ELEMENTARY PLANT PHYSIOLOGY

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BY

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WITH ONE HUNDRED AND EIGHT ILLUSTRATIONS

LONGMANS, GREEN, AND CO.
91 AND 93 FIFTH AVENUE, NEW YORK
LONDON AND BOMBAY
1902

PREFACE.

A TRANSLATION of Oel's "Pflanzenphysiologische Versuche," by the author of this volume, was published in 1894, and the entire edition was exhausted within a few months after its appearance. A similar elementary text, "Experimental Plant Physiology," was prepared at once and published in 1895, the last copy of which was sold in October, 1901. Meanwhile the "Practical Text-book of Plant Physiology," presenting a brief outline of the entire subject, with details of experimental methods suitable for the exact analyses requisite in research work, has been brought out.

The present little volume has been arranged to replace the "Experimental Plant Physiology" (1895) and to meet the constantly increasing demand for a course in elementary demonstrations which may be followed by beginners in the subject of botany. Experimentation is purposely confined to the principles capable of demonstration by the simplest methods, and without the costly and complex apparatus of a fully equipped laboratory. Furthermore, an arrangement of the book into a number of courses has been made to meet the exigencies of instruction in schools of various types.

I am indebted to Dr. C. C. Curtis, of Columbia University, and to Dr. H. M. Richards, of Barnard College, for many valuable suggestions and for their kindness in reading proofs.

D. T. MACD.

New York Botanical Garden,
January, 1902.

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Elementary Plant Physiology

CHAPTER I.

INTRODUCTORY.

THE plant is a living thing, an organism, which in its structure shows a design appropriate to the nature of its functions, which exhibits well-defined purposes in its actions, and which directs all of its performances in accordance with the nature of impressions received from external forces, or set up within its own body.

The course of observations outlined on the following pages is designed to enable the student to analyze the relations between the structure and functions of the more important organs, attention being given chiefly to the higher plants, since in them organs and functions attain their highest differentiation; to demonstrate the nature and purpose of the more important functions; to follow some of the adjustments made by the plant in the performances of its functions, changes in form or structure in response to alterations in its environment; and, lastly, to delineate the correlations or intimate interrelations existing among all of the organs of a plant, in accordance with which any modification of the action of one is followed by alterations in the functional performance of others.

The following practical recommendations are made for the successful accomplishment of the work outlined:

MATERIAL AND APPARATUS.

If a greenhouse containing a commercial, or exhibition collection of living plants is accessible, the student will have no difficulty in obtaining material to carry out all the demonstrations. In this instance it would add much to the efficiency of the work if a definite space on the benches could be secured for the experiments. A greenhouse in connection with the laboratory, in which a space of at least two square meters may be set aside for the use of the individual student, is, of course, the most suitable arrangement.

If the facilities of a greenhouse are not available, recourse must be had to plants grown from seeds obtained from florists or dealers. In schools in the lower latitudes, much of the work may be performed in the open air, in small special gardens.

The apparatus necessary is of the simplest form, and the material used in its construction may be found in the natural science laboratories of any school. A compound microscope, a balance, thermometers; tubing of rubber, lead, and glass; cork in stoppers and in sheets; wire of various sizes; wide-mouthed bottles of assorted sizes; a few bell jars, glass funnels, graduates, test tubes; a set of cork-borers or cylindrical files; sealing wax, a dozen fruit jars, burettes, thistle tubes, germinators, and a few pieces of common glassware, together with a supply of chemicals, to be obtained from any druggist, will be found sufficient to make all the demonstrations described, and much less will suffice for some of the shorter courses outlined. The exact amount and kind of apparatus will depend upon the manner of performance of the experiments and the number of students participating, and may be seen by consultation of the text.

MEASUREMENTS.

All measurements are given in the metric system. It is to be noted that the centigrade scale is not identical with that of

Celsius, although often given as such. More inclusive and complete tables may be found in the "Practical Plant Physiology."

LENGTH.

1 millimeter (mm.) = $\frac{1}{1000}$ meter = $\frac{1}{25}$ inch (.03937 inch).

1 centimeter (cm.) = $\frac{1}{100}$ meter = $\frac{2}{5}$ inch (.3937 inch).

1 decimeter = $\frac{1}{10}$ meter = 4 inches (3.937 inches).

1 meter (M.) = 1000 millimeters = 39.37 inches.

1 inch = 25 mm. (25.399 mm.).

1 foot = 305 mm. = 30.5 cm. (30.479 cm.).

1 yard = .914 m. = 914 cm. (914.399 cm.).

WEIGHT.

1 milligram (mg.) = $\frac{1}{1000}$ gram = .01543 grain Troy or Avoir.

1 gram = 15.5 grains = $\frac{1}{28}$ oz. Avoir.

1 kilogram + 1000 grams = 32.157 oz. Troy = 35.274 oz. Avoir.

1 oz. Troy = 31.103 grams.

1 oz. Avoir. = 28.35 grams.

1 lb. Avoir. = 453.59 grams.

1 lb. Troy = 363.236 grams.

CAPACITY.

1 cubic centimeter (cc.) = $\frac{1}{1000}$ liter = 1 gram of water = .034 fluid oz.

1 liter = 1000 cc. = 1000 grams of water = 1.057 quarts = 33.8 fluid oz.

1 pint U. S. = 437.18 cc.

1 quart = 946.36 cc. = .946 liter.

1 gallon = 3.718 liters.

TEMPERATURE.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
+100° =	+212.0°	+42° =	+107.6°	+24° =	+75.2°	+ 6° =	+42.8°
95 =	203.0	41 =	105.8	23 =	73.4	5 =	41.0
90 =	194.0	40 =	104.0	22 =	71.6	4 =	39.2
85 =	185.0	39 =	102.2	21 =	69.8	3 =	37.4
80 =	176.0	38 =	100.4	20 =	68.0	2 =	35.6
75 =	167.0	37 =	98.6	19 =	66.2	1 =	33.8
70 =	158.0	36 =	96.8	18 =	64.4	0 =	32.0
65 =	149.0	35 =	95.0	17 =	62.6	− 1 =	30.2
60 =	140.0	34 =	93.2	16 =	60.8	− 2 =	28.4
55 =	131.0	33 =	91.4	15 =	59.0	− 3 =	26.6
50 =	122.0	32 =	89.6	14 =	57.2	− 4 =	24.8
49 =	120.2	31 =	87.8	13 =	55.4	− 5 =	23.0
48 =	118.4	30 =	86.0	12 =	53.6	− 6 =	21.2
47 =	116.6	29 =	84.2	11 =	51.8	− 7 =	19.4
46 =	114.8	28 =	82.4	10 =	50.0	− 8 =	17.6
45 =	113.0	27 =	80.6	9 =	48.2	− 9 =	15.8
44 =	111.2	26 =	78.8	8 =	46.4	−10 =	14.
43 =	109.4	25 =	77.0	7 =	44.6	−20 =	− 4.

REFERENCES.

The student should refer to the following works in connection with the experimentation in various portions of the subject, as well as to others cited in the text:

MacDougal's "Practical Text-book of Plant Physiology." (Longmans, Green & Co., New York and London. 1901.) An outline of the entire subject, with citations of recent literature and description of detailed and accurate methods of experimentation.

Green's "Introduction to Vegetable Physiology." (J. & A. Churchill, London. 1900.) An admirable discussion of nutrition, translocation, storage of reserve food, digestion, and metabolism in general.

Ganong's "Laboratory Course in Plant Physiology." (H. Holt & Co., New York. 1901.) A series of elementary ex-

periments, with descriptions of many useful and practicable methods.

MacDougal's "Nature and Work of Plants." (The Macmillan Co., New York and London. 1900.) A simple discussion of the general anatomy and physiology of seed plants, with directions for experiments and observations.

Selected Courses.

The requirements and facilities of schools are so widely different that it is impossible to prepare a book for the laboratory exactly suitable for all of them. The attempt has been made to give methods of treatment of the easily demonstrable phases of the subject in the following pages, from which courses of work suitable for the needs of individual schools or students may be chosen. The following groups of experiments have been selected for such courses:

Course 1.

Suitable for twelve laboratory periods. Carry out experiments described under the headings given below, and read remainder of book, also the references given above.

Elongation of dicotyledonous stems, §1.
Growth of leaves, §§8, 10, 11.
Germination of pollen cells, §33.
Germination of peas, §36.
Osmose in plant tissues, §45.
Bleeding, §§51, 52.
Estimation of amount of water transpired, §65.
Passage of sap, §§70, 71.
Composition of the body, §§78, 79.
Exhalation of oxygen by green plants, §93.
Changes produced in the air by a flame and by green plants, §96.

Exhalation of carbon dioxide by germinating peas, §104.
General reactions of a plant to light, §122.
Geotropism; relation of plants to gravity, §§129, 130.

COURSE 2.

Suitable for twenty-four laboratory periods. Carry out experiments included, read remainder of book and the references to the special subjects investigated in works cited above.

Elongation of dicotyledonous stems, §1.
Measurement of growth in length by auxanometers, §6.
Growth of leaves, §§8, 10, 11.
Growth of roots, §14.
Germination of pollen cells, §31.
Germination of seeds of the squash, §38.
Sprouting of sweet potatoes, §41.
Osmose in plant tissues, §45.
Tissue tensions, §49.
Bleeding, §§50, 51.
Hygroscopic movements, §55.
Structure of leaves, §§57, 58, 59.
Estimation of the amount of water transpired, §65.
Guttation, §66.
Path of sap, §§70, 71.
Air passages in plants, §§74, 75, 76.
Composition of the body, §§78, 79.
Water cultures, §83.
Exhalation of oxygen by green plants, §93.
Changes produced in the air by a flame and by green plants, §96.
Exhalation of carbon dioxide by germinating peas, §104.
Action of diastase and associated enzymes, §111.
Action of glandular hairs, §118.
General reactions of a plant to light, §§129, 130.

Perceptive region in leaves of grasses, §125.
Movements due to changes in intensity of illumination, §128.
Geotropism; relation of the plant to gravity, §§129, 130.
Movements in response to shock, §137.
Circumnutation of growing organs, §140.
Carpotropic movements, §§141, 142, 144.

COURSE 3.

Suitable for forty-eight laboratory periods. Readings and references as above.

Elongation of dicotyledonous stems, §1.
Elongation of the stem of a monocotyledonous plant, §3.
Measurement of growth in length by auxanometers, §6.
Growth of leaves, §§8, 10, 11.
Growth of peduncles and scapes, §12.
Growth of roots, §14.
Influence of temperature upon germinating seeds, §20.
Influence of sodium chloride upon germination, §26.
Germination of pollen cells, §33.
Germination of grains of corn, §34.
Germination of seeds of *Ricinus*, §35.
Germination and propagation of *Begonia*, §39.
Propagation by various organs, §42.
Osmose, §44.
Osmose in plant tissues, §45.
Structure of an absorbing root, §46.
Tissue tensions, §49.
Bleeding, §§51, 52.
Measurement of exudation pressure, §53.
Imbibition pressure, §54.
Amount of stretching produced by imbibition and turgidity, §56.
Structure of leaves, §§57, 58, 59.
Lifting power of a transpiring branch, §64.

Estimation of the amount of water transpired, §65.

Guttation, §66.

Localization of transpiration, §67.

Hygrometer test for transpiration, §68.

Path of sap, §§70, 71.

Rate of movement of water through stems, §72.

Air passages in plants, §§74, 75.

Osmose of gases, §77.

Composition of the body, §§78, 79.

Corrosive action of plants on minerals, §82.

Water cultures, §83.

Exhalation of oxygen by green plants, §93.

Changes produced in the air by a flame and by green plants, §96.

Formation of starch in light, §97.

Estimation of the amount of carbon dioxide given off in the respiration of germinating wheat, §105.

Respiration without external oxygen, §107.

Products of fermentation, §109.

Action of diastase and associated enzymes, §111.

Digestive action of scutellum of Indian corn, §112.

Translocation of carbohydrates from leaves, §116.

Excretion of nectar, §117.

General reactions of a plant to light, §122.

Diaphototropism, §124.

Perceptive region in leaves of grasses, §125.

Movements due to intensity of illumination, §128.

Geotropism; relation of the plant to gravity, §§129, 130.

Location of motor zone in roots, §131.

Hydrotropism of roots, §134.

Chemotropic movements of pollen tubes, §136.

Movements in response to shock, §137.

Movements of tendrils, §139.

Carpotropic movements, §§141, 144.

CHAPTER II.

GROWTH.

1. Elongation of dicotyledonous stems.—The body of a plant continues to increase in size more or less continuously during its entire life. As a consequence, bulk is largely determined by age, although in many forms the death and excision of certain parts of the body take place at such rate that but little net gain is shown. The rate of increase and the variations in the rate are illustrated by the following experiments:

Select a vigorous young specimen of bean (*Phaseolus*), bindweed (*Polygonum*), or sunflower (*Helianthus*) in a greenhouse, or, under suitable conditions, in the open air. If the plant is in a pot or box, lay it on its side on a table, support the stem by means of a number of thicknesses of board, and place a ruler with its edge against the stem. If the plant cannot be adjusted in this manner, arrange a clamp and support to hold a ruler against the stem, and parallel to it, in an upright position. Bend a small piece of steel wire 12 centimeters long into the form of a V, and tie a silk thread to the ends of the arms in such manner that it will be kept taut by the spreading of the arms. Moisten the thread with India ink, using a quill or splint of wood to apply the fluid to it. Place the ruler so that it covers a section 25 cm. in length, beginning at the tip. Now press the thread on the stem, opposite the centimeter divisions of the ruler, making a single clear, sharp line. Place the plant in its customary position, and under normal conditions. Measure the intervals between the inked lines a day later, and repeat on the third and fourth days. The total

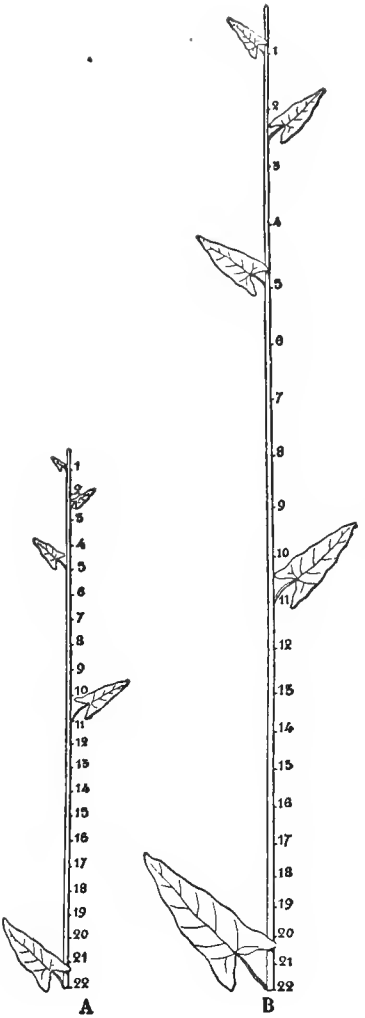


Fig. 1.—Terminal portion of stem of bindweed. *A*, stem marked into intervals of 1 cm. *B*, the same stem 24 hours later, showing the relative elongation of the various regions. The maximum amount of growth has taken place in the fifth interval from the apex.

amount of growth of this part of the stem will be denoted by the distance of the lowest mark from the apex of the stem. Compare the lengths of the different intervals. One of these, about the third or fourth from the apex, will be found to have made the greatest elongation, and may be designated as the *zone of maximum growth*. Continue the measurements three days more, and note that the zone of maximum growth has changed its position.

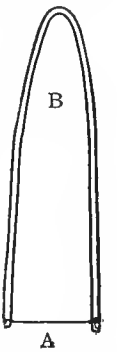


Fig. 2.—Device for marking stems with India ink. *A*, thread; *B*, wire.

It was doubtless seen during the previous measurements that the stem is made up of a number of sections or internodes; the region in which the sections are joined constitutes the nodes, at which points the leaves arise, being borne on the end of internodes. Examine the record of measurements made above, and note whether all parts of the older internodes elongate with the same rapidity. If possible, repeat both observations with the branches of trees.

