widely different varieties and compare the growth and vigor of the crossed seedlings with that of seedlings derived from self-fertilized flowers. Read the chapter on Pollination in Professor L. H. Bailey's *Nursery Book.*

RELATIONSHIP.

I. Compare the plant just studied with the wild cranesbill, noting points of agreement and difference. Give special attention to the flowers of the two genera, examining them whorl by whorl, until you are satisfied regarding their differences. Record these in detail. Refer in this connection to Müller's [2] or Lubbock's [3] account of various species of Geranium.

[1] Cf. Darwin, *Cross- and Self-fertilization in the Vegetable Kingdom*, p. 142.

[2] *Fertilization of Flowers*, pp. 149–158.

[3] *British Wild Flowers in Relation to Insects*, pp. 43, 44, 72–74.

II. Compare next the cultivated nasturtium, *Tropæolum majus*, L., with the horseshoe geranium.

1. Note the very different habits of the plant, the peculiarities of its foliage leaves, and means of protection.
2. Observe the structure and plan of the flower. Note particularly the color of both calyx and corolla, the guiding lines, nectar-tube, mode of guarding the entrance to the latter, dichogamy, structure of ovary, and number of carpels.[1]

III. In addition to the foregoing, study if possible one or more indigenous species of Impatiens, or forms of the cultivated "balsam" that have not become double. They are of special interest as regards both the peculiar modifications of the flower and the mechanism of seed dissemination.

1. Comparing the plan of the flower with that of the species previously studied, try to ascertain whether there has been consolidation or suppression of parts, or both.
2. Does the structure imply adaptation to cross-fertilization? Does dichogamy exist?
3. If opportunity permits, observe what visitors Impatiens has and their mode of operation.
4. Examine ripe fruits and investigate the mechanism of seed dissemination. Is it the same in principle as in Pelargonium and Geranium?[2]

Note. — The relationship of Pelargonium with the closely allied genus Geranium is obvious, but it differs in important

[1] Cf. Lubbock, *l.c.*, pp. 75, 76.
[2] Cf. Duchartre, *Éléments de Botanique*, p. 791.

particulars from Tropæolum and Impatiens, both of which, in recognition of their wide departure from more primitive forms, are now placed in separate families. The study of such a series of forms is in the highest degree instructive, presenting as it does very important evidence regarding the descent of these peculiarly modified genera.

XXVII. THE SPURGE FAMILY.

EUPHORBIACEÆ.

MATERIAL REQUIRED.

Spurge, *Euphorbia Cyparissias*, L., and other species of Euphorbia. Representatives of other genera of the same family as far as these are procurable.

SPURGE. *Euphorbia Cyparissias*, L.

Distribution.

In what situation is this plant usually found growing? Have you observed anything as to its persistence from year to year, where it has once become established? Do its habits indicate that it is an indigenous species?

General Characters.

Study the general features of the plant and write a brief description. In addition to the ordinary botanical characters note particularly

1. The way in which new shoots arise.
2. The abundant latex in every part.[1]
3. The great variety of foliar organs — scale leaves, foliage leaves, and floral leaves — and their form, position, and color.

Inflorescence and Flowers.

The morphology of the flower in this family has been the subject of much discussion and an extended literature.

[1] Care should be exercised in handling spurges as the juice is poisonous.

Without attempting at the outset a critical theoretical study, we shall simply undertake to observe the floral organs as they are, and give to them their commonly accepted names. Book descriptions and figures are best left alone until the plant has been studied at first hand.

I. Observe first the general arrangement of the inflorescences. They are borne on long slender stalks that arise close together near the apex of the stem, and present collectively the general appearance of an umbel. Is it strictly an umbel?

II. The slender stalks each bear near their extremity a pair of heart-shaped, yellowish, **floral leaves.** Notice carefully what there is above the floral leaves. Compare a number of specimens of different ages. Do you find still other floral leaves? If so, do they resemble the first pair in shape and color? Floral leaves of the second and third order are of common occurrence. Do you find any of a higher order?

III. Having found all the floral leaves, we come to the **inflorescence** proper. It greatly resembles a small flower, and was described as such by some of the older botanists. The cup-shaped structure that looks like a calyx is really an **involucre.** Notice the four "crescent-shaped **glands**" and their position on the involucre.

IV. Remove enough of the involucre to expose the small flowers within. Do this with several specimens of different ages. With a lens, examine the minute **staminate flowers.** Note their position and number, the form of the anther, and the point where the short filament is connected with the long pedicel. (Each staminate flower consists of a single stamen, mounted on a distinct pedicel.)

V. The single **pistillate flower** is far more conspicuous than the staminate ones. As the ovary develops it protrudes beyond the involucre, so that the entire flower is easily studied. Observe

1. The form of the ovary.
2. The number of styles and stigmas.
3. The number of cells in the ovary, as seen in cross-section, and the number and position of the ovules.

VI. With a number of entire plants review all that we have learned about the species. See that all the facts are clearly in mind, and that you are able to designate each part by its proper name. Do you consider the plant well adapted to survive in the struggle for existence? If so, show how.

RELATIONSHIP.

With the species already studied compare other members of the genus such as *Euphorbia corollata*, L., *E. marginata*, Pursh, *E. maculata*, L., and one or more representatives of other genera, as, for example, *Acalypha Virginica*, L., and the cultivated castor-oil plant, *Ricinus communis*, L. (The seeds of the latter are of large size, and are more easily studied than those of the spurge.)

Having compared as many species as practicable, see how far the characters you have found to be common to all agree with the family characters as given in the manuals.

Euphorbia Cyparissias is a familiar representative of a large and peculiar family of plants. It is found in patches by roadsides and old dwellings where it has escaped from cultivation. Its copious milky juice, narrow leaves, and tufted habit have given it the common name of "milkmoss," in addition to that of "spurge," which it shares with numerous other species of the same genus. The family to which it belongs is chiefly tropical, and is one of the few that are specially distinguished by their poisonous properties. Cases of poisoning as a result of handling species cultivated for ornament are not infrequent. It includes a number of species with powerful medicinal properties, and others that furnish valuable food products, while the fleshy Euphorbias, the Poinsettia, and others, are well-known ornamental plants.

XXVIII. THE MAPLE FAMILY. ACERACEÆ.

MATERIAL REQUIRED.

Flowers of the different species of maples as they open in the spring.

Fruits of the sugar maple gathered after they have fallen from the trees in the autumn. Fruits of the red and silver maples gathered in the summer.

Leaves of all the species. Either fresh or pressed specimens of the latter will serve.

Flowers.

The flowers of the red maple open early in the spring and may be taken first. Specimens should be gathered from a number of trees so as to have the different forms of flowers for comparison.

I. Observe the position of the flower bud and the color and position of the bud-scales.

II. Compare the flowers of different trees. Select first, for critical study, those that have well-developed stamens.

1. How many divisions of the calyx are there? Of the corolla?
2. Is this number the same in all the specimens? Does it correspond with the number of stamens?
3. How are the stamens inserted?
4. Is there a pistil?
5. Are there any organs for the secretion of nectar?

III. Next take specimens that have well-developed pistils.

1. Are stamens present? If so, how do they compare with those of the flowers previously studied?
2. Are the floral envelopes alike in all the flowers?
3. Notice the form and structure of the pistil. How many carpels are there? How many ovules in each cell?

IV. Compare with these the flowers of the silver maple, noting carefully all the points of likeness and difference.

1. Are petals present?
2. Do all the flowers have both stamens and pistils?
3. Is the ovary smooth or hairy?
4. Does it agree in structure with that of the red maple?
5. Do different specimens exhibit any variation as to the number of carpels?

V. Compare flowers of the sugar maple, which open some days later, with those of the red and silver maples.

1. Are there any differences as regards
   a. Form and position of the flower clusters?
   b. Color of the calyx?
   c. Structure of the essential organs?
2. Are all the flowers of the same tree alike? How is it with those of the red and silver maples in this respect?

The maples are described as being "**polygamo-diœcious.**" What is meant by this? Do you find that the facts correspond with the statement?

Fruits.

Study next fruits, taking first those of the sugar maple gathered the preceding fall.

With the fruits of the sugar maple, compare those of the red and silver maples, noting all the external and structural differences by which they may be distinguished.

Leaves.

Compare the leaves of all three kinds until you are able to distinguish the species at sight by means of the leaves alone.

Finally review the observations made thus far, see if anything is to be added, and write a complete account of the characters common to all three species and also of those peculiar to each.

SPECIAL STUDIES.

I. Critical comparison of the Box-elder, *Negundo aceroides*, Mœnch., with the maples. Does it have the essential characters of a maple?

II. Polygamous plants. Cf. Darwin, *Different Forms of Flowers on Plants of the Same Species*, Chap. VII.

XXIX. THE MALLOW FAMILY. MALVACEÆ.

MATERIAL REQUIRED.