2. **Location and arrangement of growing tissues.**—Cut a thin cross-section of the stem used in the previous experiment, by means of a sharp razor and a suitable clamp. Examine with magnifications of about sixty, and four hundred. In sections taken from the zone of maximum growth, it will be found that the greater part of the stem is composed of small thin-walled cells. About half way between the center of the section and its outer edge may be seen groups of cells with heavier and variously differentiated walls, constituting the fibrovascular bundles, which are arranged in a cylindrical shell in the stem (Fig. 3, A). Cut a section from the same stem, a few centimeters lower down, and the bundles will have formed a circular band which will exhibit two distinct regions. A portion lying toward the center of the stem constitutes the xylem, and consists mostly of vessels and tracheids with

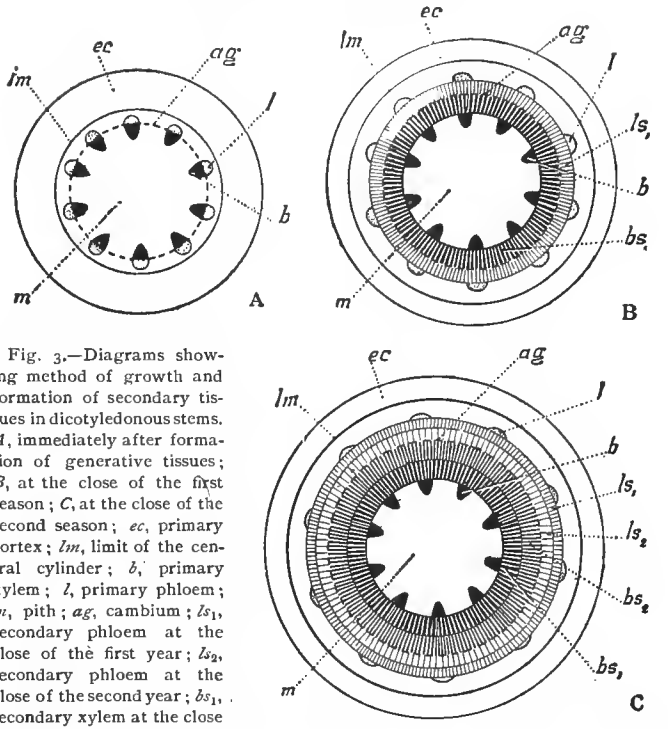


Fig. 3.—Diagrams showing method of growth and formation of secondary tissues in dicotyledonous stems. *A*, immediately after formation of generative tissues; *B*, at the close of the first season; *C*, at the close of the second season; *ec*, primary cortex; *lm*, limit of the central cylinder; *b*, primary xylem; *l*, primary phloem; *m*, pith; *ag*, cambium; ls_1, secondary phloem at the close of the first year; ls_2, secondary phloem at the close of the second year; bs_1, secondary xylem at the close of the first year; bs_2, secondary xylem at the end of the second year. After Bonnier and Leclerc du Sablon.

heavy walls, with some thin-walled elements. The outer, or external portion of the cylinder contains a larger proportion of cells with thin walls, sieve cells, and some fibrous or spindle-shaped cells constituting the phloem and cambium (Fig. 3, B). It is to be seen from a comparison of the two sections that the region of greatest growth lies in a portion of the stem in which all of the cells are living, and are capable of division and extension. In the older part of the stem, from which the

second section was taken, the walls of some of the elements have become thickened, and the protoplasts have undergone dissolution. The presence of the dead cells makes impossible any elongation, except that permitted by the elastic stretching of their firm walls. After the power of elongation is lost, growth

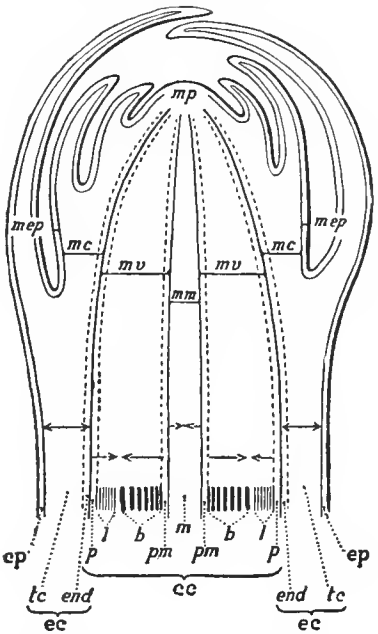


Fig. 4.—Diagram of longitudinal section of a stem. *mp*, apical meristem ; *mep*, epidermal meristem ; *mm*, medullary meristem ; *mv*, vascular meristem ; *ep*, epidermis ; *ec*, cortex ; *tc*, cortical parenchyma ; *end*, endodermis ; *cc*, central cylinder ; *p*, pericycle ; *l*, phloem ; *b*, xylem ; *pm*, perimedullary zone ; *m*, medulla. After Bonnier and Leclerc du Sablon.

in thickness may continue indefinitely by the action of cells in the phloem, especially of the generative layer, or cambium. The cylinder of fibrovascular tissue and its sheath with the enclosed pith constitute a morphological unit known as a *stele ;* the arrangement of the stelar components varies in different species.

Cut sections from older parts of a woody stem in which elongation has wholly ceased. Note the increased development of

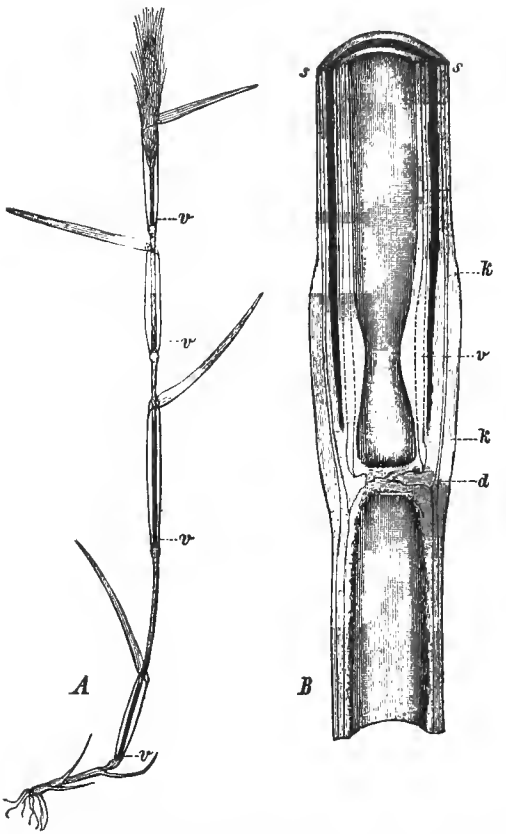


Fig. 5.—Structure of a monocotyledonous stem. *A*, a grass with sheathing leaf-bases *v*, *v*, *v*, *v*; *B*, portion of a stem including a node cut longitudinally and enlarged; *d*, point of union of two internodes above place of insertion of the leaf sheath *s*, *s*; *k*, *k*, enlarged portion of leaf base, sheathing the growing region of the internode designated by *v*. After Frank.

the woody and firm cells. Secondary bundles may be found between the primary ones seen in younger material. Note the thin layer of cambium outside the wood (Fig. 3, C).

3. Elongation of the stem of a monocotyledonous plant.—Mark the stem of a young plant of corn (*Zea*), wheat (*Triticum*), or any tall grass, with India ink, at intervals of one centimeter, as in the previous experiments. Measure on the following days, and find the zone of maximum growth; also locate the portions in which the separate internodes elongate most rapidly. Compare with similar data obtained from a dicotyledonous stem. Measure the length of the internodes of a mature cornstalk, and note the region in which the greatest length is attained. Cut across the stem in several places, and measure the diameter of the various bisected internodes. In what portions of the stem is the greatest diameter obtained?

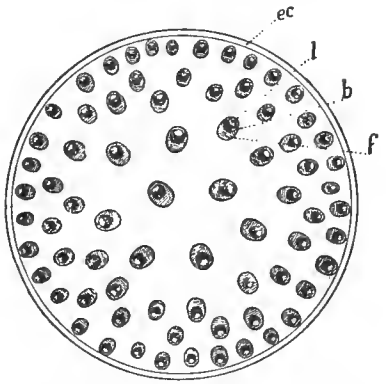


Fig. 6.—Diagram of cross-section of stem of *Zea*. *ec*, cortex and epidermis; *l*, phloem; *b*, xylem; *f*, sclerenchyma. After Bonnier and Leclerc du Sablon.

Note the manner in which a growing grass stem comes apart when stretched in the hands. The zones of maximum growth contain the mechanically strengthening tissues, and it is at these places that the stem is most easily torn apart. Observe also the manner in which the sheathing bases of the leaves surround and protect the delicate tissues (Fig. 5).

4. Arrangement of the tissues of a monocotyledonous stem.—Cut a thin cross-section of a young stem of corn (*Zea*), and examine with a magnification of 60 diameters. Note the position of clumps of denser tissue, the fibrovascular bundles. They will be found scattered irregularly in the sec-

tion, and are surrounded or imbedded in pith, while the extreme outer portion of the stem is made of cells with very heavy walls, forming the hard outer layer of the stalk (Fig. 6).

5. The fibrovascular bundle and composition of the stem.—Select a single fibrovascular bundle of which a thin cross-section has been made, and examine with a magnification of 400 to 600. The xylem, with many heavy-walled

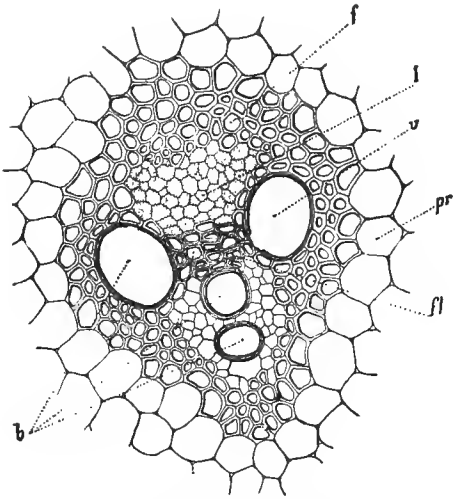


Fig. 7.—Cross-section of a fibrovascular bundle of *Zea*. *pr*, parenchyma; *f*, sclerenchyma; *b*, *fl*, *v*, xylem; *l*, phloem. After Bonnier and Leclerc du Sablon.

cells, may be seen, and the thinner walls of the cells of the phloem. Surrounding the bundle is a heavy sclerenchyma sheath, the *stereome*, in which the cells are dead, and therefore incapable of any expansion to allow the increase in size of the enclosed bundle.

Each fibrovascular bundle, with its sheath, is a separate stele, and the monocotyledonous stem is seen to contain many of them, and is therefore known as *polystelic*, in contrast with

the dicotyledonous stem, which is *monostelic*. Every stele in the internode accomplishes a definite amount of growth during a short period, and then forms the heavy stereome which marks the end of increase both in length and thickness. This fact will explain the varying thickness of the different internodes of the stem and also the non-formation of bark in such plants.

6. Measurement of growth in length by auxanometers.—Increase in length of the stem is more or less continuous during the vegetative season, but the rate of such increase is not easily calculated by the unaided eye. If the tip of the growing organ is attached to the short arm of a lever in such manner that the comparatively slow motion of the growing parts will cause a magnified movement of the long arm of the lever, a fairly accurate estimate may be made of the rate of elongation. Auxanometers, or devices for measuring growth, may be set up as follows :

Make a smooth hole, half of the length of a cylindrical cork, with a diameter of about three centimeters, and fit it to the top of the upright rod of a retort stand. Drive four pins in the top of the cork in such manner as to make two parallel X's. Secure a splint of light wood about seventy-five or eighty centimeters long, and attach a thread of slightly greater length to each end. Fasten a small piece of wood to the strip at right angles to it, and pass the cord over the top of the strip in such manner that a bracing effect is obtained that gives additional rigidity to the strip. Measure the strip of wood into two parts, in the ratio of one to twenty-five, and drive a pin through the dividing point. Suspend the lever thus formed in the bearings made by the crossed pins on the cork, and fasten pieces of lead to the short arm of the lever until it is nearly as heavy as the long arm. The length of the long arm may be increased by fastening a bristle to its end with glue, and in all instances the effort should be made to increase the ratio between the length of the arms with the greatest possible lightness. Secure

a small, rapidly growing plant, and set it under the long end of the lever. Attach a thread to the extreme tip of the stem by a running loop, and bring the thread up to the lever, fastening

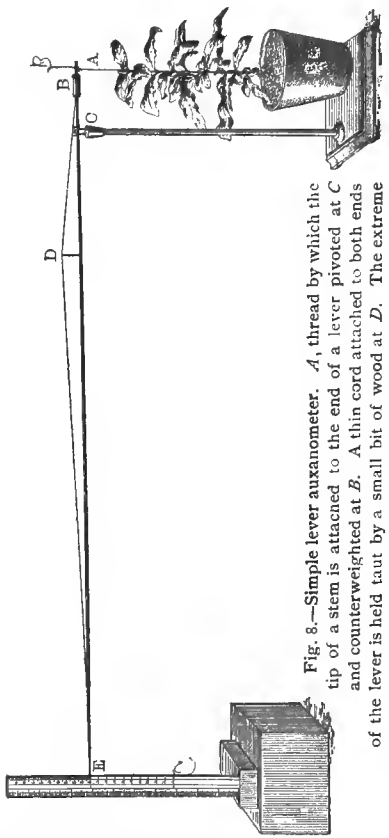


Fig. 8.—Simple lever auxanometer. *A*, thread by which the tip of a stem is attached to the end of a lever pivoted at *C* and counterweighted at *B*. A thin cord attached to both ends of the lever is held taut by a small bit of wood at *D*. The extreme tip of the lever moves along a scale at *E*.

it at such length as to hold the lever nearly horizontal. Fix a metric ruler to a small wooden box, and set upright back of the tip of the lever. A half hour later the plant will have adjusted

itself to the pull of the lever, and the exact point that may be read on the ruler scale above the lever should be noted. Now make readings at intervals of two or three hours during the day and as late at night as possible. Begin readings at similar

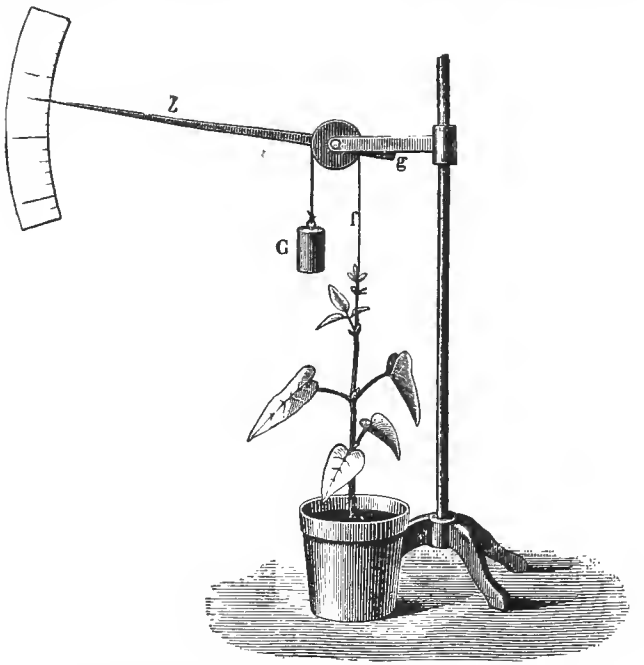


Fig. 9.—Pulley auxanometer. The cord *f* is passed over a small wooden pulley, and a small weight is attached to its end at *G*. The wooden lever *Z* is attached to the free face of the pulley, and counterweighted at *g* in such manner that, when the instrument is not attached to a plant, the tip of the lever rises. The end of the lever moves over a paper scale suitably supported. After Oels.

intervals on the following day (Fig. 8). At what hour of the day is growth most rapid? What is the total amount of growth during the day?

The same purpose may be accomplished by an auxanometer

consisting of a lever to which a small pulley is attached by the pin or needle used as pinion. The ends of the needle rest in bearings at the end of a horizontal support attached to a stand, and the thread from the plant runs over the pulley, and a weight is attached to its end (Fig. 9).

The greatest possible delicacy may be secured by the construction of a mirror auxanometer as follows:

Secure a small microchemical balance with the arms of the beam about six to nine centimeters long. Remove the upright standard, bearing the beam, from its base, and fasten rigidly to the upper surface of a block of wood by means of screws. Remove the scale pans and their swinging supports. Bore a hole longitudinally half way through a cylindrical cork stopper which is about three centimeters in diameter, and fit over the end of the scale beam. Fasten a small plane mirror, four centimeters in diameter, to the other end of the cork, by means of glue or sealing-wax, in such manner that its surface is at right angles to the long axis of the beam. With asphalt-black make a large round dot in the center of the mirror, or draw a heavy black horizontal line across the face. Next procure a strip of heavy white paper, five-centimeters in width and two meters long, and rule it into two centimeter intervals with heavy black lines. Fasten this strip to an upright support of wood, and place at a distance of five to ten meters from the mirror, and facing it. Attach a plant to the free end of the lever, as above, and add weights to the same arm to prevent too great stretching of the stem. Now set up a board or a pasteboard box at a distance of about two meters from the mirror, a short distance to one side of a line run from the mirror to the paper scale. Make a small aperture in the board or box, through which the reflection of the scale may be seen in the mirror. Some shifting of the scale, instrument, or peepsight will be necessary to get the whole apparatus in order. Note the exact division of the scale visible over the dot or line on the mirror.

Make readings hourly throughout the day and on the following day. In this instrument the indicator arm consists of half the beam and a ray of light extending from the mirror to the scale, and it is possible to magnify the amount of growth by 200, or

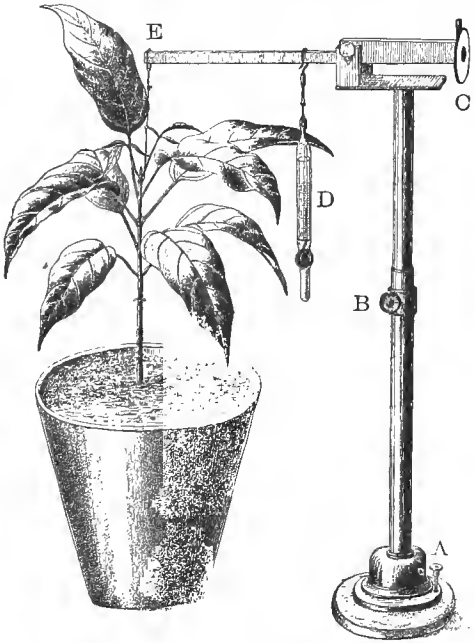


Fig. 10.—Mirror auxanometer. *E*, metal loop at the end of thread connected with apex of stem. The horizontal lever is divided into centimeter intervals by deep notches, from one of which the thermometer *D* is suspended, serving as a counterweight and to indicate temperatures; *C*, mirror; *B*, set screw for clamping telescoping support. *A*, levelling screw.

even 300, and thus detect small increments of growth which may not be measured by any other instrument (Fig. 10).

The mirror auxanometer may be constructed still more simply by attaching a mirror to the lever described in the first

part of this section. A shorter, stouter strip of wood should be used, or a glass rod may be substituted for it.

The reading of the mirror auxanometer may be taken in another way if desired. To do this, remove the peepsight, and set a lamp with reflector exactly in its place. Darken the room, and note the interval covered by the reflection.

The continuance of any of the above measurements during more than one day involves the readjustment of the plant to the instrument. This may be accomplished by setting the pot on a base consisting of half a dozen small sheets of thin glass, at the beginning of the experiment, and removing one or more of them to throw the mirror reading back to zero.

7. **Increase in thickness of stems.**—The most casual glance at any tree of the dicotyledonous type will show that the stems are usually thicker at the base than above. This is due to the fact that increase in thickness takes place during every vegetative season, and the oldest portions have naturally accomplished the greatest increase in bulk. Such increase in the wood of a tree-trunk takes the form of the "annual cylinders, or rings," of wood, and is also partly accountable for the formation of bark.

Examine the younger twigs of any convenient tree. The surfaces will be seen to appear smooth, and are green in many species. Cut a thin cross-section from a place near the apex, and note that the outer portion of the stem is made up of living cells, in which the protoplasm is stained yellowish brown by a drop of iodine solution run in under the cover glass. Underneath the cortical and outer region of the stem is the thin sheet of delicate cambium surrounding the central cylinder. Cut a thin cross-section from a place 2 or 3 cm. from the tip, and examine as before. The outer portion of the stem appears to consist of dead and dying cells, as may be seen by tests for protoplasm with the iodine solution. Such tissues are, of course, incapable of further expansion, and hence are

torn by the increase in volume of the tissues formed from the generative layer, or cambium. The concentric rings of wood in the stem may be made out with the unaided eye, if the surface is fairly smooth. One ring is ordinarily formed every year. If the growing season should be interrupted by a mid-summer drought, two rings might be formed in a single season.

The thin cylindrical sheet of cambium develops cells in its inner layers, which become converted into woody tissues. The tissues external to the cambium arise by various methods. (For a detailed study of the characters of a woody stem see Gregory, E. L., "Elements of Plant Anatomy.")

Examine the trunk of any tree which has been recently felled, or the freshly cut stump, and count the number of rings of wood. Taking into account the exigencies of climate, the age of the tree in years will be something less than the number of annual rings. Determine the height of the tree. If possible, compare the two measurements with those obtained from a second tree of the same species.

8. **Growth of leaves with netted veins.**—Select some plant, such as sunflower (*Helianthus*), dandelion (*Taraxacum*), peach (*Amygdalus*), maple (*Acer*), chestnut (*Castanea*), or squash (*Cucurbita*), in which the young leaf as it unfolds from the bud is but a fraction of its adult size. Mark off a series of intervals of 5 mm. in a straight line from the base to the apex, using a glass tube drawn to a fine point as a pen. Mark off a second series of right angles to this in the middle of the leaf. Take lengths of these intervals on successive days until full size has been reached. What is the position of the zone of maximum elongation? Does the extension of a leaf in breadth come from the growth of tissues near the midrib or near the margin? What is the daily rate of growth in both directions?

9. **Growth of a frond of a fern.**—Select a fern with

an unrolled frond which has not reached adult size. Mark off divisions of one centimeter on the stipe and on the lamina. *Osmunda* or *Asplenium* will offer good material for this work. Make measurements and determine the location of the zone of maximum growth.

10. **Growth of a leaf with parallel veins.**—Mark off intervals of one centimeter on a leaf of any of the early-blooming bulbous plants, such as *Narcissus*, *Iris*, or *Gladiolus*, and make daily measurements to locate the zone of maximum growth. Compare its position in such leaves with that of dicotyledonous forms. What is the daily rate of growth?

Make similar experiments with the leaves of *Smilax glauca* or *S. rotundifolia*, in which the veins of fibrovascular tissue are arranged in a slightly different manner. Is the method of enlargement of a leaf correlated in any manner with the arrangement of the veins?

11. **Rate of elongation of a leaf.**—Attach the tip of a leaf of any plant used in the last experiment to the lever of a mirror auxanometer, and determine the rate of growth during an hour or two. Determine the rate during an hour early in the morning and late in the afternoon. It would also be of great interest to repeat the experiment as late as midnight. Does the leaf elongate with the same rapidity at all hours of the day?

12. **Growth of peduncles and scapes.**—Mark off the scape of a young plant of *Arisæma*, or any arum, into intervals as above, and measure from day to day to ascertain region of greatest growth and also daily rate of elongation. Repeat with peduncles of tulip or any convenient plant.

Attach the tip of a peduncle or scape to the mirror auxanometer, and note the rate of growth during an hour early in the morning, at midday, late in the afternoon, and late at night. What variations are found?

13. **Growth of petioles.**—Mark the petioles of young

leaves of *Calla* or *Caladium* into intervals, as in the previous experiments, and make daily measurements to determine the zone of maximum growth and the daily rate. Does the petiole elongate at the same rate in all stages of its development?

14. Growth of roots.—Germinate seeds of pea (*Pisum*), bean (*Phaseolus*), or squash (*Cucurbita*) in fine, moist, clean sawdust, until the main roots are two to three centimeters in length. Remove, and wash free from adhering particles, selecting six of the most vigorous specimens with straight roots. Lay each seedling in turn on a strip of moist filter paper, on a table, against the end of a ruler, with the root extending along the top of the ruler. Use the wire-and-thread inking device described above, and mark the roots into intervals of 1 mm. Allow the ink to harden, dip the seedlings in water, and replace in the sawdust, with the roots depending vertically; place in a room kept at a temperature between 16° and 22° C. Take up two of the seedlings a day later, and lay on a table, in the same position with a ruler as before, making exact measurements of the distances between the marks. Take up two more on the following day, and measure. Take up the third lot on the third day, and make measurements. Find the total amount of growth in each root, and ascertain the location of the region of greatest growth.

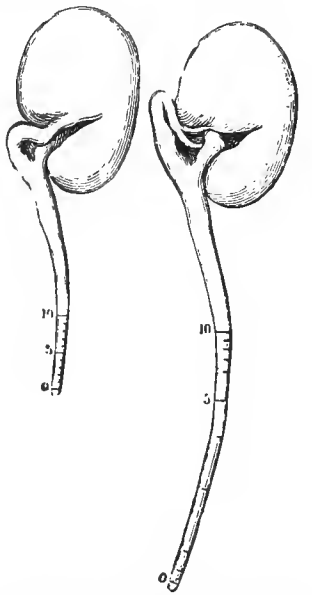


Fig. 11.—Seedling of pea with the root marked into centimeter intervals, and the same 24 hours later, showing the location of the zone of maximum growth. After Sachs.

15. External force exerted in growth.—The enlargement and change of form of an organ during growth is accompanied by a display of energy the amount of which becomes manifest when some mechanical resistance is encountered. Place as many germinated peas or beans as possible on the surface of closely-packed sand in a pot, and cover to the level of the brim with sawdust or loose soil. Lay a board or sheet of glass over this pot, and place a weight of a few grams on it. Prepare three other pots in the same manner, with increased weights. Note the lifting power exerted by the shoots as they emerge from the soil. Similar action may be observed in the emergence of seedlings from the soil. Some buds, shoots, and leaves have a pointed tip suitable for piercing the soil, and may even bore through the roots and runners of other plants in their upward growth (Fig. 12).

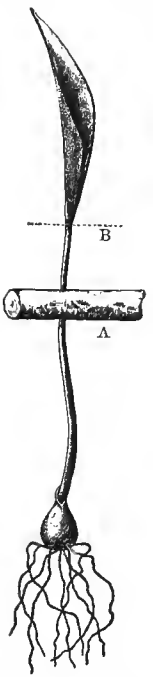


Fig. 12.—Leaf of *Erythronium* which has pierced a twig *A* in its upward growth through the soil, the surface of which is indicated by the dotted line *B*. After Bessey.

16. Growth of a fruit.—Train a vine of a pumpkin, squash (*Cucurbita*), or gourd so that a branch bearing a young fruit may be brought under cover or indoors, and the fruit placed on the pan of a druggist's balance of sufficient capacity. Adjust the stem so that it will bend easily, to allow the movement of the arms of the balance upward and downward. Equalize the balance by placing weights on the empty pan. Repeat the process several times daily, keeping record of the amount of weight added to the free pan to balance the increasing fruit. If the apparatus can be attended until late at night,

the results will be more valuable. Examine the data accumulated in observations extending over a week, and ascertain time of the day or night in which the greatest growth takes place, and also period in the development of the fruit when it increases most rapidly.

Mark off intervals on a line drawn longitudinally from the base of the fruit, and note the increase in size in the same manner in which stems were studied.

17. Growth of a cell.—Take a bit of epidermis from young buds of any member of the squash family, or from unopened flower buds of wandering jew (*Tradescantia*), mount in rain water, and examine with the microscope. Make a drawing showing form, size, and disposition of the nucleus, wall, and protoplasm. This may be done best after a drop of iodine solution has been run in under the cover glass. Mount some epidermis from an opened bud, and make similar drawing of the cell. What changes occur in the cell during its growth and development?

18. Awakening growth.—A great number of perennial plants form tubers, or thickened stems, or shoots of some kind, in which condition they endure unfavorable seasons, and the development of a seed or spore is usually followed by a resting stage, in which the plant may remain for a long time under the most adverse conditions. The growth of a plant from these forms is of great interest, since, in the case of all seeds and some tubers, corms, and also some cuttings, it is accompanied by the phenomena of development of an adult form from an embryonic or juvenile form.

19. Awakening growth of a tuber.—Place a number of potatoes in moist soil, in a warm room, in midwinter or early spring. A few days later note the growth of buds on the upper, or apical, portion of the potato. A thickened stem of limited growth is formed from every bud, or "eye." Cut away those formed first, and note that their destruction is fol-

lowed by the wakening and activity of buds hitherto dormant below. Continue the process until all of the buds have started into activity. The leafy stems of this plant are lateral branches of the fore shoot. Remove the branches as soon as they appear, and follow the development of the main, or fore shoot. In many instances it will take on a lengthened, club-shaped form. Taste the inner portion of the germinated potato. It will be found to have developed a slightly sweetish taste, owing to the conversion of some of the starch into a sugar, probably glucose. Other chemical changes in the tubers make it unsafe to swallow much of the material because of the poisonous action of some of the substances formed.

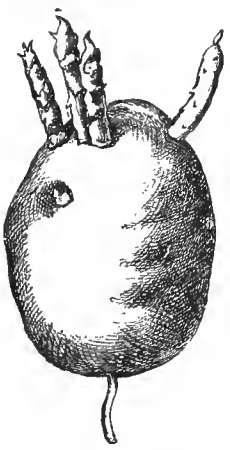


Fig. 13. — Germinating potato showing fore shoots arising from buds near the apical end. After Detmer.

20. Influence of temperature upon germination of seeds.—Soak a number of seeds of corn (*Zea*), wheat (*Triticum*), or oats (*Avena*) in water for a few hours, and then place a dozen in each of four germinating-dishes, or in tumblers wrapped in damp cloth or blotting paper. Place one on a table in the laboratory; another in the chamber of an ice box; a third on the blocks of ice in the top of the refrigerator; and a fourth near a heater or stove, where the temperature will remain about 20° to 25° C. Note the readings of a thermometer in each of these places two or three times for a week. How many of each kind of seed have germinated under the different conditions offered? Do all seeds germinate at the same temperature?

21. Endurance of high temperatures of seeds.—Place twenty air-dried seeds in a small dish, and set in an incubator, or in a compartment of an oven kept at about 40° C.,

for a day. Remove the seeds, and place in a germinator under temperatures at which the seeds ordinarily grow. Note the number that have germinated at the end of a week. Put a second lot of the same seeds in the incubator, and keep at about 60° C. for a day, then test in germinator. Repeat both

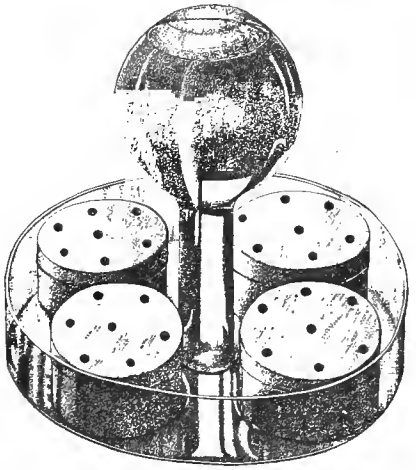


Fig. 14.—Zurich germinating-dishes standing in a glass dish in which a constant supply of water is kept by an inverted flask.

tests, placing the seeds that are in the incubator in dishes of water. Compare with results obtained from air-dry seeds.