Common mallow, *Malva rotundifolia*, L., in flower and fruit.
Other representatives of the family, such as Hollyhock, *Althœa rosea*, Cav.; Shrubby althæa, *Hibiscus Syriacus*, L.; Musk mallow, *Malva moschata*, L.; Velvet-leaf, *Abutilon Avicennœ*, Gærtn.

COMMON MALLOW. *Malva rotundifolia*, L.

Distribution.

In what situation is this plant generally found? Have you any evidence as to whether it is an indigenous or introduced species?

General Characters.

I. Study first the habits of the plant and note its characteristic features.

1. The strong taproot.
2. Position and direction of the numerous branches.
3. Presence or absence of stipules.
4. Form and venation of leaves.
5. Position and character of inflorescence.
6. The remarkably strong bast fibers.
7. Mucilaginous contents, particularly of the fruits.

II. Enumerate any advantages that this plant possesses in competition with others. Is it easily eradicated? Why? Is it attractive to grazing animals?

Flower.

I. Examine the flower in various stages of development. Note

1. The plan of the flower and how modified.
2. The three-leaved **involucel**, "like an outer calyx."
3. Insertion of the corolla and the relation of the latter to the **stamen-tube** (best seen on longitudinal section).
4. The **monadelphous stamens.**
5. Form and mode of **dehiscence of anthers.**
6. Number of stigmas. Does this correspond with the number of divisions of the ovary?

II. Ascertain whether there are any adaptations favoring cross-fertilization, or any that render self-fertilization impossible.

1. Are there any guiding lines?
2. Is nectar produced? If so, is it protected in any way?
3. Compare flowers of different ages and ascertain whether dichogamy exists.[1]

Fruit and Seed.

I. Examine the fruit, making both transverse and longitudinal sections of specimens of different ages. Ascertain

1. The number of carpels.
2. Form and place of attachment of the ovules.
3. Structure and position of the embryo. (This is easily made out with a lens by means of repeated sections, trying different specimens until the most favorable ones are found.)

[1] Lubbock, *British Wild Flowers in Relation to Insects*, p. 41; Müller, *Fertilization of Flowers*, pp. 142, 143.

II. Ascertain approximately the number of seeds produced by a single strong plant.

RELATIONSHIP.

Compare with the common mallow at least one, and if possible several, of the plants named above, noting the various points of difference and likeness. Write a brief summary of the characters common to them all.

The Malvaceæ exhibit a number of interesting peculiarities, some of which indicate relationship with several other families, among them the Tiliaceæ. They are widely distributed in both hemispheres, but with a preference for the warmer parts of the globe. The cotton plant is the most important member of the family, from an economical standpoint. A few species are of medicinal value, and a considerable number, as Althæa, Hibiscus, Abutilon, and others, are well-known ornamental plants.

XXX. THE VIOLET FAMILY. **VIOLACEÆ.**

MATERIAL REQUIRED.

Specimens of the cultivated pansy in flower. Indigenous species of violets.

Flower.

Our study in the present case will be restricted to the flower, taking first that of the pansy.

I. Compare several good specimens as to size and color, and observe how far they agree.

II. Study the external features of the flower in order. Note the number of parts in each whorl, and their peculiarities of form, structure, and position.

1. Form of the sepals. Aside from their size and position are they readily distinguished from foliage leaves?
2. Peculiarities of the corolla. To which of the petals does the **spur** belong? Cut into it and see whether it contains anything likely to be of use to the flower. What do you conclude as to its function?
3. Study the disposition of colors. Compare as many specimens as practicable. Where do the "**guiding lines**" converge?
4. Examine the center of the flower with a lens. Notice the thick brush of **hairs** on either side. The position of the essential organs, partially visible farther in.

III. Remove carefully the floral envelopes on one side so as to expose the essential organs without disturbing them. Notice the relative position of stamens and pistil, and their structural peculiarities. The large, rounded stigma with an orifice in front. The "**lip**" forming the lower edge of this orifice. The **syngenesious anthers** and their membranaceous **connectives** united into a tube just back of the stigma. The two **nectaries** projecting into the spur. The narrow canal lined with hairs leading from the entrance of the corolla back to the spur.

Jar the stamens and see where the pollen falls out and where it lodges.

IV. Go over all the structures again, in more than one specimen, and see if you can determine the use of each part of the mechanism. Imitate the action of a bee by inserting a slender piece of quill or wood, pushing along the groove down to the nectar cavity. Withdraw it and see if it brings away any pollen. Insert it into another flower and examine the stigma of the latter with a lens before and after the operation to see if any pollen has been left on it.[1]

V. Make a true longitudinal section of the flower (a razor is best for this purpose), and sketch the parts in outline so as to show their relative position. Name and locate each, using letters and guiding lines.

VI. Make a transverse section of the ovary and examine under a lens. Note

1. The number of placentæ.
2. Number, direction, and form of ovules. If practicable, compare ripe capsules.

[1] Cf. Sachs, *Physiology of Plants*, p. 795.

VII. Construct a diagram of the flower. In what respects does the pansy differ from a "typical flower," as described by Gray, *Lessons*, pp. 81, 82?

VIII. Write a full description of the pansy.

NOTE. — It is hardly necessary at this stage of the student's progress to remind him that a description of such a flower involves much more than an enumeration of the parts of each whorl, with an account of their surface, outline, etc. An appreciation of the marvelous beauty and exquisite adaptations here displayed, and a scientific temper that seeks to know how all this has come to be as it is, will hardly be satisfied with mechanically filling the blanks of some "plant analysis." Write as though your account were to stand as the only written description of the result of a long series of natural experiments, of which we now see the culmination in a perfect piece of mechanism.

IX. Consult the references already given and those named under "Special Studies" below.

RELATIONSHIP.

As the flowers of various indigenous species appear in spring, *e.g. Viola palmata*, L., *V. pedata*, L., *V. pubescens*, Ait., etc., compare them with the pansy, and note the characters common to them all. If the green violet, *Solea concolor*, Ging., is to be had, compare this with the true violets.

Summarize briefly the points in which all these agree.

SPECIAL STUDIES.

I. Observation of various insects that visit the pansy. Müller, *Fertilization of Flowers*, p. 118, gives an interesting account of the habits of different bees.

II. Advantages of crossed over self-fertilized pansies. See Darwin's experiments, *Cross- and Self-fertilization in the Vegetable Kingdom*, pp. 123–128, 286, 296, 304.

III. Variation as seen in the cultivated pansy. Observations of differences of size, shades, and distribution of color and other peculiarities, even if restricted to the pansies grown in a single town, give a vivid impression of the extraordinary capacity for variation and the equally remarkable persistence of essential features exhibited by this species.

IV. Dissemination of seeds by different species of violets. See Lubbock, *Flowers, Fruits, and Leaves*, p. 54 *et seq.*

V. Cleistogamic flowers. See Darwin, *Different Forms of Flowers on Plants of the Same Species*, Chap. VIII.

XXXI. THE EVENING-PRIMROSE FAMILY.

ONAGRACEÆ.

MATERIAL REQUIRED.

Evening primrose, *Œnothera biennis*, L., in flower.

Fire-weed, *Epilobium angustifolium*, L., Enchanter's-nightshade, *Circæa Lutetiana*, L., and other representatives of the family, such as the cultivated Fuchsia.

EVENING PRIMROSE. *Œnothera biennis*, L.

Distribution.

Where were the specimens obtained? In what other places in this country have you seen it growing? Does it grow in any other parts of the world?[1]

Flower.

I. Examine the whorls in order and draw a diagram of the flower. Cut a true longitudinal section, study carefully the relation of the parts, and draw.

II. Note particularly the very long calyx-tube, insertion of petals and stamens, the versatile anthers, elongated style, and four thickened divisions of the stigma.

III. Taking specimens past flowering, cut transverse and longitudinal sections of the ovary, and observe under a lens the number of rows of ovules in each cell, and their form and direction.

[1] Cf. Lubbock, *British Wild Flowers in Relation to Insects*, p. 93.

IV. Using still older specimens, observe and describe the structure of the fruit and its mode of dehiscence.

Physiological Adaptations.

If possible, visit both in the daytime and evening the place where the plant is growing, and study its habits. Ascertain when the flower opens, whether its color and odor are attractive to any particular class of insects, and whether the length of the calyx-tube or any other structural features indicate special adaptations. Endeavor to ascertain by direct observation how pollination is effected. Accounts of this, so far, are very meager, but suggest a curious keeping in tow of two or more different sorts of visitors, some of them coming by day and others by night.[1]

RELATIONSHIP.

I. Obtain specimens of the great willow-herb, or fireweed, *Epilobium angustifolium*, L., often very abundant on newly cleared land that has been burnt over, and compare the plant throughout with what you have seen of the evening primrose. Note

1. Habits and external characters.
2. Structure of the flower, especially its plan and the relation of the various whorls to each other.
3. Adaptations to insect visitors. Observe particularly the position of the style in flowers of different ages, and the time when the stigmas open. Is this before or after the anthers have shed their pollen?

NOTE. — This species furnishes an excellent example of proterandrous dichogamy.[2]

[1] Cf. Lubbock, *l.c.;* Müller, *Fertilization of Flowers*, p. 264.
[2] Cf. Gray, *Structural Botany*, p. 222.

II. Compare the enchanter's-nightshade (*Circæa Lutetiana*, L.), also in flower in midsummer, with the evening primrose.

1. Construct a diagram of the flower and observe how it differs from that of the latter species.
2. Examine the flower under a lens and observe
   a. The conspicuous nectary. (Abundant nectar may also be found in some flowers.)
   b. The surface of the ovary. Can you suggest more than one use of the hooked bristles with which it is covered?
3. Observe, if practicable, the way in which pollination takes place.[1]

III. A study of the cultivated Fuchsia may be made at any time during several months of the year, and if more convenient may be taken as the type instead of the evening primrose.

IV. Compare your observations of the various members of the family that you have obtained for study, and note the morphological characters common to them all.

[1] Cf. Müller, *l.c.*, pp. 266, 267.

XXXII. THE PARSLEY FAMILY.

UMBELLIFERÆ.

MATERIAL REQUIRED.

Harbinger-of-spring, *Erigenia bulbosa*, Nutt., in flower.

Later in the season, representatives of other genera, such as Osmorrhiza, Heracleum, Pastinaca, Thaspium, Daucus, Cicuta.

Fruits of fennel, *Fœniculum vulgare*, Gærtn., dill, *Anethum graveolens*, L., and coriander, *Coriandrum sativum*, L. (to be procured at the drug store).

HARBINGER-OF-SPRING. *Erigenia bulbosa*, Nutt.

Distribution and General Characters.

I. Record what you have noticed as to the habitat of this species. Does it appear to be indigenous or introduced?

II. With perfect specimens at hand, study the general features of the plant, noting particularly

1. The underground stem. Describe its form and structure. As a modified stem how is it to be classified?[1]
2. The habit of the plant as regards size, branching, and any other feature that appears to be characteristic.
3. Leaves. Compare a number of proper foliage leaves and describe one that you regard as typical. Notice
   a. The expanded, sheathing petiole.
   b. The extent to which the leaf is compound.

[1] Cf. Gray, *Lessons*, p. 42 *et seq.*

c. The uppermost leaves. Those subtending a group of inflorescences constitute an **involucre**, those subtending each separate inflorescence an **involucel**. Do the leaves of involucre and involucel differ in any important particular from the lower leaves?

4. The character of the **inflorescence**, and the grouping of several inflorescences to form a **compound umbel**.

Flower.

I. Examine different flowers until you are satisfied as to what parts are present. Note the essential facts of form, number, position, etc.

II. Write a description, and indicate all the points in which this differs from a "typical flower."

NOTE.— In this family the inflorescence and flowers are particularly characteristic; it is important, therefore, that their distinctive features should be impressed on the mind before proceeding farther.

Fruit.

Fully mature specimens are indispensable in studying the fruit of any member of this family; accordingly, instead of waiting for the Erigenia to ripen, it will be convenient to take commercial specimens of fennel, coriander, and dill, which will serve as good representatives of the fruits of umbelliferous plants. Moreover, by studying several kinds, instead of one, we shall gain a clearer impression of their really characteristic features.

I. Observe carefully the external features of the three fruits. That of the coriander is globular, fennel is more nearly cylindrical, while dill is much flattened. In spite, however, of these marked differences, there are a number of characters common to all three. Note

1. The ready splitting of the fruit into two halves, **mericarps.**
2. The strongly marked longitudinal **ribs** on the outer surface of each mericarp.
3. The **stylopodium**, a short conical body in which the fruit is prolonged above.
4. The **carpophore**, or prolongation of the pedicel; its two thread-like branches each supporting one of the mericarps. (Best seen in specimens of fennel that have lain in water an hour or two.)

II. Compare the three fruits more in detail, using a good lens for the purpose. Observe

1. The number and position of the ribs. Begin with fennel, in which it is at once seen that each mericarp has five strong ribs, two lateral, one dorsal, and two intermediate. How does the dill fruit compare in this respect?

   The coriander fruit differs remarkably from either of the preceding. If a mericarp is carefully studied, it will be seen to have five **primary ribs**, corresponding to those of fennel, but wavy in outline and less prominent than four **secondary ribs** alternating with them.
2. Remains of floral envelopes. If uninjured specimens are examined, it will be seen that the calyx teeth of the coriander are conspicuously present at the apex of the fruit. Is this true of the dill and fennel?

III. Prepare transverse sections of the mericarps of all three species, and examine with the low power of a compound microscope. In each case it will be necessary to take at least two sections, one near the apex of the fruit, and one near the middle or lower down.

It will be seen that all three kinds have a relatively thick **pericarp** and abundant, white **endosperm**, within which lies the small embryo, near the apex of the fruit, and consequently not seen in sections taken lower down. In the pericarp are a number of **vittæ**, or oil-tubes. The coriander has two of these in each mericarp lying next to its inner, or ventral face. In fennel and dill, in addition to these two, there are four more vittæ alternating with the ribs of the outer, or dorsal face.

Draw in outline, representing accurately the position of ribs and vittæ. Letters and guiding lines will conduce to clearness.

IV. Write a complete description of the three fruits, taking care to distinguish the characters common to all, from those that are only of specific or generic value.

RELATIONSHIP.

Later in the season many other species of umbellifers that will serve for comparative study are easily obtained. Thaspium, or some other common genus, may be substituted for Erigenia if found more convenient. As the study is continued it will be apparent that the external characters to which attention has already been directed, although variously modified, are constantly repeated in nearly all the genera. The hollow stem, compound leaves with inflated petioles, flowers in umbels, and the very marked and distinctive features of flowers and fruit occur over and over again, sometimes in connection with specific characters by which a given plant is easily identified, sometimes with these characters so far wanting that identification becomes extremely difficult. All in all, the family is one of the best marked groups in the vegetable kingdom. It includes about thirteen hundred species, distributed chiefly over the temperate regions of the globe. They are remarkable for their widely different active properties, a considerable number being edible, a large proportion pleasantly (or unpleasantly) aromatic, and a comparatively small number poisonous. It is a curious fact that while very largely dependent upon insects for fertilization, the flowers of umbellifers attract, as a rule, a very common lot of visitors such as "short-lipped flies, beetles, and other short-lipped insects in immense variety."[1] Numbers, rather than quality, has become the rule, and while the family has held its own, and has even established a claim to be considered one of the dominant natural orders, it is one of the least attractive.

The best preparation for the further study of this rather difficult family will be made by getting together a collection of ripe fruits, especially those occurring in commerce, and becoming thoroughly familiar with their anatomical structure.

Useful directions for collecting and other needed suggestions are given by Coulter and Rose, in their *Revision of North American Umbelliferæ*.[2]

SPECIAL STUDIES.

I. Morphology of the "tuber" of *Erigenia bulbosa*.

A critical botanist writes: "Is it really a stem? Who ever examined it? It appears to me to be half hypocotyl, and the other half a root."

II. The terminal, colored flower of *Daucus Carota*.

[1] Müller, *Fertilization of Flowers*, p. 287.

[2] Separate monograph. Issued by the Herbarium of Wabash College, December, 1888.

XXXIII. THE MILKWEED FAMILY.

ASCLEPIADACEÆ.

MATERIAL REQUIRED.

Flowers of *Asclepias Cornuti*, Decaisne. Alcoholic specimens will serve if fresh ones are not to be had, but there is an advantage in having a supply of both.

MILKWEED. *Asclepias Cornuti*, Decaisne.

Flowers.

Our study of the milkweed will be restricted to the flowers, which present an extraordinary mechanism for securing cross-fertilization through the agency of insects. They are borne in a conspicuous umbel and attract numerous visitors, particularly bees, wasps, and flies. Both the odor and color are attractive, and there is an abundant supply of nectar. The plant is absolutely dependent on insects for fertilization.

Observe first the form and position of the floral envelopes. They are reflexed and covered on their lower surface with short, woolly hairs. (This is contrary to the general rule noticed by Kerner, *Flowers and their Unbidden Guests*, that plants protected by milky juice have smooth leaves, and are without any other appliances for the protection of their flowers from crawling animals.)