22. Effect of freezing temperatures.—Set a pot containing any species of rapidly growing and tender annual out in the open air during the night, when the temperature falls a few degrees below the freezing point. Place a small packet of air-dry seeds of the same species on the soil around the shoot. Also put in the same place a shallow dish containing some of the seeds which have soaked in water for a day. Bring the entire preparation into a warm room the next morning, making sure that the temperature has been sufficient to form a heavy

coating of ice on water in the open air. After four or five hours note what portions of the shoot have been injured by the exposure. Can any deterioration of the seeds be noted? Test the two lots of seeds in a germinator, and ascertain if they have suffered equal damage.

Place a number of filaments of *Spirogyra* in a small dish of water, and set in the open air during a night in which the temperature is sufficient to freeze the water solidly. If the experiment is to be performed during a warmer season, the freezing may be accomplished by a mixture of ice and salt, or by the use of the liquid carbonic-acid gas sold in small steel cylinders by the manufacturers. (See MacDougal's "Practical Plant Physiology" for preparation of freezing mixtures.) Thaw the frozen material, and examine in water under a magnification of 400 to 600, and note the changes produced in the cells by freezing.

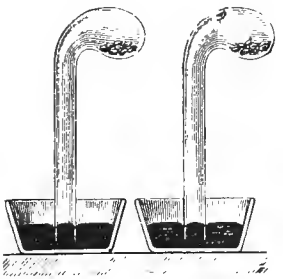


Fig. 15.—Respiration tubes containing seeds, and with the open ends immersed in mercury.

23. Influence of cold upon the rate of growth.—Select two young plants showing rapid growth of the stems or petioles, and cover with similar bell jars. Suspend thermometers in the bell jars to indicate the temperature of the air around the plants. Now remove the bell jars, and mark the organs to be observed into centimeter intervals, as in § 1. Set closely around one plant a number of tall beakers containing freezing mixtures or large pieces of ice, which should be renewed at intervals of two hours. Read the temperatures in both bell jars every hour for six hours, then remove the plants, and measure the amount of growth in both plants. Replace under the bell jars, and continue under the above conditions for

twenty-four hours more, then measure again. Note the final amount of difference of elongation.

24. Relation of oxygen to growth.—Soak a number of seeds of wheat in water for a few hours, and then place a dozen in each of the bulbs of two respiration tubes or two small retorts (Figs. 15, 16). If respiration tubes are used, invert and fill with water, then invert in a dish of mercury, taking care to exclude all air. If a retort is used—and this apparatus will be found most suitable for this work—support with the end of the outlet resting in a dish of mercury. Fill with water, and seal the stopper in place with vaseline or wax. Raise the end of one respiration tube or one retort, and allow the air to enter as the water runs out, then replace in its original position. The water in the remaining tube or retort is to be replaced with carbon dioxide or hydrogen. To prepare hydrogen, put a handful of granulated zinc in a wide-mouthed bottle for which a tightly fitting stopper with two openings for tubing should be provided (Fig. 17). Insert a thistle tube or funnel in one opening, with its tube extending to the bottom of the flask. Insert a bent glass tube in the second opening, and connect it with a section of tubing bent at right angles, which extends through the stopper of a

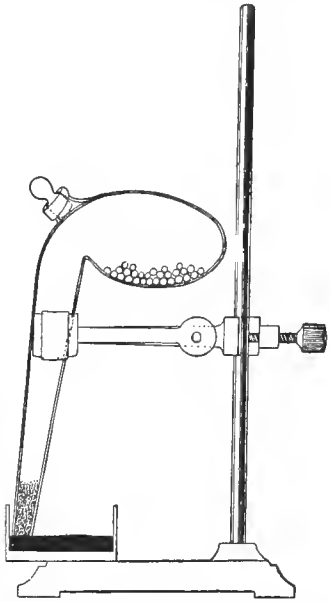


Fig. 16.—Small retort used for testing germination of seeds in an atmosphere lacking oxygen.

second bottle and nearly to its bottom. The second bottle should be filled to a depth of about six to eight centimeters with a solution of potassium permanganate, and should be provided with an outlet tube to which may be attached suitable connections for filling the retort containing the seedlings. When all is in readiness, pour hydrochloric acid in the funnel or thistle tube until the zinc is covered to some depth with the liquid. A mixture of one part sulphuric acid and six parts of water may be used instead of hydrochloric acid. A rapid evolution of hydrogen gas should ensue immediately, and after two or three minutes all of the air will have been expelled from the apparatus, and the hydrogen passing off through the wash bottle will be purified by the potassium permanganate solution. Run the tip of the outlet connection under the opening of the retort or respiration tube, and fill it with the gas.

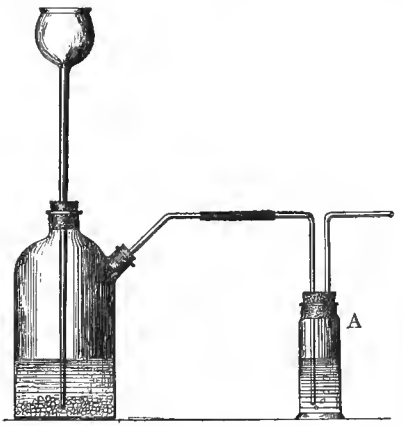


Fig. 17.—Apparatus for generation of hydrogen. *A*, wash bottle containing solution of potassium permanganate.

Carbon dioxide may be generated in the apparatus described above, using fragments of marble instead of zinc, and ordinary hydrochloric or muriatic acid. Some care will be necessary to make all the fittings proof against leakage of gas. After a sufficient supply of gas has been produced, the acid should be poured out and the zinc or marble well washed in water.

The following form of generator may be found more conve-

nient for continued use. Fit two wide-mouthed bottles of equal capacity with stoppers. Make two cylindrical holes in each stopper, with a round file or cork borer. Bend a short piece of glass tubing at an acute angle, and pass through the cork of one bottle, and fit a short section of rubber tubing to the free end, which is closed by means of a clamp. Bend a second piece of glass tubing at right angles, making one arm of sufficient length to extend to the bottom of the bottle. Con-

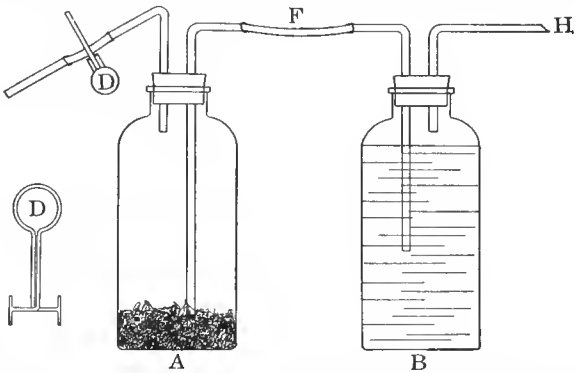


Fig. 18.—Apparatus for generation of carbon dioxide or hydrogen. *A*, bottle containing fragments of marble; *B*, bottle containing hydrochloric acid; *F*, rubber tubing; *D*, clamp closing a short section of rubber tubing at outlet; *H*, outlet.

nect the short free end with the free end of a similar tube which extends only half way to the bottom of the second bottle. Fit a short section of tubing to the remaining opening in the second stopper. Now place zinc or marble fragments in the first bottle, and fill the second nearly full of a solution of hydrochloric acid. To generate gas, remove the clamp from the outlet tube, which is suitably connected with the wash bottle. Apply the mouth to the free end of the short tube of the second bottle, and blow, forcing the acid over into the bottle containing the zinc or marble until it is covered to a depth of a

few centimeters. After sufficient gas has been generated and used as above, close the outlet tube by means of the clamp, and the pressure of the gas being liberated will drive the acid back into the second bottle, and action will cease (Fig. 18).

The above experiment may also be performed by the use of a narrow beaker instead of a retort or respiration tube. The seeds are placed on a thin circular sheet of cork or wood and allowed to rise to the upper end of an inverted beaker filled with water, and with the mouth immersed in a dish of mercury. Displacement of the water is carried out as above.

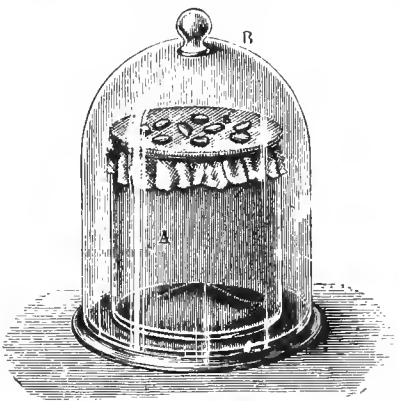


Fig. 19.—Apparatus for testing influence of ether on germination. *A*, beaker containing solution of ether and water; *B*, bell jar.

The carbon dioxide used in any of the above experiments excludes the air containing oxygen, and it will be interesting to note the difference of the action of the seeds in the air and in carbon dioxide. The results would be still more conclusive if the retort containing air should be filled with oxygen.

25. Influence of ether upon seeds.—Provide three bell jars with ground edges, and three strong sheets of glass. Prepare a cerate of equal parts of beeswax and vaseline or lard. Soak thirty grains of corn (*Zea*) in water for twenty-four hours. Place ten of the seeds in a germinator, or in folds of moist cloth, and put on one of the glass plates. Set by it a beaker containining 100 cubic centimeters of water and one cubic centimeter of sulphuric ether. It may be found more conve-

nient to place the seeds on netting fastened over the top of the beaker containing the water and ether (Fig. 19). Line the inside of a bell jar with moist filter paper, then set over the preparation, and seal tight with the cerate. Make a second preparation, but put 5 cm. of ether in the water. Make a third, from which the ether is omitted. Note the appearance of the seeds daily. Compare the period of time elapsing before the germination of the seeds in the three bell jars, and thus determine the influence of ether upon germination. Allow the experiment to continue for a week after germination has taken place, replacing the ether solutions with fresh ones of the same strength at the end of the first five days of the test, and allowing the bell jars to become thoroughly ventilated before sealing again to the plates.

It would be profitable to repeat the experiment, using chloroform instead of ether.

26. Influence of sodium chloride on germination.—Pour 400 cubic centimeters of distilled water (or rain water) in each of three vessels of suitable size. Dissolve 3 grams of common salt in one, and 12 grams in another. Soak 100 seeds of pea (*Pisum*) in each of the two jars containing the salt solution, and another 100 in the one containing water only, for twenty-four hours. Transfer the seeds to moist blotting paper, each lot being placed under a separate bell jar, or in a separate box of moist sawdust. Note the number of seeds sprouting from each lot. Does sodium chloride exert an influence corresponding to its concentration upon seeds?

Repeat the test with a one per cent. solution of the salt, exposing the seeds to its action twenty-four, forty-eight, and sixty hours, and note results.

27. Influence of copper sulphate upon germination.—Prepare solutions containing .5, 1, 2, 3, 5, and 10 per cent. of copper sulphate in water, and soak lots of 100 seeds of oats in each of these solutions for fifteen minutes. Soak a

similar lot in distilled water for the same length of time. Place all of the lots in a suitable germinator, and note results. Compare the action of this substance with that of common salt.

Repeat the test with a 1 per cent. solution, but soaking one lot for 30 minutes, another for an hour, another for two hours, and another for three hours. What is the effect of lengthened exposure to this substance? Does its deleterious effect increase in a degree corresponding with the length of time of exposure?

28. Epinasty and hyponasty.—Observe the fronds of some large fern such as *Woodsia* or *Osmunda*, and note that the apices are curled upward into a compact roll. This position is due to the fact that the lower (outer) side is growing faster than the upper, constituting hyponasty. Later the upper side of the frond begins to increase its rate of growth, and in consequence the frond is gradually unrolled, finally lying in one general plane. Inequalities in the rate of growth thus cause many organs to assume different positions at various stages of their development.

Follow the course of growth of leaves of some plant forming rosettes, such as the thistle, mullein, or dandelion, at various ages, and note the positions of the leaves resulting from epinasty. Mark the surfaces into intervals, as in § 8, and determine the location of the growing regions. Extend these observations to include leaves unfolding from buds of perennials.

Follow the movements of the leaves of any onion (*Allium*) during their development from a bulb.

Make a series of sketches showing the successive positions of the parts of the calyx, corolla, stamens, and pistils of any polypetalous flower during its opening and development. (See "Carpotropism.")

29. Correlations.—Select a vigorously growing specimen of some young tree, or any convenient perennial, and decapitate it by removing the apical bud at the end of the main

shoot. What effect does this have on the buds and branches below? Several days will be necessary to secure the full exhibition of the reaction.

This experiment may also be repeated with young plants of the tomato or any member of the squash family (*Cucurbitacea*). It may be seen as a result of the above tests that an injury of one organ may be followed by the development or more rapid growth of another one, some distance away, which takes up the functions of the missing or damaged member. All parts of the body are most intimately connected, and operate together; when one is destroyed, impulses are transmitted to all the others, which make the necessary adjustment to carry on the work of the organism in the absence of the missing member.

30. **Formation of new tissues in healing wounds.**—Cut off some branches of a rapidly growing young tree, at the beginning of the spring season, and follow the course of the healing over of the surfaces of the wounded member. Make sections of the tissues formed, and compare with those of the stem formed in the customary manner. If time does not permit, or if the season in which the work is performed is not suitable to make the above experiment, find old cuts or incisions on trees, and note the mass of tissue formed about wounds. Compare structure with that of normal uninjured stems. If the course of a healing wound is followed, it will be found that a specialized mass of cells is formed over the cut surfaces, which is afterward differentiated into wood, cork, and bark, effectually closing the wound and protecting the injured part.

Repeat the above tests with soft-bodied herbaceous species. In some instances it will be found that the outer cells nearest the injured surfaces merely dry up and form a corky layer which prevents bleeding and bars the entrance of destructive fungi and other organisms. (See "Practical Plant Physiology," pp. 36–38.)

CHAPTER III.

REPRODUCTION AND GERMINATION.

31. Nature of reproduction and germination.— One of the chief purposes of every plant is to give rise to similar individuals, or to others which will reproduce the species. This is accomplished in a great variety of ways, all of which fall into two general classes, according to the manner by which the new individuals originate. By one method specialized masses of protoplasm from different parts of the body of the same or different individuals are brought together and allowed to fuse, producing a single cell, or protoplast, which is known as an *egg*, and its formation constitutes *sexual reproduction*. The uniting masses of protoplasm in sexual reproduction are unlike, and are generally incapable singly of producing an individual of the typical kind. The mechanism of sexual reproduction may not be adequately presented without a study of the minute structure and action of the fusing protoplasts, and should be taken up in more advanced studies of the subject.

By a second general method, a single cell or mass of cells may give rise to a new individual, constituting a *non-sexual reproduction*. In some instances single cells known as *spores* are separated, and give rise to the new plant; in other cases masses of cells known as *gemmæ* are cut off and serve the same purpose; while in still other cases an entire organ, or a part of it, may be separated from the plant, and may then grow and regenerate the missing organs in such a manner as to give rise to a new and complete individual. Formation of new plants by gemmæ, and from organs or parts of organs, may be

classed as *somatic reproduction*, or as specialized instances of growth.

Eggs of the higher plants are generally retained in the ovary until they have developed into an embryo, in which the main axis of the new individual is differentiated in different stages, according to the species. The embryo is generally protected by coatings of resistant tissue, and may have stored in its own cells a quantity of reserve food before its connection with the parent plant is severed. The awakening of the embryo, constituting the germination or sprouting of the seed, may also be regarded as a specialized form of growth, since the method of nutrition in the earlier stages of the seedling are entirely different from those of the adult plant.

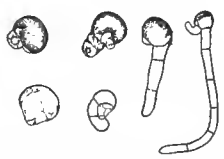


Fig. 20.—Germinating spores of *Schizæa pusilla*. After Britton and Taylor.

The propagation of a plant from a part of the body, such as a fragment of a stem or leaf, is accompanied by regenerative processes, the development of callus and other protective tissues over cut surfaces, and the formation of new growing layers. Propagation, therefore, is also a specialized method of growth, widely different in meaning and final effect from reproduction by spores and eggs.