The **crown** is the most conspicuous part of the flower. It consists of five hollow bodies, **cuculli**, each of which has an incurved horn projecting from its opening.

There are five anthers placed close together, each terminating in a membranous appendage that projects over the thickened **stigma disk.**

The anthers are separated from each other laterally by a deep, vertical slit, bordered on either side by a thin triangular process, the **anther wing.** At the upper extremity of the slit is a minute, black body, **corpusculum,** which, when removed by a needle, is found to be connected by means of a delicate, curved band on either side, with a flattened, yellow, and waxy pollen-mass, **pollinium.** Longitudinal swellings on the outside of each anther indicate the position of the pollinia before their removal.

Each of the slits already described is continuous within with the **stigmatic chamber,** into which the pollen must be introduced in order that fertilization may take place. It is obvious that this cannot happen unless the pollinia are removed from the anthers, and brought into the stigmatic chambers by some external agency.

This is accomplished by bees and other insects that visit the flowers for honey.[1] Alighting on the umbel the insect easily gets its foot caught in the lower part of one of the slits, and in attempting to withdraw it, one of the claws is guided into the notch in the lower end of the corpusculum. With a strong pull, the latter is removed from its place, and the insect carries away with it the two pollinia, which by the twisting of the delicate bands, **retinacula,** that connect them with the corpusculum, are now brought into such a position as to be readily introduced into the slit leading to the stigmatic chamber of some other flower. If this has been done, and the insect is strong enough, it frees itself by a vigorous pull, breaking the

[1] Hildebrand and Müller have given a full account of the process, the latter writer with illustrations. *Fertilization of Flowers,* p. 396 *et seq.*

retinacula, and leaving the pollen masses in the stigmatic chamber, while it proceeds to other flowers and continues gathering honey.

Weaker insects are frequently unable to break the retinacula. Flies may often be seen making unavailing efforts to extricate themselves, and honey-bees are not infrequently found that have been caught in the same way, and have died after prolonged struggles to get free.

By means of the preceding description, accompanied by careful observation at each step, the student will be in a position to study the entire mechanism to advantage. He should now go over the whole independently, until every part of the flower is perfectly familiar. The study of external structure should be followed by a comparison of cross and longitudinal sections (best made from alcoholic material), with sketches to show the parts and their relations to each other.

Several hours will be required to do this properly. Müller's drawings may be consulted, but they are less easily understood than the flower itself. Nothing can possibly take the place of direct, personal, and long-continued study of the object under investigation. Further, it is very desirable that the pupil should not only understand the mechanism, but that he should also see it in operation. A few days in summer spent in watching the flowers of the milkweed, as the visitors come and go, will give full opportunity for this.

RELATIONSHIP.

The Asclepiadaceæ constitute a large and very remarkable family of plants, including about thirteen hundred species, which are largely tropical, although many representatives occur in the temperate regions of both hemispheres. They are chiefly interesting for the extraordinary structural modifications of their flowers, which "rival the orchids, if not in the variety of their forms, at least in their complexity and their perfect adaptation to insect visitors." A study of the steps by which this gradually increasing complexity of structure has been attained is of the highest interest. The student should carefully compare the flowers of other genera of Asclepiadaceæ, and such representatives of related families as Apocynum, Vinca, and others.

SPECIAL STUDIES.

I. It is found that only a very small proportion of the flowers in an umbel set fruits. Why is this? and are those flowers which do not set fruits of any value to the plant?

II. Minute structure of pollinia and retinacula.

III. Morphology of the cuculli.

IV. Development of the flower.

V. Protective appliances in this family.

XXXIV. THE BORAGE FAMILY.

BORRAGINACEÆ.

MATERIAL REQUIRED.

Common hound's-tongue, *Cynoglossum officinale*, L., in flower.
Similar specimens of any of the following genera: Echinospermum, Mertensia, Lithospermum, Symphytum, Heliotropium, Myosotis. Cultivated species of some of these, as forget-me-not and heliotrope, will serve a good purpose.

HOUND'S-TONGUE. *Cynoglossum officinale*, L.

Distribution and General Characters.

I. This species is described as an introduced weed. Do its habits confirm this statement?

II. Examine the plant with reference to general features. Note its coarse aspect, hairy surface, and disagreeable odor.

Inflorescence.

The inflorescence is characteristic and should be critically studied, as it is of a form that appears in many representatives of this family.

I. Notice first the order of development of the flowers. The lowest have already formed their fruits; higher up are the open flowers, and at the apex are the unopened flower buds.

II. The inflorescence is apparently a one-sided raceme. Is it really so? Notice the position of an open flower. Is it terminal or lateral?

III. Compare a number of inflorescences with reference to the occurrence of bracts. Read Gray, *Structural Botany*, pp. 153–155.

IV. If they can be obtained at the same time, compare the inflorescence of other representatives of the Borraginaceæ, such as puccoon and forget-me-not, with that of hound's-tongue. Do they agree essentially in the arrangement of flowers?

Flower.

I. Note first the numerical plan of the flower. Is the number five maintained throughout?

II. Observe the peculiar structure of the corolla, particularly the conspicuous folds or scales arching over the essential organs. Is the flower perfectly regular?

III. Taking a recently opened flower, make a longitudinal section so as to show the precise relation of all the parts. Draw.

Does the position of stigma and anthers, and the mode of dehiscence of the latter, afford any indication as to the way in which pollination is effected?

IV. Examine the ovary, noting the number of its divisions, and their form and position.

Fruit.

I. Study the fruit in different stages of development, taking flowers of different ages for the purpose. Observe

1. Its rapid increase in size.
2. The formation of peculiar barbed appendages, thickly covering its surface.

II. Make longitudinal sections of young fruits so as to show the form and position of the seed. Compare with similar sections of older fruits.

RELATIONSHIP.

Compare with this species as many others of the same family as can be obtained. Note especially

I. Any general external characters in which they agree.

II. The inflorescence, which in this family presents very interesting peculiarities.

III. The structure of the flowers, differing in details in the different genera, but showing marked agreement in plan.

IV. The characteristic fruit.

V. Structure and position of the seeds.

Write a brief summary of the features that you consider characteristic of the family.

The Borraginaceæ include about twelve hundred species, widely distributed throughout the world. A number of ornamental ones are common in cultivation. Some have been employed in medicine, and the curious doctrine of signatures is still called to mind by such names as lungwort and stonewort. The marked variety of external appearance, in connection with great persistence of essential characters, as seen, for example, by comparison of the exquisitely beautiful and fragrant heliotrope with the coarse and rank hound's-tongue, is interesting as suggesting how widely the different genera have diverged in externals from earlier forms, while still retaining their most deeply seated ancestral traits.

The student will do well to make a special study of the inflorescence as it presents itself in various members of the family, and in the same connection review the whole subject of floral arrangement as presented by Gray, *Lessons*, Sec. VIII, or *Structural Botany*, Chap. V.

XXXV. THE MINT FAMILY. LABIATÆ.

MATERIAL REQUIRED.

Specimens of ground-ivy, *Nepeta Glechoma*, Benth., in flower.
Similar specimens belonging to different genera of the Mint family, as they can be obtained. See list below.

GROUND-IVY. *Nepeta Glechoma*, Benth.

Distribution.

As in previous studies, notice the habitat and consider the evidence as to whether this is an introduced or indigenous species. Gray, in the *Manual*, says "naturalized from Europe." What is meant by this?

General Characters.

I. Observe first the most obvious characters, among them the following:

1. The habit of the plant, its stem creeping and taking root at short intervals. Describe the root system.
2. The characteristic odor.
3. The shape of the stem and arrangement of the leaves.

   Note. — The aromatic properties, square stem, and opposite leaves are characteristic not only of this species but of the whole family to which it belongs.

4. The relation of leaves and stem. Note particularly the ridges connecting the bases of each pair of petioles, and their chevaux-de-frise of bristly

hairs. Which way are the latter directed? What do you infer as to their use?

5. Structural features of the leaves. Describe their form and venation. With a good lens examine closely the surface and margin. Are they smooth or rough?

II. Study the plant throughout with reference to its various means of protection and their efficiency.

Inflorescence.

I. The flowers are in small axillary clusters. How many in each group? In what order do they open? Is this order constant? Classify the inflorescence, giving its appropriate name.[1]

II. Are there any arrangements, in addition to those already noticed, for the protection of the flower?

Flower.

I. Study critically the plan of the flower. How many calyx-teeth are there? How many lobes of the corolla?

Remove the corolla with a pair of fine forceps, and lay it open by making a longitudinal slit its entire length, passing through the middle of the lower lip. Fasten it on a flat piece of cork with needles, so as to fully expose the stamens, and examine under a dissecting microscope. One of the stamens has been suppressed. Which? Notice the insertion of the style, the peculiar form of the ovary, and the nectary surrounding its base.

II. Taking flowers of different ages, observe the fruit in its various stages of development. How many carpels are there?[2]

[1] Cf. Gray, *Structural Botany*, p. 151.

[2] Cf. Gray, *Structural Botany*, p. 296; Luerssen, *Botanik*, p. 1014.

III. Construct a diagram of the flower. Consult Eichler, *Blüthendiagramme*, for diagrams and theoretical discussion of the morphology of the flower of the Labiatæ.

IV. Examine the flower with reference to the way in which fertilization is accomplished.

1. Notice the spots and lines on the lower lip of the corolla. Examine different specimens and ascertain whether they are constant in position. Are they placed so as to serve as path-pointers?
2. Using a needle or bristle, imitate the action of an insect inserting its proboscis so as to extract the nectar. Would it be likely to come in contact with anthers or stigma, or both?
3. If practicable, examine flowers from different localities, and compare them as to size, position of the anthers, and other features.[1]
4. Nepeta is reckoned by Müller among the genera in which, for at least some of the species, self-fertilization has become impossible. Does this appear to be the case with *Nepeta Glechoma?*

V. Compare, if they can be obtained, the highly modified flowers of Salvia, either those of the common sage, or of species cultivated in conservatories.[2]

RELATIONSHIP.

Examine as many of the following species as practicable, comparing them with ground-ivy, and noting all common characters.

Catnip, *Nepeta Cataria*, L.

[1] Cf. *Botanical Gazette*, I, p. 41, II, p. 118; Müller, *Fertilization of Flowers*, p. 484.

[2] Cf. Sachs, *Physiology of Plants*, p. 794; Müller, *l.c.*, p. 477 *et seq.*

Wood-sage, *Teucrium Canadense*, L.
Richweed, *Collinsonia Canadensis*, L.
Spearmint, *Mentha viridis*, L.
Wild mint, *Mentha Canadensis*, L.
Wild bergamot, *Monarda fistulosa*, L.
Skullcap, *Scutellaria galericulata*, L.
Motherwort, *Leonurus Cardiaca*, L.
Dead-nettle, *Lamium maculatum*, L.
Cultivated species of *Salvia.*

Notwithstanding the fact that the Labiatæ include some twenty-six hundred species scattered over the entire globe, they constitute a very natural group of plants; that is, certain strongly marked characters are so uniformly present that it would almost seem, as some botanical writers have suggested, that all the species might be placed in one great genus. Accordingly the distinction of genera in this family becomes a difficult task. The modifications of the floral structures in those species that have become most dependent on the agency of insects for fertilization are peculiarly interesting. The student may profitably devote considerable time to the comparison of the various species of Salvia, for example, with each other and with simpler forms. Another interesting subject of investigation, and one throwing additional light on the relationship of groups that apparently have but little in common, is the developmental history of the fruit, which is essentially the same in this family as in the Boraginaceæ.

XXXVI. THE NIGHTSHADE FAMILY.

SOLANACEÆ.

MATERIAL REQUIRED.

The cultivated potato in flower. The tomato may be substituted.

Specimens of matrimony-vine, *Lycium vulgare*, Dunal, in flower, and similar specimens of ground-cherry, *Physalis pubescens*, L., bitter-sweet, *Solanum Dulcamara*, L., or other easily procurable representatives of the family.

POTATO. *Solanum tuberosum,*

Distribution and General Characters.

The common potato is indigenous to a portion of the coast region of western South America. It has been widely cultivated in the northern hemisphere for more than three hundred years, apparently with little specific change, there having been no inducement to artificial selection of any other part than the tuber, which, however, presents many, often striking, varieties.[1]

In examining the cultivated plant, study its habit, noting the peculiarities of stem and leaves, and the characteristic odor.

Inflorescence.

Examine a number of specimens. Do they agree in the character of the inflorescence? Describe this and draw a diagram showing the position of the flowers and their order of development.

[1] Cf. De Candolle, *Origin of Cultivated Plants*, p. 45 *et seq.*

See if you can find a description of this kind of inflorescence in any of the books of reference. Does it correspond with that of any other family that you have studied?

Flower.

I. Study the parts of the flower in order and describe them. Note particularly

1. The plan of the flower and whether it is strictly regular or not.
2. The extent to which coalescence has taken place.[1]
3. Whether there is adnation of any parts.
4. Form of calyx and corolla.
5. Structure, position, and insertion of the stamens, and their mode of dehiscence.
6. Number of carpels composing the ovary. State the evidence on which you have determined this.

II. Construct a diagram.

III. Determine whether there are any arrangements favoring cross-fertilization, and whether self-fertilization is possible.[2]

Note the persistence, for at least several hundred years, of structures that under present circumstances are of little, if any, use to the plant, but which if it were neglected by man and allowed to run wild, might again be needed.

RELATIONSHIP.

I. With the potato compare other species of the same genus, as far as these are procurable, also representatives of other genera as Lycopersicum, Physalis, Nicandra, Lycium,

[1] Cf. Gray, *Structural Botany*, p. 179.

[2] Cf. Müller, *Fertilization of Flowers*, p. 425.

and Petunia. The last two are widely cultivated, and their flowers may be had for weeks together. Attention should be directed to

1. Such general external features as the plants possess in common. Between certain species and genera this likeness in general characters is very striking, in other cases it is not apparent.

2. Active properties, manifested in part by odor and taste.
3. Structure of flower and fruit.
4. Structure of seeds. The seeds of different plants of this family exhibit great likeness of form and structure, as may be seen by comparing longitudinal sections of those of tomato, egg-plant, stramonium, etc. It is very desirable that the student should make an extended and critical comparison of the seeds of as many different species as possible. This should be assigned as a special study, and time given for a thorough piece of work.

II. Write a summary of the characters in which all the species examined agree.

III. Compare the characters of the Solanaceæ with those of any other families that you remember as showing resemblances to them. If you have already studied any of the Scrophulariaceæ point out the best characters by which the two families are to be distinguished.

In the study of every family, comparisons of this kind should be made as fast as the necessary data are in hand. In most cases the relationships of families among themselves are by no means as satisfactorily made out as could be desired, but that is no reason for not studying them.

The Solanaceæ include over twelve hundred species, chiefly tropical and sub-tropical, some representatives, however, being widely cultivated in temperate regions. Many of them possess strongly narcotic and poisonous properties, as the names deadly nightshade, henbane, etc., indicate. A few are much employed in medicine. The potato is the most useful, the tobacco plant the most harmful member of the family. Morphologically this group of plants is of interest in its affinities, more or less distinctly marked, with several conspicuous families, the Scrophulariaceæ and Convolvulaceæ among them. Physiologically it offers comparatively little of special importance, although some species exhibit interesting adaptations for insuring fertilization.

XXXVII. THE FIGWORT FAMILY.
SCROPHULARIACEÆ.

MATERIAL REQUIRED.

Butter-and-eggs, *Linaria vulgaris*, Mill., in flower.
Common species of any of the genera named below.

BUTTER-AND-EGGS. *Linaria vulgaris*, Mill.

Distribution.

In what situations have you seen the plant growing? Have you made any observations as to its natural range? Is there anything in its habits that affords evidence as to whether it is indigenous or introduced?

General Characters.

I. This species is perennial. How is the fact ascertained?

II. Describe the underground portion of the plant. The stem and leaves.

III. Is there anything about it that secures protection from grazing animals?

Inflorescence.

Character and kind of inflorescence. Notice the position of the individual flowers. Do they all face outward? Do the position of the flowers and the order of their development present any advantages?

Flower.

I. Study the plan of the flower. What is the original numerical plan as indicated by the floral envelopes? Is this plan apparent in the andrœcium? In the gynæcium? How many perfectly developed stamens are there? See if you can find traces of another one. If so, how does it compare with the rest? How many carpels compose the pistil? On what evidence is this determined?

II. Construct a diagram of the flower. If you find a trace of a fifth stamen, mark its place with an x.

III. Examine a transverse section of an ovary from which the corolla has fallen, and notice the arrangement of the ovules, and the position and form of the placentæ. In a still older ovary observe the form and structure of a young seed.

IV. When the capsules are ripe study their structure and mode of dehiscence.

V. Study carefully the adaptations for securing fertilization by the agency of insects. Begin with the corolla and note

1. Its **bilabiate** form.
2. The conspicuous **palate** and its color as compared with the rest of the corolla.
3. The **spur**. Where is the nectar? Is it easily accessible to all sorts of visitors? Imitate the action of a bee in gathering honey. Depress the lower lip by pushing down the palate with a needle. Are there any path-pointers? Notice the position of anthers and stigma.

If possible, watch a bee visiting a plant, and observe the mutual relations of insect and flower.