32. Germination of spores.—Take a small fragment of soft brick, and boil it thoroughly to kill all organisms attached to it. After it has been in the water for an hour, remove and set in a saucer of spring water. Cover with a large tumbler. After the brick is cool, sprinkle the spores from the opening sporangia of some fern liberally over it. Replace the tumbler, and set the preparation aside for three or four weeks. After this period, examine it frequently. As soon as some of the small greenish prothallia are seen, scrape off some of the material from the brick, and examine with a magnification of sixty to four hundred diameters. Make a series of drawings

showing the awakening growth of the spore and the various stages leading to the formation of the green prothallus.

33. **Germination of pollen cells.**—Add one gram of gelatine and four or five grams of cane sugar to fifty cubic centimeters distilled water. Warm until a homogeneous solution is obtained. Place a drop of this solution on a glass slip, and when cold add a number of pollen cells from bursting anthers of *Narcissus*, *Fritillaria*, *Lathyrus*, or *Hyacinthus*. Cover with a thin glass slip, and set in a small moist chamber kept at the temperature of a living-room. Examine eight or ten hours later and on the following day. Make a series of drawings showing the development and growth of the tubes sent out by the germinating cells as seen under a magnification of 400 diameters. (See "Practical Plant Physiology," p. 61.)

34. **Germination of grains of corn.**—Soak a number of grains of Indian corn (*Zea Mays*) in water for twenty-four hours, then imbed in a box containing moist sawdust, and keep at a temperature of 16° to 20° C. for several days, to observe the process of awakening growth. Reserve a few of the seeds for dissection. Cut one of the grains in halves longitudinally through the shortest diameter of the seed. Note the embryo, which has been split in two parts, lying in the depression on one side of the apical portion of the grain. A conspicuous organ of absorption, the *scutellum*, lies in contact with the starchy portion, or *endosperm*. Measure the young root seen to be pointed toward the small end of the grain, and the plumule extending in the opposite direction. Repeat the dissection two days later, with a grain taken from the germinator. Continue the dissections daily, noting the development of the shoot and root, and the action of the scutellum. Write out a description of the growth shown in sprouting. When the shoot has attained a length of 3 to 6 cm., make a longitudinal section through the entire plant. Note the origin of other roots besides those arising from the extreme lower end of the stem.

A number of internodes which have attained but a fraction of their final length may be distinguished near the apex of the stem. What is the fate of the endosperm? (See "Nutrition and metabolism.")

35. Germination of seeds of Ricinus.—Soak some seeds of the castor-oil plant (*Ricinus*) in water for a day, then place in moist sawdust or soil. Dissect one of the swelling seeds, and note the form and consistency of the thin, white cotyledons, and the endosperm filled with fatty and proteid re-

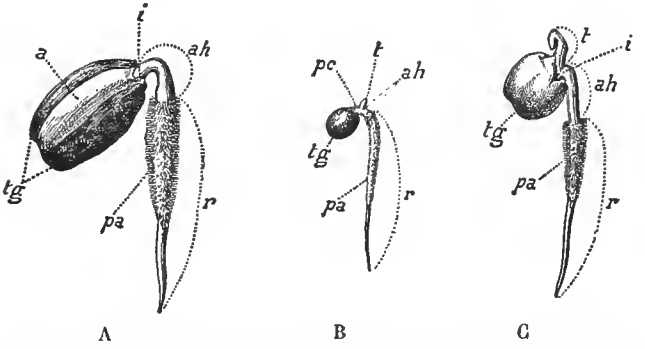


Fig. 21.—Germination of seeds of *Ricinus* (A), *Asparagus* (B), and *Pisum* (C). *tg*, integuments; *r*, main root; *pa*, root-hairs; *ah*, hypocotyledonary axis; *i*, *i*, *pc*, insertion of cotyledons; *i*, stem; *a*, endosperm. After Bonnier and Leclerc du Sablon.

serve material. Make out the manner in which the cotyledons are inserted on the short hypocotyl, and also the apical portion of the young root.

Follow the course of the embryo by daily dissections, noting the development of the root, change in the endosperm, the origin of the root-hairs and of the secondary roots. Examine curved portions of the main root, and ascertain whether the secondary roots arise on the concave or convex surfaces of the curved portion. Follow the growth of the hypocotyl, measure

its rate of elongation by the method described in § 1, and note the manner in which the cotyledons burst the integument. Measure the cotyledons into intervals of 5 mm. on a line drawn longitudinally, and on another drawn transversely, through the center. Note the regions of greatest growth and the total amount of enlargement (Figs. 21 and 22). Do all cotyledons behave in this manner?

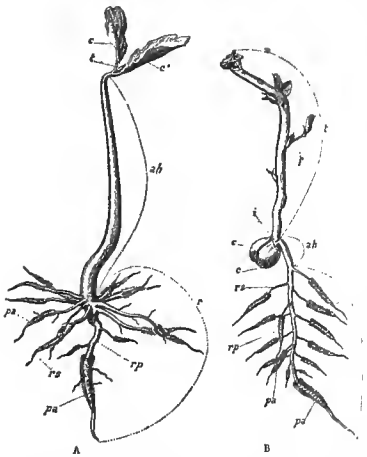


Fig. 22.—Advanced stages of germination of *Ricinus* (A) and *Pisum* (B). *r*, root system; *rp*, main root; *rs*, secondary roots; *pa*, *pa*, root-hairs; *ah*, hypocotyledonary axis; *c*, *c*, cotyledons; *i*, insertion of cotyledons; *t*, stem; *f*, leaves. After Bonnier and Leclerc du Sablon.

36. Germination of peas.—Soak some peas (*Pisum*) in water for a day, then place in moist sawdust, and make daily dissections. Note structure of swollen seed. The hemispherical cotyledons, filled with reserve material, are inserted on the short hypocotyl, at the lower end of which may be seen the rudimentary root. Follow the comparative growth of the root and shoot. Compare the origin of the root-hairs and secondary roots with those of the plants previously examined.

Compare the fate of the cotyledons with those of the *Ricinus*. Note the unequal growth of the young stem by which it is arched as it is pushed up through the soil. (See "Epinasty and hyponasty.") Mark off intervals on the stem, and ascertain the rate and region of growth (Figs. 21 and 22).

The earlier leaves formed on the stem are seen to be simple

bracts, but each succeeding leaf is larger and more complex than the one below, until the sixth or eighth is reached, and then the adult and mature form is exhibited. Make drawings of the series.

Profitable studies of the rudimentary and juvenile forms of leaves exhibited by seedlings may be made of *Adlumia cirrhosa*, *Sisymbrium*, radish (*Raphanus*), or clover (*Trifolium*).

37. Germination and propagation of the tomato.—Secure a number of seeds of tomato, and also a large plant at least three months old. Set a shallow box filled with moist earth near the plant, and trail a branch out over it, fastening it firmly down on the soil with small hooked stakes. It will have sent out adventitious roots from several points within a week or two. Now cut the branch into sections a few centimeters in length, and press each one separately down in the soil in a pot. New plants will arise from these cuttings.

Soak and germinate a number of seeds, and follow the germination of the seedlings as in the previous experiments. When the seedlings, and the young plants from the cuttings, are a few centimeters in height, compare their general appearance as to the size and form of the stem and leaves, and the rate of growth as ascertained by measurements. Are the earlier leaves formed by the cuttings and the seedlings similar, and are juvenile forms exhibited? Follow the development of both series of plants, and, if possible, determine which one is capable of forming flowers and fruit earlier.

38. Germination of the seeds of the squash.—Soak a number of seeds of the squash in water for a day, then place in various positions in moist soil or sawdust. Note the manner in which the seedcoats are ruptured, and the extrusion of the main root. Near the place of origin of the main root may be seen a "peg" or "heel" which engages the lower half of the testa of seeds placed in a horizontal position, and aids in splitting the halves apart to free the cotyledons. Observe behavior

in seeds in a vertical position. Note the manner in which the cotyledons are withdrawn from the testa, and also the action of the hypocotyl, due to its unequal growth. Ascertain the rate of growth. What is the fate of the cotyledons? Compare with *Ricinus* and the pea. Make exact drawings of the earlier leaves, and compare with adult forms. Follow the course of growth of the roots, and note the origin of the branches and root-hairs.

39. Germination and propagation of Begonia.—Trail a stem and leaves of any species of *Begonia* of which fresh seeds are at hand, across a shallow box containing moist soil or sand. Lay small stones on the leaves and stems to press them firmly on the soil. As soon as roots are formed, or buds are developed, cut the stem and the leaves into convenient portions, each of which is furnished with a root or bud, and imbed in a separate dish of sand or soil. Follow the growth of the plantlets from these cuttings. Are the plantlets grown from the stem similar to those originating from the leaves or not? Compare with seedlings which have been grown at the same time. Which series develops most rapidly? Are any differences to be noted between the plants arising from the cuttings and from the seeds?

40. Germination of seeds of Peltandra Virginica.—Collect seeds of *Peltandra*, which may be found floating around the margins of ponds in early spring, and place in a vessel containing spring water, and keep in a room at ordinary temperatures. Examine the thin pericarp, the integuments, and the embryo in the seed. Note the occurrence of two important events in the germination. The first leaf begins to enlarge, and frees itself from the clasping cotyledon, and the outer integument of the seed begins to swell, finally attaining a bulk greater than that of the seed in its resting form, breaking up the pericarp, which is freed and lost. Follow the development of the roots. Note the position in which the

seedling floats. What would be its probable fate in a sluggish stream?

Germinate seeds of skunk cabbage (*Spathyema*), or any convenient bog or land plant, and note the position of the seedlings in water. This will determine whether the plant is adapted to develop its seedlings in an aquatic habitat or not.

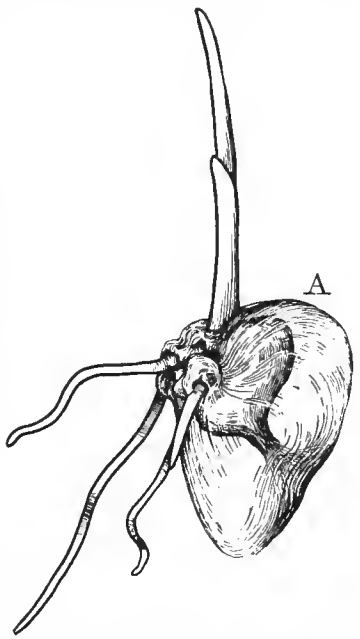


Fig. 23.—Germination of *Peltandra virginica*. *A*, gelatinous mass, formed from outer integument, serving as a flotation organ.

41. Sprouting of sweet potatoes.—Place several sweet potatoes (*Ipomea*) or yams in moist earth, and water freely. Keep in a room slightly warmer than an ordinary living-room, and note the development of buds which form the characteristic trailing stems of this plant. Compare the position of the stems when a few centimeters in length, and the positions of the tips when a length of half a meter has been attained. Note the movements of the apical portions of the stems. Mark off a number of intervals on the stems, and determine the rate and region of elongation. Are the earlier leaves similar in form and size to those on older stems?

Trail some of the stems across a box containing moist soil, and note the formation of numerous adventitious roots. Cut

the stem into several small pieces, and allow the sections to lie on the soil. Observe the origin of new plants and the development of roots and leaves; compare with those on the main stems before cutting.

42. Propagation by various organs.—Secure entire living specimens of *Kleinia*, *Bryophyllum*, or tubers, bulbs, or corms of *Arisæma*, lily, crocus, onion, *Narcissus*, or any convenient form, and make experimental cuttings to ascertain what portions may propagate the species.

It would also be of great interest to cultivate cuttings of such plants as *Marchantia* or some moss in a small moist chamber made of two glass dishes, and containing some moist sand.

CHAPTER IV.

EXCHANGE AND MOVEMENTS OF GASES AND LIQUIDS.

43. General physical nature of the plant.—The body of a plant is composed of a great number of units of living matter, or protoplasts. From a physical point of view the protoplast, or cell, may be regarded as a simple or compound sac of protoplasm, or living matter, which is automatic in its actions, and in which chemical changes are constantly in progress. The protoplasmic sac encloses spaces containing solutions known as vacuoles, and it is enclosed by a wall or sac of cellulose. The cellulose wall is not alive in the same sense as the protoplasm, but its properties may be materially modified, and its action is at all times under the direct control of the protoplasm. A constant interchange of material is in progress between the vacuole and the substance of the protoplasm, and between the vacuole and protoplast, and the medium in contact with the cell (Fig. 24). In addition, the dead walls of mechanical cells form a small proportion of many of the simpler plants of aquatic species and of the soft-bodied herbaceous species. In species which live several seasons, a definite number of cells or a distinct layer perishes every season, and the

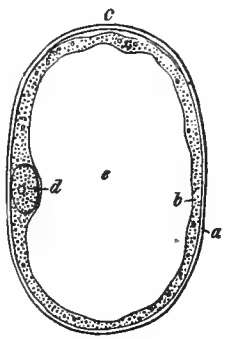


Fig. 24. — Diagram of structure of a cell. *c*, wall; *a*, lining layer of protoplasm; *b*, cytoplasm; *d*, nucleus; *e*, large central vacuole containing solutions. After Hartig.

lifeless walls remain, becoming a part of the machinery of the plant, under more or less direct control of the living part of the organism. Thus a tree consists of a trunk made up largely of a central cylinder of dead woody cells surrounded by a layer of living cells under the bark, usually not more than a few millimeters in thickness, and enclosed by the dead or dying bark.

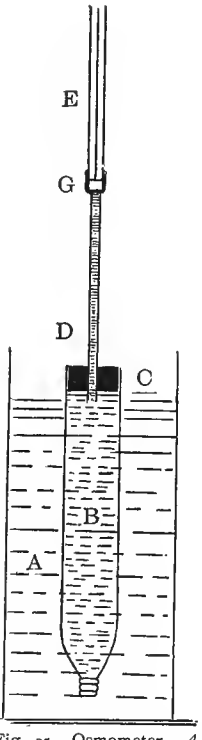


Fig. 25.—Osmometer. *A*, water; *B*, cylinder of dialyzer tubing containing salt solution; *C*, perforated stopper; *D*, short section of glass tubing which is connected with a long capillary tube *E* by a piece of rubber tubing at *G*.

The walls enclosing the living protoplasts are devoid of openings large enough for the passage of any appreciable solid body, hence substances entering the living cells, or being thrown out by them, must be in liquid or gaseous condition. A leafy-stemmed plant may be regarded, from a purely physical point of view, as a cylinder with walls of parchment; the lower end of the cylinder extends in a great number of minute ramifications in the roots, and the upper end is divided into branches bearing the leaves. The roots are in contact with solutions in the soil, and the leaves are immersed in the gases of the atmosphere.

Exchange of fluids between the roots and the soil solutions, and between the leaves and the atmosphere, is taking place constantly by osmose. As a consequence, two constant streams are found in the plant; one from the roots to the leaves, and another from the leaves to the roots, in

which osmose also plays an important part. The nature of the latter process may be illustrated by the following demonstrations:

44. Osmose.—Smooth the ends of a section of glass tubing a meter long, with an internal diameter of five millimeters, and fit to one end a rubber stopper with one perforation. Soak a section of dialyzer tubing 20 cm. in length in water for a few minutes. Pleat one end into a compact mass, then fold back, and wrap tightly with a small strong cord. Remove the stopper from the tube, and slip the open end of the dialyzer tubing over the stopper, wrapping tightly with cord. Now fill the dialyzer tube with a saturated solution of sugar, and re-insert the long tube in the perforation in the stopper. Support the tube in an upright position, with the dialyzer suspended in a large cylinder of distilled water. Note the gradual rise of the liquid in the glass tube, due to the fact that sugar has drawn water into the dialyzer by osmotic force, and that the increased volume is forced up into the upright tube (Fig. 25).

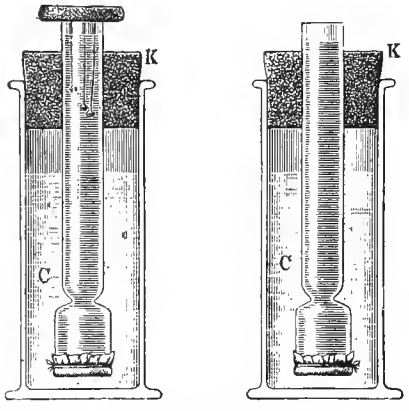


Fig. 26.—Osmometer consisting of a lamp chimney *C* over the lower end of which a piece of bladder or parchment is fastened. The lamp chimney is supported by a large stopper *K* in a glass cylinder containing water. After Oels.