This plant has been widely introduced into the United States, and, notwithstanding its botanical interest, is a pernicious weed, difficult to eradicate. Aside from reproduction by seed, it persistently maintains itself by means of its rhizomes, each of which sends up several or many aërial shoots. The unpleasant odor and taste of the plant render it distasteful to grazing animals, so that it is efficiently protected by its own disagreeable properties.

The adaptations for securing cross-fertilization by the agency of insects are striking, and, for the most part, easily understood. The flowers are rendered conspicuous by massing in a crowded raceme, and face outward, so as to be immediately accessible to flying insects, while the orange-colored palate, with its smooth median groove on the inner side, directs visitors at once to the nectar collected in the spur. The anthers and stigma are so disposed as to come in contact with the head and back of the insect (commonly a bee), as it depresses the palate and inserts its long proboscis into the spur. While thus accessible to large insects with a long proboscis, the nectar is protected from unbidden guests by the palate, that completely closes the throat of the flower, and springs back to its place when the force by which it is depressed ceases to act. It is further protected by its position, being out of the reach of insects with a short proboscis that may in some way have effected an entrance into the flower.

The mechanical arrangements for the dissemination of the seeds are also of interest. The hygroscopic action of the capsules is readily shown by placing them when dry in water. In less than a minute the teeth at the apex begin to bend inwards, and in a short time the capsule is tightly closed, opening again when it has been thoroughly dried. In this way the seeds are scattered when the weather is most favorable for their being conveyed to some distance. On the whole, the plant with its simple but effective means of protection, persistent subterranean stems, admirable adaptations for cross-fertilization, and numerous seeds with special arrangements for dissemination, is exceedingly well adapted to survive in the struggle for existence.

RELATIONSHIP.

I. Compare several of the following plants with the species just studied, directing attention particularly, though not exclusively, to the flowers. (Some of these that bloom earlier than the Linaria, as the wood-betony, may be studied before the latter if more convenient.)

Wood-betony, *Pedicularis Canadensis*, L.
Painted-cup, *Castilleia coccinea*, Spreng.
Beard-tongue, *Pentstemon pubescens*, Solander.
Turtle-head, *Chelone glabra*, L.
Monkey-flower, *Mimulus ringens*, L.
Various species of *Veronica*.
Some cultivated species also may be used such as
"Kenilworth ivy," *Linaria Cymbalaria*, Mill.
Snapdragon, *Antirrhinum majus*, L.
Foxglove, *Digitalis purpurea*, L.

How do these compare as regards

1. Plan of the flower?
2. Shape of corolla?
3. Number of stamens?
4. Structure of ovary?
5. Number and position of seeds?

II. State concisely, and in general terms, what characters you have found to be common to all the species studied.

There is evidence that the Scrophulariaceæ are an old family of plants, and one that may fairly be reckoned to have gained a place among the dominant groups. There are nearly two thousand species distributed over the entire globe. While well marked as regards family characters, the different genera and species exhibit very wide divergence of structure, often associated with peculiarities of color that stand in evident relation to the insects on which they have come to depend. A considerable number have entirely lost the capacity for self-fertilization, and the mechanical arrangements are in some cases so complicated as to be difficult of explanation. The gradation of forms from comparatively simple ones to others that show remarkable adaptations to highly specialized insects, offers a peculiarly interesting study of developmental history.[1]

SPECIAL STUDIES.

I. Morphology of the flower of the Scrophulariaceæ.

II. Peloria in this family and its significance.

III. Comparison of mechanisms by which fertilization is effected in different genera of Scrophulariaceæ.

IV. Exclusion of unbidden guests as accomplished in Pentstemon and other genera.

V. The genus Veronica. A comparison of different species of the genus, and of the genus itself with other representatives of the family.

[1] Cf. Müller, *Fertilization of Flowers*, pp. 429-465.

XXXVIII. THE HONEYSUCKLE FAMILY.

CAPRIFOLIACEÆ.

MATERIAL REQUIRED.

Common elder, *Sambucus Canadensis*, L., in flower. Other specimens of the same species, with the fruit partially developed. Species of Viburnum, coming earlier in the season, may be substituted.

Any of the indigenous species of Lonicera, Diervilla, Symphoricarpus, Linnæa, and Triosteum that are procurable.

COMMON ELDER. *Sambucus Canadensis*, L.

Distribution.

In what situations have you observed the plant growing? Is it indigenous?

General Characters.

I. Record what you have noticed as to its mode of growth. Is its habit that of a shrub or of a tree?

II. Mode of branching. Differences observed in different specimens.

III. Do the stems exhibit any peculiarities of form, structure, or surface markings? If so, describe in detail.

NOTE. — The lenticels are generally a conspicuous feature. For an account of these, see Strasburger and Hillhouse, *Practical Botany*, pp. 153, 154.

IV. Describe the leaves. Note variations.

Inflorescence.

I. Observe the number and position of the main branches. Compare specimens until the normal arrangement is clearly understood.

II. Ascertain the order of development of the flowers. Take a small division of the inflorescence, to avoid confusion, and represent it on paper diagrammatically.[1]

III. Classify the inflorescence.[2] Does such an arrangement of flowers present any physiological advantages?

Flower and Fruit.

I. What is the numerical plan of the flower? Is this constant in all the specimens? Is it exhibited in all the whorls?

II. Note the relation of the different whorls to each other. Is the ovary superior or inferior? Where are the stamens attached?

III. Does the relative position of anthers and stigma favor cross- or self-fertilization, or both?

IV. Make transverse sections of a number of immature fruits. Are they all alike? Draw a section that you consider typical. Compare the ripe fruits, if they are to be had, and note the changes that have taken place. Describe and classify the fruit.

RELATIONSHIP.

The relationship of the common elder must necessarily be made a subject of special study rather than a piece of class work, since the indigenous species of Caprifoliaceæ

[1] Cf. Bessey, *Botany*, pp. 138, 139.
[2] Cf. Gray, *Structural Botany*, pp. 151, 152.

flower, for the most part, at widely different times, and some of the genera exhibit among themselves such marked structural differences as to obscure, except to a trained eye, the common family characters. The contrast between the simple, open flowers of the elder and the extremely elongated corolla of species of Lonicera that have become adapted to the visits of night-flying moths, is a striking example. The student who wishes to familiarize himself with this family, which presents many interesting features, will find in the course of spring and summer enough indigenous species of the genera named above to enable him to make a fairly extended comparative study. The clue to the wide divergence of form, and the remarkable series of colors exhibited by flowers of the different genera, is apparently found in progressive adaptation to different insect visitors.[1]

Another remarkable feature is the great difference of habit exhibited by different members of the family, as seen, for example, in a comparison of the slender, trailing Linnæa with the coarse, upright Triosteum, or the climbing species of Lonicera with the shrubs or trees of the genera Sambucus and Viburnum. Even within the limits of a single genus, as in the case of Lonicera and Viburnum, wide differences of structure and habit present themselves, affording an opportunity to observe adaptations that appear to have been acquired within comparatively recent times.

[1] Cf. Müller, *Fertilization of Flowers*, p. 299.

XXXIX. THE GOURD FAMILY.
CUCURBITACEÆ.

MATERIAL REQUIRED.

The common cucumber, *Cucumis sativus*, L., in flower.[1]
Similar specimens of squash, melon, wild cucumber or gourd.
Seeds of pumpkin, melon, and various other cucurbits.

CUCUMBER. *Cucumis sativus*, L.

Distribution.

The cucumber has been widely cultivated from an early date, and presents a remarkable case of the persistence of specific characters for an indefinite period. According to De Candolle, it has been cultivated in India no less than three thousand years, yet its wild form found at the foot of the Himalayas has stems, leaves, and flowers that are "exactly those of *Cucumis sativus*."[2]

General Characters.

I. Note first the habit of the plant as regards position and direction of growth. Is it capable of supporting itself in an erect position? How do young specimens compare with older ones in this respect?

II. Observe the leaf arrangement.

III. Is the plant protected in any way? Examine the

[1] Well-formed plants, with flowers and young fruits, are easily obtained by sowing the seeds in flower-pots a few weeks before the specimens are wanted.

[2] *Origin of Cultivated Plants*, pp. 264–266.

surface of stems, leaves, flowers, and fruit, first with the naked eye, and then with a good lens. Imagine a soft-bodied animal attempting to crawl up to the leaves or flowers. Which parts are best protected?

Tendrils.

I. Study carefully the tendrils, noting particularly their origin, form, and mode of grasping a support. How do they compare in their subsequent behavior with those of bryony, described by Sachs? [1]

II. Rub one of the young tendrils and watch it for a few minutes. Is there any movement? Does it make any difference whether the concave or convex side is rubbed? [2]

III. Watch a vigorous specimen long enough to observe the spontaneous movements of its tendrils.

Inflorescence and Flowers.

I. How many flowers compose the inflorescence? Are they all alike? Compare those in the axils of the lower leaves with the ones produced higher up. Is this species monœcious or diœcious? [3]

II. Examine carefully the stamens, noting the form and structure of the anthers and their peculiar mode of cohesion.[4]

III. How many stigmas are there? Examine their surface with a lens.

IV. Are there any nectaries? How far do the flowers of the cucumber agree with those of *Bryonia dioica*, as

[1] *Physiology of Plants*, pp. 663, 664.

[2] Cf. Darwin, *Climbing Plants*, p. 127 *et seq.*

[3] Cf. Gray, *Lessons*, p. 85.

[4] Cf. Goebel, *Outlines of Classification and Special Morphology*, p. 357.

described by Müller?[1] Does their structure indicate self- or cross-fertilization?

V. Examine the ovary of one of the oldest flowers. Is there any external indication of the number of carpels? Make a transverse section and notice the number of cells, the position of the placentæ, and the form and direction of the ovules. Draw the section in outline. Represent by dotted lines the commissural lines of union of the carpellary leaves.[2]

RELATIONSHIP.

Seeds of squash, melon, and many other plants belonging to this family, are easily procurable, and afford the means of extended and instructive comparative study. Seedlings, which may be had in the course of a few days, exhibit with remarkable uniformity in the different genera the characteristic contrivance by which the seed-coats are ruptured and the cotyledons released.[3] Tendrils of various species, that may be studied anywhere a little later in the season, are of the greatest interest, morphologically as well as physiologically, and in their turn contribute to the sum of characteristic features by which this family is marked. If all these are carefully studied, as well as the flowers and fruits, and due weight is given to every well-marked trait, it will be found that the "family characters" include more than the structural details usually given. The behavior of the seedlings in breaking through the ground, the highly developed tendrils and their mode of action, and even the active properties of some of the

[1] *Fertilization of Flowers*, pp. 268, 269.

[2] Cf. Eichler, *Blüthendiagramme*, p. 306.

[3] Darwin, *Power of Movement in Plants*, p. 102.

species are as truly characteristic as various other features upon which more emphasis is usually laid.

The student is recommended to make a special study of seeds and seedlings of the Cucurbitaceæ, and to proceed from these, as material and opportunity permit, to the characters observable in later stages of growth.

XL. THE COMPOSITE FAMILY. COMPOSITÆ.

MATERIAL REQUIRED.

Specimens of the common dandelion in flower, others with the fruits in different stages of development.

Similar specimens of robin's-plantain, *Erigeron bellidifolius*, Muhl. (or other species of Erigeron), plantain-leaved everlasting, *Antennaria plantaginifolia*, Hook., golden ragwort, *Senecio aureus*, L.

Later in the season, yarrow, *Achillea Millefolium*, L., mayweed, *Anthemis Cotula*, DC., oxeye daisy, *Chrysanthemum Leucanthemum*, L., wild lettuce, *Lactuca Canadensis*, L.

In the fall, asters, goldenrods, and various species of Bidens, Prenanthes, and other late flowering composites.

THE DANDELION. *Taraxacum officinale*, Weber.

Distribution.

Where were the specimens gathered? Does the plant manifest any choice of locality or surroundings? Is it an indigenous or introduced species?

General Characters.

With a perfect specimen in hand, note the several parts of the plant and write a brief description, including an account of the form, structure, and apparent duration of the root, the stem (so short that the plant is said to be acaulescent), the position and form of the leaves, the character of the inflorescence and its support, and any conspicuous peculiarities, such as taste, color of the **latex**, etc.

Inflorescence.

I. Observe first the cylindrical hollow stalk (scape) by which the **head** is supported. How do those of older specimens compare in length with those of younger ones? Can you suggest any advantage in this?[1]

II. The head is subtended by an **involucre** of green, leaf-like bracts.

1. Is there more than one row of bracts? How do the outer differ from the inner ones?
2. Compare the position of the involucre in the early morning with that assumed later in the day, and finally in the evening; in clear and rainy weather. Do these observations suggest anything as to the function of the involucre?

III. Taking a well-developed head, not so old but that a few of the flowers of the center are still unopened, make a longitudinal section.

1. Observe the disk-like, expanded end of the stalk on which the flowers are borne, the **receptacle**. Is it concave or convex? How does it compare in this respect with the oldest receptacles from which the seeds have fallen? Suggest advantages.
2. Note the order of development of the flowers. Centripetal or centrifugal?

Flowers.

These should be studied in position and also separately, removing for this purpose several flowers with a pair of fine forceps.

I. Examine a fully developed flower throughout. With a good lens observe

[1] In this and some other cases it will be necessary to supplement the laboratory exercises by out-of-door observations.

1. The **seed-like ovary**, its form and surface, and the prolongation of its upper end into a short beak, which afterwards becomes greatly elongated.
2. The calyx, with its limb of numerous fine bristles, **pappus.**
3. The yellow, **ligulate corolla.**
4. The stamens inserted on the corolla, **epipetalous**, with their anthers united in a hollow cylinder around the style, **syngenesious**, the latter soon projecting beyond them and divided above into two slender, recurved, and finally coiled branches. (Specimens should be gathered in the morning and also in the afternoon.)

II. Compare successively older, outer flowers with the younger ones, approaching finally the unopened flowers at the center. Note the different stages of development of the flower, particularly of the stamens and pistil. Observe

1. The way the pollen is pushed out by the style.
2. The short, stiff hairs on the outer surface of the latter.
3. The papillæ on the inner, stigmatic surface of each of its branches. (These latter require higher magnification in order to be seen clearly.)

III. Imitate the action of a bee or other insect by repeatedly brushing a large number of flowers. Examine the stigma before and after the operation. Is there anything to favor cross-fertilization?

Fruit.

Study next a head in fruit. Compare the hard, seed-like **achenium** with the immature ovary already examined and note differences. What arrangements are there for the dissemination of the fruits?

Review your observations and record them precisely.

I. In writing an account of the flower treat it first from the morphological standpoint, including a discussion of

1. Original plan of the flower, as indicated by notches at the end of the corolla and number of stamens.
2. Relation of calyx and ovary.
3. Other evidences of modification.

II. Enumerate the various physiological adaptations such as

1. Protective arrangements.
2. Adaptations for securing fertilization.[1]
3. Means of dissemination of seeds.

ROBIN'S-PLANTAIN. *Erigeron bellidifolius*, Muhl.

Distribution.

Where have you noticed the plant growing most abundantly? Does it appear to be indigenous or introduced?

General Characters.

Describe the root, stem, and leaves. Note means of protection, if such exist.[2] It is said to produce "offsets." Verify the statement.

Inflorescence and Flowers.

I. Compare the heads with those of the dandelion. What are the most striking differences?

II. Make a longitudinal section and examine in their natural position, and also separately, the purple **ray flowers**, and the small, yellow **disk flowers**. The ray flowers are

[1] Cf. Lubbock, *British Wild Flowers in Relation to Insects*, p. 111 *et seq.*; Müller, *Fertilization of Flowers*, pp. 316–318, 359.

[2] Cf. Kerner, *Flowers and their Unbidden Guests*, Chap. IV.

ligulate, like those of the dandelion; the disk flowers are tubular.

Do both ray and disk flowers have stamens and pistil? Are both fertile?

III. In older heads examine the achenia, and observe their form and surface.

IV. How far do the arrangements for securing fertilization correspond with those observed in the dandelion?

V. Compare the flowers of the two plants as regards modification from an assumed original form.

PLANTAIN-LEAVED EVERLASTING. *Antennaria plantaginifolia*, Hook.

As in preceding cases, note where this plant occurs, and record any peculiarities in its mode of growth. Notice particularly its habit of spreading by runners.

It will be observed that there are two sorts of flowering heads, on different individuals, one, **pistillate**, more elongated and lighter colored than the other, **staminate**, ones.

Study critically the flowers of the two different kinds of heads. Note all the points in which they are unlike, including differences of pappus and corolla, fertility, color, size, etc.

Compare the flowers of this species with those of the dandelion and robin's-plantain, noting in each case points of similarity and difference.

RELATIONSHIP.

A comparative study should be made of as many other genera of Compositæ as practicable. There are so many species, ranging in their time of flowering from spring to late autumn, that there is no difficulty in obtaining abundant material. With patience and close attention to details of structure, there is no reason why the student should not become thoroughly familiar with the characters of this important and extremely interesting family, although the determination of the limits of genera and species is often a matter of great difficulty, owing to the number of intermediate forms and the tendency to variability exhibited by many species.

When as many species have been studied as the time will permit, write a careful summary of the morphological characters in which they all agree. This should be accompanied by a *résumé* of their physiological peculiarities, especially the arrangements for securing fertilization and the dispersal of seeds.