Make a second preparation exactly similar to the first, but fill the dialyzer with a solution consisting of one part concentrated sugar solution and one part distilled water. Compare the height to which the liquid rises in the glass tube in both

instances, and thus determine the influence of concentration upon osmotic attraction. Root-hairs contain sugars and acids, and act in much the same manner as these dialyzers.

This demonstration may also be made by the use of the following material: secure a cylindrical lamp chimney, and fasten a piece of well-soaked bladder or parchment over the larger end. Support in a large cylinder, as in Fig. 26. Fill the lamp chimney one-third full of moist sugar, and pour water in the cylinder until it rises to the level of the sugar. Observe results an hour and four hours later. Make a second test with a weak solution of sugar.

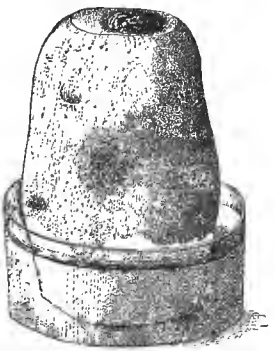


Fig. 27. — Potato osmometer. The lower end of a potato is pared, and set in a dish of water. A central cavity is made, which is filled with sugar.

45. Osmose in plant tissues.—Secure a long potato tuber, and bore a hole from one end nearly to the other, about two centimeters in diameter. Peel the closed end of the potato carefully, over an area extending about 5 cm. from the closed end, and cut the end squarely across, so that the tuber will stand upright on this end as a base. Care must be taken that the tuber is not cracked or pierced. Now set the tuber upright in a shallow dish containing sufficient water to immerse all of the peeled surface. Fill the cavity with granulated sugar to a depth of about six or eight centimeters. Add enough water to saturate the mass of sugar. Set aside for a few hours. The sugar in the cavity will draw water from the living cells nearest it, and these in turn will draw water from the next layer, by reason of their superior concentration of cell sap; and so on to the outer layer of the potato, which takes in water from the

dish. Constant movements of this character are in progress in the plant. Note the amount of water drawn into the central

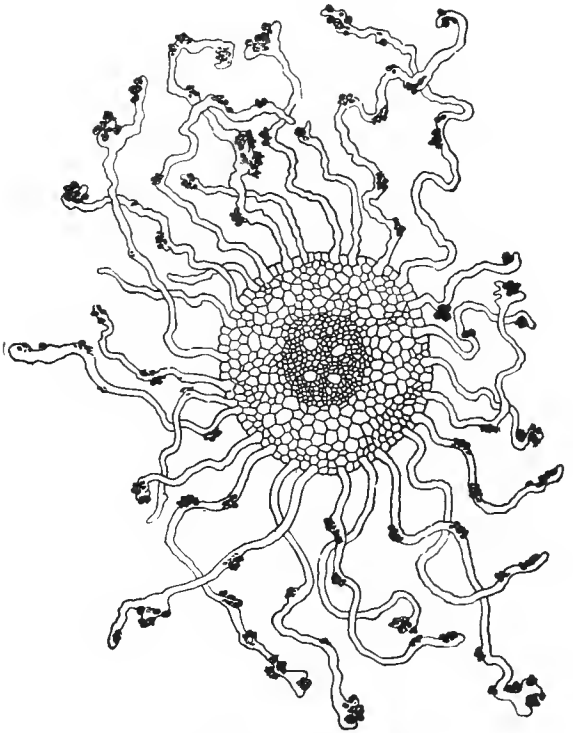


Fig. 28.—Transverse section of a root through the zone of root-hairs. After Frank.

cavity of the potato, and the change in level of the liquid in the dish (Fig. 27).

46. Structure of an absorbing root.—Examine the roots of a seedling grown in a germinator, with a magnification of about sixty. Numerous root-hairs, consisting of tubular

extensions of the epidermal cells of the roots, are to be seen. Cut a thin cross-section of one of the roots. Observe the relation of the root-hairs to the underlying parenchymatous tissues. Note also the open tubes and vessels to be seen in the center of the root. Take up seedlings grown in soil, and note the adhesion of soil particles to the root-hairs.

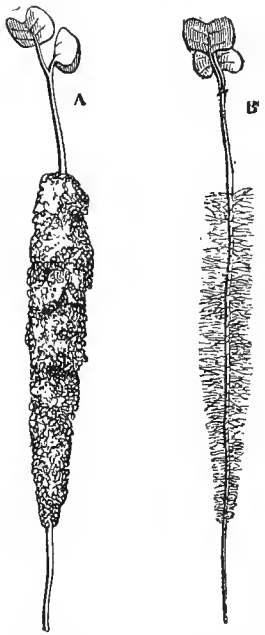


Fig. 29.—Seedlings of mustard. *A*, with particles of soil clinging to root-hairs; *B*, after removal of soil by a stream of water. After Sachs.

The walls of root-hairs consist of cellulose, much like parchment, through which liquids pass by osmose in the same manner as through the parchment walls of the dialyzer. The root-hair, however, contains protoplasm, a thin layer of which lines the wall and forms a second membrane with qualities different from those of the outer wall. Furthermore, the qualities of the living membrane may be changed by the protoplasm, and are under its control at all times. All substances do not pass through both membranes with equal rapidity, and some may penetrate one and not the other, giving rise to the phenomena of plasmolysis.

47. **Plasmolysis.** — Place some filaments of *Spirogyra* or a bit of epidermis with root-hairs in water, on a slide, and examine with a magnification of 400 to 600 diameters. Now, with a bit of blotting paper, draw off the water from one side of the cover glass, and add a drop or two of a 5 per cent. solution of common salt at the opposite

edge of the cover. Observe the action of the solution on the cells. A few minutes later remove the salt and add distilled water, and note the resumption of the original position of the parts of the cells. The salt solution is more concentrated than

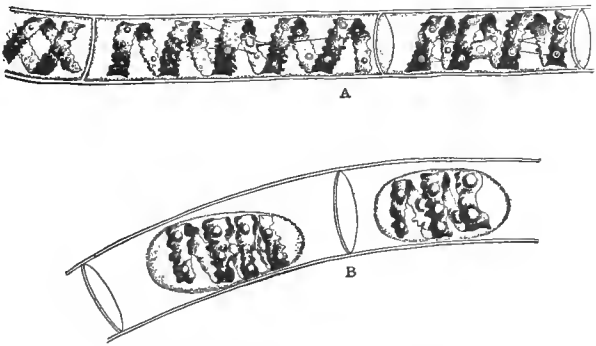


Fig. 30.—Plasmolysis of *Spirogyra*. *A*, normal turgid cells; *B*, plasmolyzed cells.

the sap of the cells. As a consequence, some of the water is withdrawn from the cell (Fig. 30).

48. Turgidity in an osmometer.—Soak a section of dialyzer tubing in water for a few minutes, then pleat and tie both ends after filling with moist sugar. Lay in a dish of rain-

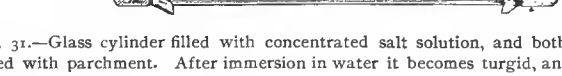


Fig. 31.—Glass cylinder filled with concentrated salt solution, and both ends covered with parchment. After immersion in water it becomes turgid, and fluid is forcibly expelled when the parchment is punctured. After Oels.

water, and note condition a half hour later. If parchment tubing is not procurable, tie convenient pieces of parchment or bladder over the ends of a glass cylinder, such as a lamp chimney, by means of cord, having first filled the cylinder with moist sugar. The parchment cell is soon distended by the

additional volume of water taken into the cavity, and the walls are held rigid and firm by the pressure. Living cells are generally in a similar state of turgidity, and the firmness of soft-bodied organs is due almost entirely to the turgidity of the cells. Large plants, such as trees, secure firmness of the trunks and branches by great masses of dead tissues mechanically joined and arranged to secure stiffness (Fig. 31).

The walls of some cells are more elastic and stretch farther under the pressure of turgidity, and the osmotic value of the cell sac varies greatly in different instances. Inequalities in turgidity of tissues fastened together, and joined to dead cells in which turgidity does not exist, gives rise to stresses and tensions between the different parts of stems and other structures.

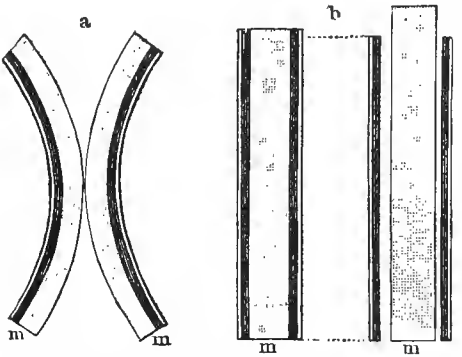


Fig. 32.—Behavior of tissues due to tensions. *a*, positions assumed by the halves of a slice through the center of a stem; *b*, diagram of a stem and relative length of pith and wood when separated; *m*, *m*, *m*, *m*, parenchyma. After Hansen.

49. Tissue tensions.—If the parts of a tent or some similar structure are cut apart, they quickly assume forms and positions quite different from those in which they were bound together under tension. The same may be said of the tissues in a stem.

Cut a slice a centimeter in thickness, and 10 cm. in length, from the center of a petiole of rhubarb (*Rheum*), petiole of *Calla*, or young stem of elder (*Sambucus*). Lay flat in a dish. Now divide longitudinally in the middle by a single downward

pressure of a long knife-blade. Note the position and form of the two portions a few minutes later. What parts of the stem were most highly turgid? What causes the curvature of the separated portions? (Fig. 32.)

Divide the hollow flower stalk of a dandelion (*Taraxacum*) into several longitudinal strips, and note the action of these strips. Place all the above material in a shallow dish containing a 5 per cent. solution of common salt, for half an hour, and compare the positions assumed when plasmolyzed with those assumed immediately after their isolation.

Cut a ring of bark from any rapidly growing woody stem, and allow it to lie in a moist chamber for a few minutes. Now replace in its original position. It will be found that it does not completely encircle the stem, and must have been in a stretched condition when taken from the stem. (Fig. 33.)

Fig. 33.—Diagram of a cross-section of a young stem from which the bark has been removed and replaced. After Detmer.

50. Wilting.—If the portions of the stem which were laid in a salt solution are examined, they will be found quite limp and flaccid. A similar condition prevails when for any reason turgidity is lost. The loss of turgidity by the cells of a stem is followed by a drooping position of leaves, and by a bending of stems under their own weight. Leaves are constantly losing water, and, if not supplied, the turgidity is soon lost and wilting follows. Wilting may be induced by immersion of a shoot in a salt solution, which plasmolyzes the cells but induces a different condition from that following an insufficient supply of water.

Cut off a young shoot of sunflower (*Helianthus*) or *Coleus*, and force the base of the excised stem through a perforation

in a rubber stopper. Fix the stopper in one of the mouths of a U-tube, or, if this is not at hand, use two short tubes connected by a short section of rubber tubing. Fill the U-tube with water, and support it in sunlight. The shoot will doubtless wilt and assume a drooping position. Now pour enough mercury in the

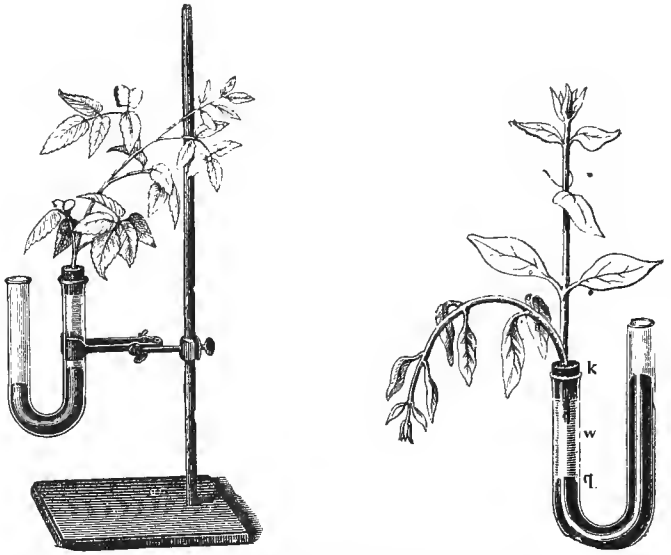


Fig. 34.—Effect of forcing water into a wilted stem. *q*, level of mercury when poured into U-tube, to which is fastened a flagging shoot; *w*, water; *k*, stopper supporting shoot. The continued action of the shoot lifts the mercury in the arm underneath it. After Sachs.

open end of the U-tube to make a column several centimeters in height, and drive the water against the end of the stem, with a strong pressure. Unless the stem is wilted too badly it may be restored by this method, which furnishes the depleted cells with sufficient water to allow them to regain their normal turgidity and consequent rigidity (Fig. 34).

51. Bleeding.—If the action of the osmometers in § 44 is followed, it will be found that after the column has risen to a certain height in the vertical tube the column remains stationary for a short time, then begins to fall. This is due to the fact that the pressure forces some of the liquid taken into the cavity of the dialyzer out through its walls. A similar occurrence is to be found in plants. Water is absorbed by the concentrated cell sap in quantity, and a pressure set up in the cells is sufficient to drive some of it out again through the walls. As a consequence, while the root-hairs are absorbing soil solutions in great volume from the soil, a small amount of liquid is constantly being forced through their outer walls, carrying substances capable in some instances of corroding rocks. The solutions taken into the root-hairs are at the same time withdrawn into the parenchymatous cells immediately underneath the epidermis, partly by this exudation pressure, but chiefly by the osmotic attraction of the substances in these cells, which also set up such pressure that some of the sap is forced through their walls. As a result of this exudation, water is forced into empty spaces outside the cells, and into the cavities of the dead vessels and tubes in the fibrovascular tissues in the roots. This action is not confined to the roots, however. Wherever active thin-walled cells are supplied with water freely, such exudation will ensue. If a stem or any organ in which exudation is taking place is cut across, the sap in the spaces and vessels will flow out, giving the appearance of "bleeding." This phenomenon was first observed on the stumps of excised shoots, and was supposed to be due to a pressure set up by the roots, and is termed "root-pressure," even in many modern text-books. As a matter of fact, this exudation may take place in almost any part of the plant, and if a gauge is attached to the end of an excised organ, the amount of the pressure may be measured. It will be most convenient to take such observations on a stump of a stem cut down nearly to the roots,

although it might be done with equally marked results on branches or trunks of any vigorous plant with a good absorbing system, before the appearance of the leaves.

52. Amount of liquid exuded in bleeding.—Cut off the stem of an actively growing specimen of *Dahlia, Geranium*, sunflower (*Helianthus*), grape (*Vitis*), or tomato a short distance above the ground, and fasten a long glass tube to the stump by means of a short section of rubber tubing passed over the ends of both. Support the tube in an upright position, and keep the preparation well supplied with water, and place in a warm room. Note the gradual rise of exuded sap in the tube. A drop or two of oil on the liquid in the tube will prevent evaporation. Four or five days later mark the height of the column on the tube and remove. Now determine the amount of water necessary to fill the tube to the given height (Fig. 35).

Fig. 35.—Glass tube attached to stump of plant to collect the sap exuded in bleeding. After Detmer.

The above experiment may also be performed in another manner by the use of a bent tube, the end of which projects into a test tube into which the exuding sap will flow (Fig. 36).