The Compositæ constitute the largest family of flowering plants, including over one thousand different genera. Admirably fitted to survive in the struggle for existence, they have become distributed throughout the world, and retain tenaciously their dominant position. Some of the genera are represented by so many species, and are so abundant as to form in their season a characteristic feature of the landscape, as is the case, for example, with the asters and goldenrods in eastern North America. "The numerical preponderance, . . . and extreme abundance of many of the species, are due to the concurrence of several characters, most of which, singly, or in some degree combined, we have become acquainted with in other families, but never in such happy combinations as in the Compositæ." See Müller's discussion of these points in the *Fertilization of Flowers*, p. 316 *et seq.*

REVIEW AND SUMMARY.[1]

After such exercises as those outlined in the preceding pages, even if only a small number of families have been studied, the student can hardly fail to have grasped the conception of degrees of relationship, a conception that lies at the very foundation of biological science.[2] If we now extend our study farther, and compare families with each other, as we have been comparing their genera, we shall find that the principle is general, and that families, as well as genera and species, show relationships among themselves, falling naturally into larger groups to which the term "order" is now commonly applied.[3] In some cases these groups are distinctly marked, and the close relationship of the families composing them is unmistakable, while in others the affinities of a family are obscure. In an inquiry of this kind there are necessarily inherent difficulties, and it must be said frankly, that, in the present state of botanical science, it is impossible to construct a system that will fully and truthfully represent the relationship of families of plants to each other. Nevertheless it is desirable before proceeding farther to notice

Degrees of relationship.

[1] It is assumed that the order recommended on page 96 has been followed, or at least that the student has acquired a reasonably familiar acquaintance with the prominent families of flowering plants.

[2] "For myself, there comes from the eighth year memory of an awakening to the conscious grasp and knowledge of genus and species. I see it yet . . . in my lap the shredded petals of almond, plum, and the yellow rose of Persia, and in myself sense of a new concept and tool for classifying and accumulating knowledge through all life." — Talcott Williams, in the *Century*, January, 1893.

[3] "Natural order" is still employed by many writers as equivalent to family, but the usage indicated above is becoming prevalent.

some of the cases in which such affinities are plainly marked. A few of these will serve as examples of many others.

Groups of families.

The Cruciferæ, as we have seen, are so plainly defined by their cruciform, tetradynamous flowers, pungent properties, and characteristic fruits and seeds, that we naturally think of them as sharply marked off from all other families of plants. A number of smaller families, however, are manifestly related to them. In one of these, the Capparidaceæ or caper family, the flowers are cruciform, the plants often pungent, the pods nearly the same as those of the Cruciferæ, and the seeds similar; but there are certain differences of the embryo and stamens that require a separation of the two families, which otherwise are nearly identical in their characters. In like manner the members of the Rosaceæ, another prominent and well-marked family, show such plain affinities with the Saxifragaceæ that the differences by which the two families are distinguished from each other seem trivial in comparison with their strong likeness. Again, while the Labiatæ, with their square stems, opposite leaves, bilabiate flowers, and aromatic properties, form a most characteristic group of plants, their relationship with the Verbenaceæ, which exhibit a number of characters in common with them, is manifest at a glance. In the same way the Asclepiadaceæ and Apocynaceæ show a remarkable likeness, and this is still more strikingly true of the Liliaceæ and a number of families that form with them another marked group, or order.

Orders and higher groups.

These examples are sufficient to illustrate the natural grouping of families into orders. Thus, the Labiatæ with nine other families constitute the Labiatifloræ, the Liliaceæ with fifteen other families the Liliifloræ, and so on. At present botanists recognize some thirty orders of dicotyledons, including about one hundred and sixty-three families, and seven orders of monocotyledons with about forty families, while the gymnosperms include three orders with thirteen families.[1] The orders themselves are associated in higher groups, which in their turn make up the great classes just named.[2]

Another fact of prime importance, that cannot well have escaped the student's attention, is the gradually increasing complexity of structure, particularly of the floral organs, met with as we proceed from more primitive to more advanced families. Comparing a lily, for example, with an orchid, or a buttercup with a dandelion, it is plain that the flowers of the higher families have undergone very remarkable changes of form and structure, although the fundamental plan may still be recognized. These changes of structure represent, as a rule, progressive adaptation to cross-fertilization through the agency of insects. It appears, too, from all we can learn of them by comparative study, that these progressive modifications have taken place step by step with corresponding modifications of structure and habit on the part of their visitors. The history of such a flower as that of the sweet-pea or violet, of the milkweed or daisy, must, if this view is correct, reach far back into the past, so far that the imagination fails to reproduce the long series of changes that have taken place in the succession of intervening generations. A glimpse of this history, helpful and satis-

Progressive modifications of floral organs.

[1] Cf. Luerssen, *Botanik*, Bd. 2, pp. vii–x.

[2] These groups of a higher order are less satisfactorily defined. For an attempt at their systematic presentation, see Goebel, *Outlines of Classification and Special Morphology*, pp. xi, xii. The student will do well to remember that all such attempts to represent the affinities of families and higher groups involve more or less uncertainty, and that all classifications are of necessity provisional.

factory as far as it goes, is given by Müller in his general retrospect at the close of the *Fertilization of Flowers*, as follows: "Insects must operate by selection in the same way as do unscientific cultivators among men, who preserve the most pleasing or most useful specimens, and reject or neglect the others. In both cases, selection in course of time brings those variations to perfection which correspond to the taste or to the needs of the selective agent. Different groups of insects, according to their sense of taste or color, the length of their tongues, their way of movement and their dexterity, have produced various odors, colors, and forms of flowers; and insects and flowers have progressed together towards perfection."

Cryptogams. A progressive series.

Turning to the lower or so-called cryptogamic plants, it appears that precisely the same principles hold good. Ferns and mosses, quite as plainly as plants higher in the scale, exhibit degrees of relationship. Here, as elsewhere, closely related species fall naturally into genera, closely related genera into families, and these into orders and higher groups. Furthermore, a review of these higher groups shows that the vegetable kingdom as it exists to-day presents a progressive series, rising from such simple plants as Spirogyra, and even more primitive forms of the green algæ, through the liverworts and mosses to the vascular cryptogams, and from these by an almost insensible step through Selaginella and its allies up to the gymnosperms and flowering plants. It is believed by those who have the most extended and critical knowledge of plant life that this series corresponds closely with the order of development of the vegetable kingdom, and, as a matter of fact, it is found that the geological record strikingly confirms this view. In earlier geological times, beginning with the Silurian Age, marine algæ and other cellular cryptogams were the dominant forms of plant life. Vascular cryptogams appeared in the Devonian; after them came the gymnosperms; then the monocotyledons; and finally the different classes of dicotyledons attained their present supremacy.[1]

The life history of the flowering plants and higher cryptogams still further confirms the same view, passing as they do through successive stages of development that repeat in miniature the history of past ages of plant life. The fern prothallium in its earlier stages of growth is so nearly a filamentous green alga as to be distinguished from one by its origin rather than by its structure; a little later it becomes a flat expansion of cells, so like a liverwort as to deceive the inexperienced eye; and these and other phases of their developmental history may still be recognized, not only in the gymnosperms, but in the higher flowering plants.

Conclusions.

From facts like these, it seems impossible to draw any other conclusion than that there has been from the earliest appearance of plant life on the globe a slowly progressive development from simpler to higher forms, and that the record of this is still preserved to us in the natural groups that form the present vegetation of the earth.

We are to think, then, of the plants we have studied and those we have yet to study, as in reality all members of one vast and ancient family, some closely, others remotely related, some still retaining the simple forms and habits of earlier days, and others, through a long course of selection, exquisitely adapted to animal structures no less highly modified and adapted to them. In this great family, we

[1] Lester F. Ward, *Am. Nat.*, August, 1885.

have learned to distinguish species, genera, families, orders, and classes; but these are simply expressions of so many different degrees of relationship that pass insensibly into each other, and call for the exercise of clear judgment, profound knowledge, and critical attention to details on the part of those who attempt to recognize and define them.[1]

This is a conception widely different from that which supposes "that species, and even genera, are like coin from the mint, or bank-notes from the printing press, each with its fixed marks and signature, which he that runs may read, or the practiced eye infallibly determine," but "there is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning, endless forms most beautiful and most wonderful, have been and are being evolved."[2]

[1] After some months of such training as is outlined in the preceding exercises, the student should be prepared to take up with profit a study of the flora of the region in which he lives. In this way, with an indefinite amount of painstaking, independent, and long-continued work, he will gradually become more familiar with the systematic grouping of plants and accumulate for himself the evidence that more and more confirms the conclusion formulated above.

[2] Darwin, *Origin of Species*, p. 429.