53. Measurement of exudation pressure.—The force with which liquids are thrown out of turgid cells may be measured approximately if some form of a gauge is attached to the cut end of a stem, and the exuding liquid confined. It will be

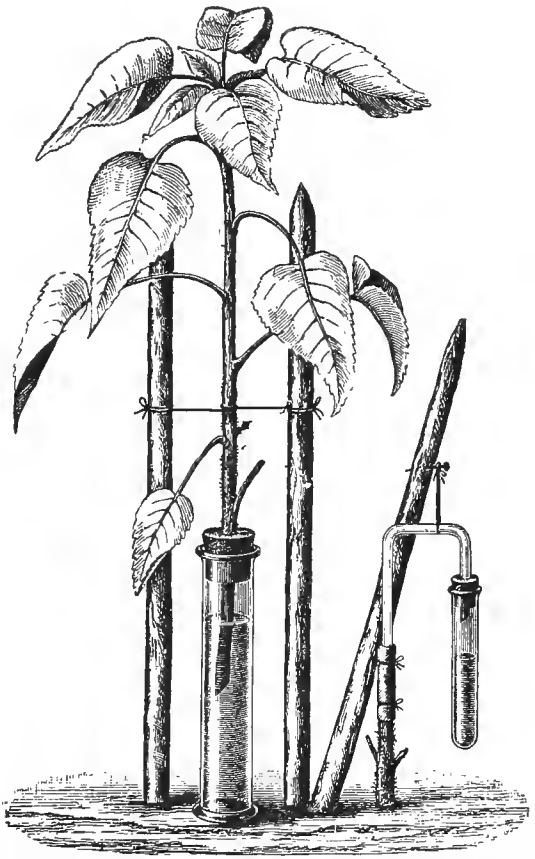


Fig. 36.—A bent tube is attached to the stump of a plant by means of a section of rubber tubing, and conducts the sap exuded into a test tube. The excised shoot is placed with its base immersed in a cylinder of water, to ascertain amount of water taken up. After Oels.

most convenient to allow the liquid to compress a column of air, and its volume will indicate the amount of pressure exerted

by the exuding fluid at any time. Secure a section of glass tubing of about the same diameter as that of the stem of a plant to be tested. Cut off a piece by means of a blowpipe flame about eight to ten centimeters in length, drawing out the tip to a tapering point with a small opening. Now attach the large end of the tube to the stump of some plant cut off a few centimeters above the soil. The test may be made with any of the species named in the previous experiment. The joints must be made proof against a possible pressure of more than an atmosphere. To accomplish this, first fit a short section of rubber tubing to the stump, drawing it down over it to a distance of about two centimeters. Wrap a short length of copper wire around the tube and stump, bring the ends together, and twist tightly with a pair of small pliers. Thrust the glass tube down into the rubber tube until it comes in contact with the stump. Wire this fitting also. Seal the end of the glass tube by the sudden application of a blowpipe flame to the thin tip. Ascertain the exact length of the column of air in the closed tube above the mark. As exudation proceeds, the air will be compressed, and the amount of pressure may be found by comparing the volume of the compressed air with its original volume, in accordance with Boyle's law. The pressure varies inversely with the volume of the air. The length of the tube may be taken as an index of the volume. Thus if the air occupied a length of tube equal to 8 cm. at the beginning of the test, and is compressed to 6 cm., the pressure will be eight-sixths of an atmosphere, or one and one-third atmospheres. If compression continues until the air occupies a half of its former volume, the pressure would be eight-fourths of an atmosphere, or two atmospheres, a limit which will probably not be reached in the tests. The above method is subject to many errors, one of which lies in the presence of watery vapor in the enclosed air.

An exact calibration of the pressure may be made by the following method: secure a long glass tube of about three or four

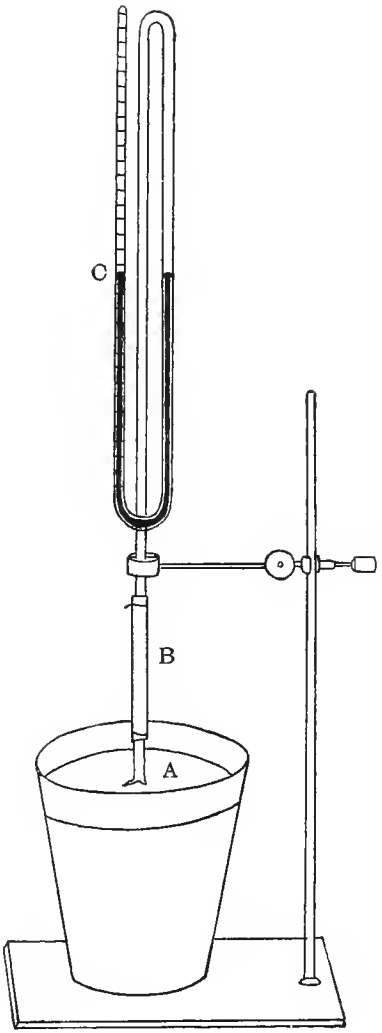


Fig. 37.—Measurement of exudation pressure. *A*, stump of plant to which is attached a manometer by a section of rubber tubing with heavy walls; *B*, rubber tubing; *C*, level of mercury in manometer at beginning of test.

millimeters internal caliber. Carefully heat in colorless Bunsen flame, and bend in the form of two engaging U-tubes, as in Fig. 37. Close one end of the tube by fusing in the flame. Invert and fill with mercury so that it will fill half of the closed arm and stand at exactly the same level in the other arm of the U-tube. Now fill the remainder of the free arm with distilled water, and attach to the stump of the plant to be tested in the manner described above. If the apparatus is properly set up, no water will gain access to the air above the mercury in the closed arm of the manometer, and this air will be under normal atmospheric pressure. The exudation pressure of the plant will be registered by the decreased volume of the enclosed air, and may be calculated by Boyle's law, as above.

54. Imbibition pressure.—The energy of the surface tension existing between the particles of a wall, a starch granule, or other similar substance, and water, causes the liquid to penetrate the particles of the solid substance, pushing them apart and giving rise to the phenomena of swelling. The expansion of the solid is accompanied by a display of enormous force, which may not be easily computed. It will be profitable, however, to note the results obtainable by some common forms of apparatus. Secure a fruit jar with a screw top, and make a hole in the center of the top sufficient to receive a glass tube from which a manometer may be made. Bend the glass tube into a closed-arm manometer, as in §53, and thrust the open end through the hole in the lid. Fill the manometer with mercury and water, as in the preceding experiment, using all the necessary precautions, and then thrust the end of the manometer tube into a rubber bulb of a capacity of about 100 cubic centimeters, which has been filled with water. Bind this fitting tightly with copper wire twisted in place with a pair of pliers. Hold the bulb in the center of the glass jar, and pour peas (*Pisum*) or soja beans around it until the jar is completely full, when the lid should be screwed on. A second

small hole should be made in the lid, and the jar set in a cylinder of water. Note the position of the mercury column, or measure the length of the enclosed column of air. As the seeds swell, the bulb will be compressed and the mercury driven against the air in the closed arm. The volume of this air will denote the amount of pressure as calculated by Boyle's law. (See "Practical Plant Physiology," p. 176.)

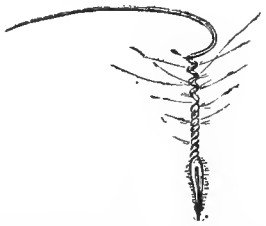


Fig. 38.—Awn of *Erodium*, showing torsion of basal portion. After Detmer.

55. Hygroscopic movements.—When the particles of walls are forced apart during imbibition, movements may result of more or less importance to the plant. The twisting movements of the awns of certain seeds are of this character. Secure a few awns of *Stipa avicennacea* or *Erodium*, which are usually curved midway. Warm a cent piece, and put a drop of sealing wax in the middle of one side. Attach the basal end of the seed to the wax, and set the preparation in a small circular glass dish, the edges of which are marked into regular intervals. Note the position of the tip of the awn with respect to one of these marks. Pour water in the dish, and follow the movements of the awn. After an hour pour out the water, and set the preparation where the awn may dry out. Observe the behavior of the awn.

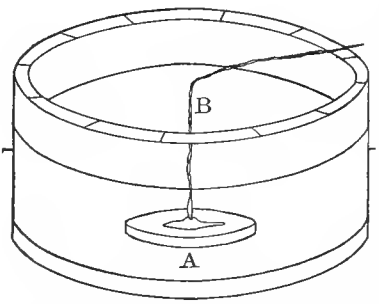


Fig. 39.—Preparation to show hygroscopic movements of an awn of *Stipa*. *A*, small metal disk; *B*, awn.

56. Amount of stretching produced by imbibition and turgidity.—Take two or three fresh and rapidly growing, nearly mature leaves of sunflower (*Helianthus*), maple (*Acer*), *Catalpa*, or *Plantago*, and trace their exact outlines upon a sheet of paper. Now place between folds of dry blotting paper, and apply pressure in the same manner as in the preparation of herbarium specimens. Change the papers daily, renewing them with dried and warmed sheets. About a week later take the leaves from the blotters, and lay each one centrally upon the print made from it. Trace the outline of the dried leaf. In what portion of the leaf has shrinkage taken place? Compute the area of the surface of the fresh and dried leaf. A dried leaf will show a shrinkage of eleven to forty-five per cent. from the extension of the fresh specimen.

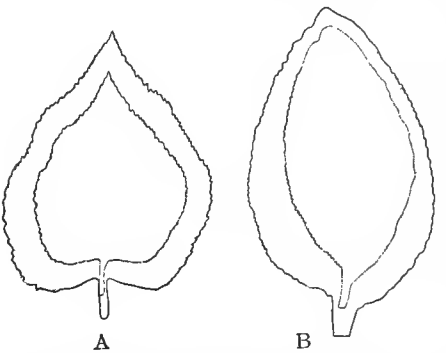


Fig. 40.—Shrinkage of leaves during drying. *A*, leaf of *Catalpa*; the inner figure shows outline of dry leaf. *B*, leaf of *Plantago major*; the inner figure shows outline after drying. After Halsted.

A growing leaf is under a state of tension from the stretching force of the turgidity of all its living cells, and, in addition, the walls are also slightly increased in both length and thickness by imbibition. During desiccation as practised above, the cells die, and turgidity is lost altogether, while much of the water of imbibition of the walls is lost, allowing the leaf to shrink from its original dimensions.

57. Structure of a leaf of a mesophytic plant.—Examine the leaf of any convenient mesophytic species, such as clover (*Trifolium*), beech (*Fagus*), apple (*Malus*), oak (*Quercus*). Place a few leaves in alcohol to extract the chlorophyl, then trace the ramifications of the nerves. Make diagram of same. Cut a thin cross-section of the petiole, and note the formation of the bundles. Cut a thin cross-section of part of the blade. Note the arrangement of cells contiguous to the

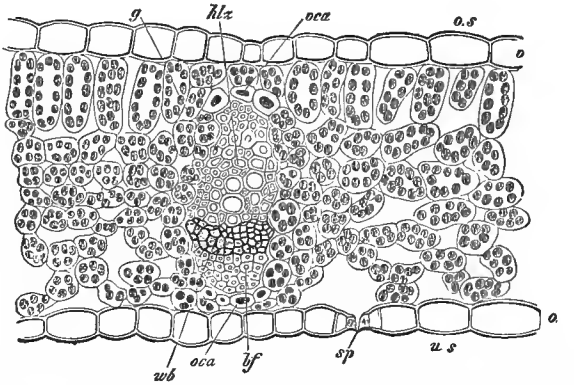


Fig. 41.—Transverse section of leaf of *Trifolium pratense*. *o. s*, upper surface; *u s*, under surface; *o*, epidermis; *sp*, stoma; *oca*, crystals; *hlz*, wood of fibrovascular bundles; *g*, vessels; *wb*, phloem; *bf*, bast fibers. After De Vries.

fibrovascular bundles. What differences are to be found in the arrangement of the cells on the upper and lower sides of the leaf? Take thin sections from the upper and lower surfaces. Estimate the number of stomata per square centimeter in both places, by the use of an eye-piece micrometer.

58. Structure of a xerophytic leaf.—Examine the surface, structure, and arrangement of the tissues of some species adapted to living under arid conditions, or in a situation in which transpiration is to be restricted. Russian thistle

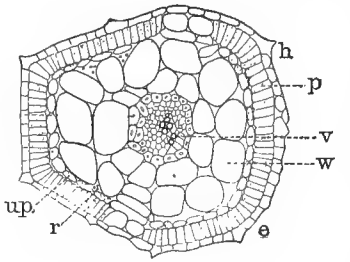


Fig. 42.—Transverse section of leaf of Russian thistle (*Salsola Tragus*). *p*, palisade parenchyma; *up*, single layer of small parenchyma cells; *w*, water storage tissue; *r*, reduced fibrovascular bundle; *e*, epidermis; *v*, vessels of larger fibrovascular bundle; *h*, trichome. After Pammel.

(*Salsola Tragus*), *Tissa rubra*, and *Ambrosia* (ragweed) will be convenient examples. Are loosely arranged parenchyma cells to be seen, and are the stomatal openings of the same character? Estimate the number of stomata per square centimeter.

59. Structure of a succulent leaf.—Examine, as above, the leaf of some succulent such as *Sedum*, *Portulaca*, *Othonna*, or any convenient form. Note the features to which attention has been paid in the above examinations, and also look for cells which might serve for the storage of water.

60. Structure of a cladode.—Examine the leaf-like expansions borne by the "smilax" of the florist, or the needle-like branches serving for

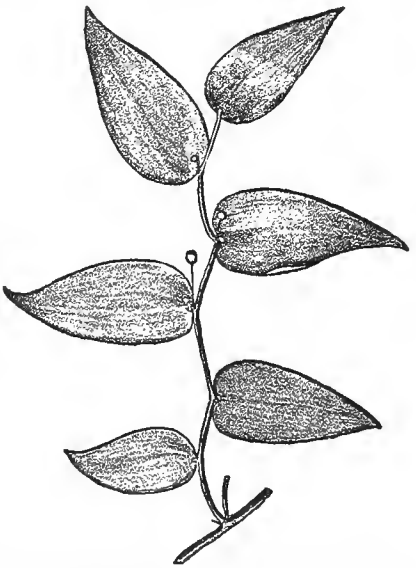


Fig. 43.—Branch of *Asparagus medeloides* (smilax) with flattened cladodes. After Reinke.

leaves in asparagus. Compare with the structures shown by various types of leaves. The true leaves of the smilax are minute bracts which have ceased to be of functional value

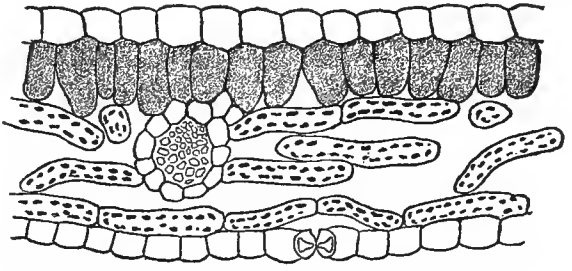


Fig. 44.—Transverse section of cladode of *Asparagus medeloides* (smilax). After Reinke.

to the plant. Short branches arising from their axils are flattened and expanded as cladodes, and perform some of the functions of the leaf, including those of transpiration and food formation.

61. Stomatal openings.—Note the structure and appearance of the stomata of the species examined. The open-

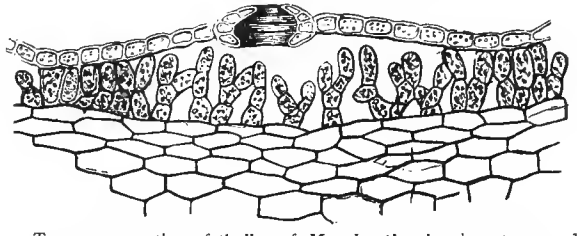


Fig. 45.—Transverse section of thallus of *Marchantia*, showing stoma and the arrangement of chlorophyl-bearing cells beneath. After Kerner.

ing which the stoma affords is seen to be a slit between two guard cells. (For a complete examination of the structure and action of stomata, see "Practical Plant Physiology," pp. 196–

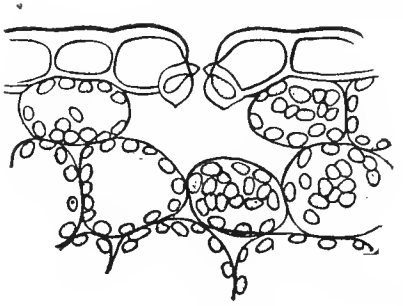


Fig. 46.—Transverse section through stoma of *Iris florentina*. After Strasburger.

203.) Among the lower forms of plants, openings through external layers of the body are not always under the control of the plant. If the student is not already familiar with the thallus of *Marchantia*, cross-sections should be made, to obtain a view of the structure of the openings.

62. Nature of transpiration.—The mineral salts absorbed by the roots are used in all parts of the body, but in greatest quantity in the leaves. These salts are absorbed in the proportion of about one part to ten thousand parts of water. Transpiration may be regarded as a device for conveying salts to the leaves and upper parts of the plant. As a result of this process, a constant stream of water sets from the roots to the leaves, carrying mineral substances at a much faster rate than might be done by diffusion, and, having reached the extremities of the body, a large part of the water evaporates, and leaves the salts behind. An enormous amount of water is

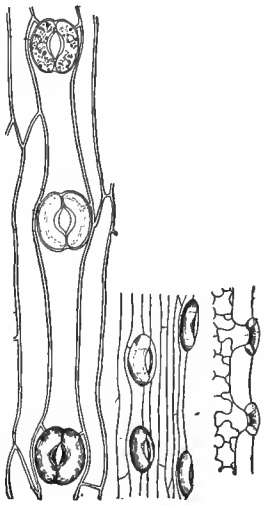


Fig. 47.—Surface, three-fourths profile, and profile views of stomata of *Schizæa pusilla*. After Britton and Taylor.

thus necessary as a medium for the transport of salts, and about ninety-eight per cent. of the energy of the sunlight which falls upon the plant is used in the work of lifting it. It may be seen that a more or less continuous loss or transpiration of water is an urgent necessity with the plant, and it may also be said that the leaves of every species are adapted to carry on this function in a manner more or less exactly suited to its environment. Not only is the structure of the leaf fitted to throw off an amount of water defined by the supply furnished the plant, and under the conditions existing in the atmosphere, but the stomata or organs of transpiration are under the direct control of the organism.

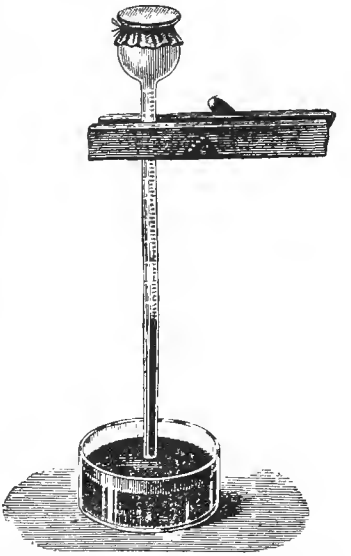


Fig. 48.—Apparatus to demonstrate lifting power of transpiration. After Oels.

63. Evaporation from an artificial membrane.—Soak a piece of bladder or strong parchment in water for an hour, then stretch over the mouth of a thistle tube, and wrap tightly with a small, firm cord. Seal the edges of the membrane to the glass with soft gelatine. Invert the tube and fill with boiled water. Close the end with the finger, and place in an upright position, with the open end immersed in a dish containing a few centimeters of mercury. Care must be taken that the membrane is free from perforations and that no air is admitted into the tube. Water should evaporate from the mem-

brane. Observe the consequences, and note behavior of column of mercury for a day or two.

64. Lifting power of a transpiring branch.—Fit a rubber or cork stopper to the top of a burette, or graduated tube. Secure a woody branch of any convenient species with active leaves. If possible, cut the branch from the plant by bending under water the portion to be severed, then using a sharp knife. If this is impracticable, cut the branch much too long, and bring it into the laboratory, and cut to proper length, as shown in Fig. 50. Make a hole in the stopper to admit the branch. Seal the fitting externally with gelatine which has soaked in water for an hour or two. Invert the preparation, and fill the

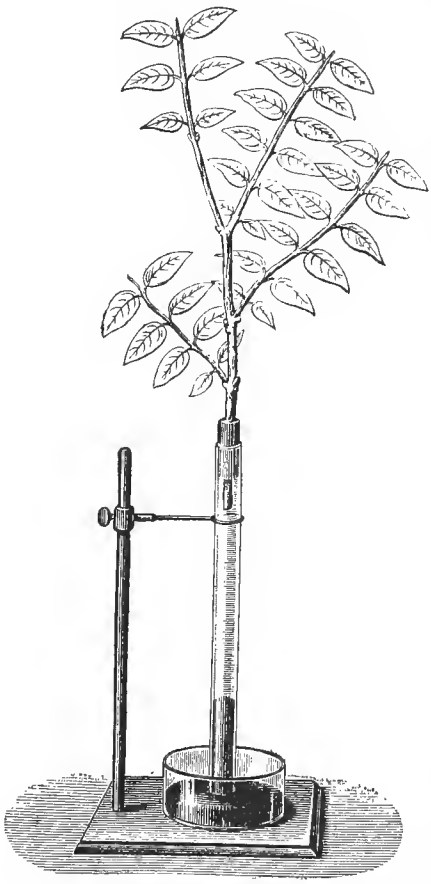


Fig. 49.—Preparation to demonstrate lifting power of a leafy branch. After Detmer.

tube with boiled water. Support in an upright position, with the lower end of the tube immersed in mercury to the zero point, or to the lowest division of the calibrated portion. If the leafy shoot withdraws water from the tube, mercury drawn up will replace it. Transpiration thus exercises an indirect lifting power. The living cells in the leaves give off watery vapor into the intercellular spaces, and withdraw water from the nearest cells to replace the loss. These in turn act in the same manner until those nearest the woody cells are

Fig. 50.—Method of cutting branch under water. After Oels.

replenished from them, and thus communicate the movement throughout the entire branch. The branch may be joined to the tube by a short section of rubber tubing. In this instance the joints should be wrapped with wire twisted into position.

65. Estimation of amount of water transpired.—Secure a balance with a capacity of 5 kilograms, and a plant growing in a four or five inch pot, and which has a large leaf surface. Set the pot in a small glass jar, and tie a sheet of rubber around the top of the jar and the base of the stem by means of a cord, taking precautions not to injure the plant.

Any loss of weight from this preparation should be due to the transpiration of water from the leaves. Set the plant on one pan of the balance, together with a small measuring-glass, and add weights to the other pan to bring the balance to an equilibrium. Four hours later note the condition of the balance. Fill a burette with water to the level of one of its divisions. Carefully run water from the burette into the measuring-glass on the pan until the balance is brought back to its original position. The amount of water in the glass will represent the transpiration. Note the temperature of the air around the plant during the experiment. Take the cloth from the plant, and water it in the usual manner. On the following day repeat the test as before, at a lower or higher temperature, with the plant prepared as before. Compare results. Make other tests in sunlight and shade.

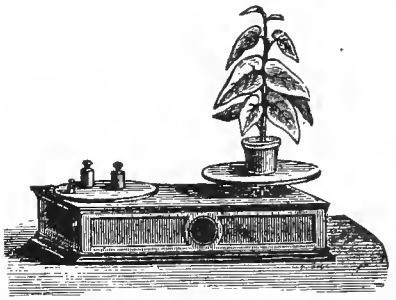


Fig. 51.—Balance for estimation of amount of transpiration. After Oels.

66. Guttation.—Procure a number of seedlings of wheat (*Triticum*), corn (*Zea*), rice (*Oryza*), or young plants of *Coleus*, growing in soil in a pot, and set on a glass plate. Water freely, and then cover with the bell jar. A few hours later note the exudation of drops of water at various points on the plant. Make a careful sketch of two or three specimens, showing exact location of drops. Remove the bell jar and note results. Make a careful examination of sections through the parts on which drops of water had collected, in a search for water pores and outlets for liquid under pressure. The exudation pressure of the living cells forces water into the vessels and other dead

cells, and these finally become filled, and then some of the liquid is pressed out through openings, collecting in drops. The greater part of the dew formed on grass tips owes its origin to this action.

67. Localization of transpiration.—If some method of detection of watery vapors is applied to the surfaces of a plant, the organs adapted for transpiration may be ascertained. For this purpose two successful methods have been found. In one, known as the "cobalt test," paper saturated with salts of cobalt change color when coming in contact with moisture. The second method consists in the employment of a narrow strip of material which changes its form, on the addition and loss of moisture, in such a regular manner that it is used as a hygrometer.

To detect transpiration by the cobalt test, proceed as follows: procure a few small pieces of good filter paper, and saturate in a 10 per cent. solution of cobalt nitrate in distilled water, then dry thoroughly in sunlight. This should be done by pinning the wet paper by one corner to a horizontal strip of wood so that it may depend freely in the air. If the wet paper is allowed to come into contact with other objects, it may become stained and worthless. Secure a number of small pieces of mica 2 cm. square. Cut a piece of the prepared paper 1 cm. square, warm it over a flame, and lay it on the upper surface of a leaf. Cover it with a square of mica, and seal the edges of the mica to the leaf with a wax composed of one part each of beeswax, vaseline, and resin. Attach a similar preparation to the lower surface of another leaf. If water vapor is given off by the surface underneath the mica, the impregnated filter paper will be changed from a blue to a reddish color. Compare reactions shown in ten minutes, an hour, and two hours. Make tests of as many organs of a species as possible, and describe the distribution of the surfaces from which watery vapor may be exhaled.

Select some species, and make tests of the leaves in shade, in strong sunlight, and at high and low temperatures.

68. Hygrometer test for transpiration.—Construct a differential hygrometer as follows: secure a section of copper or iron wire one to two millimeters in diameter and twenty-five centimeters long. Thrust directly through the center of a cylindrical cork 1 cm. in diameter and 2 cm. long. Bend a section of the wire four centimeters long at right angles, and bring the cork near the bend on the long arm. Bend the wire

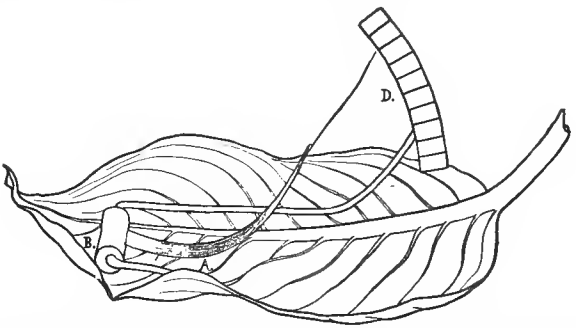


Fig. 52.—Differential hygrometer for testing transpiration. *A*, strip of film with gelatine on upper side; *B*, cork for holding end of film; *D*, scale.

again at right angles, beyond the cork, and in the same plane as the first bend. Secure a film plate, sold by dealers in photographic supplies, which consists of a thin sheet of celluloid, which does not absorb water, coated with gelatine, which does so very readily, and swells during the process. Cut a strip 8 cm. long and 5 mm. wide, and thrust one end into the cork. Attach a bristle to the other end by means of glue. The strip will be curved, and the long arm of the wire should now be bent so that it will support a small paper scale near the tip of the bristle. This should be arranged so that the convex surface of the hygroscopic strip will lie within 2 mm. of the surface of a

table when laid upon it, and the bristle should point to the upper division on the scale. If this apparatus is placed on a leaf, the exhalation of watery vapor will be detected by the straightening tendency of the strip and the movement of the bristle pointer over the scale. Test the upper and lower surfaces of leaves of various parts of the plant, which should in every instance be placed horizontally.

Care must be taken not to disturb the action of this delicate instrument by the vapor of the breath, or that coming from the hand. Do all stomatal surfaces transpire constantly? Make tests in different conditions of light and temperature.

69. Action of stomata.—Take thin surface sections of a number of leaves of different species, and examine in water, with magnifications of about 300. Stomata of some species are closed, and others are opened, by the action of the guard cells with regard to the water. Replace the water with a 5 per cent. sugar solution, and note results in one or two species. *Iris*, *Tradescantia*, or tomato will be found suitable for this work. Allow a growing specimen of tomato to become wilted. Now take a surface of the leaf, and also one from a fresh leaf, and examine in a dry condition. Run in water, and examine again.

70. Path followed by sap in ascending from the roots to the leaves.—It has been shown that water is taken up by the roots, and that water is constantly being exhaled from the leaves in the form of vapor. It yet remains to demonstrate the path followed by the stream which replaces the loss and carries mineral salts upward through the stem. This may be done if some colored fluid is given the plant in such manner that it may be conducted through the ordinary channels, staining the walls in its course. To do this, cut off a stem of *Zea*, *Impatiens*, *Helianthus*, tomato, or mignonette, under water, and allow it to remain immersed for an hour. Support the excised shoot with the base of the stem in a beaker containing a strong

solution of eosin. Note the appearance of the dye in certain tissues a few hours later. What is the path of the ascending sap? It is to be borne in mind that the color is diffused laterally from the channels through which it is conducted in greatest volume.

To follow the course of the sap through a leaf, cut off a leaf, and place the base of the petiole in an eosin solution for a few hours. Remove, and hold up to light.

It will be interesting also to place the base of the peduncle of some flower with white petals in the solution, and observe the course of the sap in parts of the flower. Ordinary red ink will serve as a coloring fluid in all of the above tests.

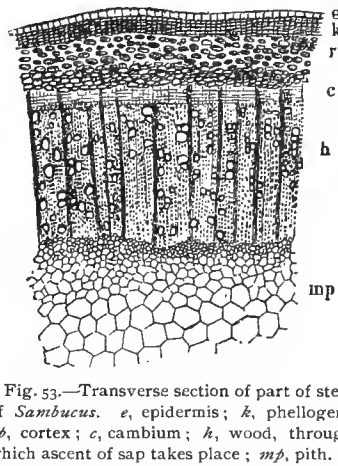


Fig. 53.—Transverse section of part of stem of *Sambucus*. *e*, epidermis; *k*, phellogen; *rp*, cortex; *c*, cambium; *h*, wood, through which ascent of sap takes place; *mp*, pith.

71. Passage of sap through a woody stem.—Cut off a large branch of oak, or cherry, or any convenient tree, and place the base of the stem in a dish of water for a short time, then in a vessel containing colored fluid, in which it should be allowed to remain for a day. Remove, and wash off adhering coloring matter, and cut away one side of the branch nearly to the center as far upward as the color may be seen. Through what part of the stem has the colored fluid ascended? The capacity of the wood for the conduction of water depends upon its age, and very marked differences are found between the recently formed and the older wood.

72. Rate of movement of water through stems.—Cut off a stem of bean, sunflower, *Bryonia*, or *Cucurbita* under

water, and after the cut end has remained immersed for an hour, set it in a beaker containing a solution of eosin or red ink. An hour later begin at the base and cut away portions of the stem in sections about 2 cm. long, to ascertain the distance which has been penetrated. A current of water will traverse the stem more rapidly than that shown by this test, however, since the coloring matter is filtered out as it ascends, and the water carrying the uppermost traces of eosin will have traversed the stem to some distance above the colored tissues when the examination is made. A much more accurate test is made by the use of lithium salts. The base of the stem is to be placed in a beaker containing a 2 per cent. solution of lithium nitrate. After an hour cut the stem into sections about 2 cm. long, and number them to preserve their relative position. Dry these sections, and then, beginning at the basal portion, burn each one in succession, in a colorless Bunsen flame, observing the carmine-red tint given by the lithium salt. This may be best observed through a sheet of blue glass. Note the first section from which the lithium flame reaction is absent, and find distance from the base of the stem. This will give the approximate rate of ascent of the sap.

73. Diffusion streams in the plant.—Water and mineral salts ascend from the roots to the leaves chiefly through the non-living woody cells, from which diffusion constantly takes place laterally in the stem, and at the termination of the woody elements in the leaves. The stream is thus seen to start in living cells, to traverse dead elements, and end in living cells which use some of the water and salts as food and exhale the superfluous water as vapor. On the other hand, sugars and other organic substances are formed in the leaves and slowly diffuse downward through the body of the plant, through the living cells. The principal pathways for such conduction consists of the sieve, companion cells, and other tubular elements in the phloem. The killing of trees by girdling is effected by

the cutting of the channels which carry food substances from the leaves to the lower part of the stem, although the incisions may be made deep enough to sever the conduits of the upwardly moving current of water also. If the downward stream only is interrupted in the girdling of a tree, it may live through the season in which the operation was performed, but die soon afterward from starvation of the roots.

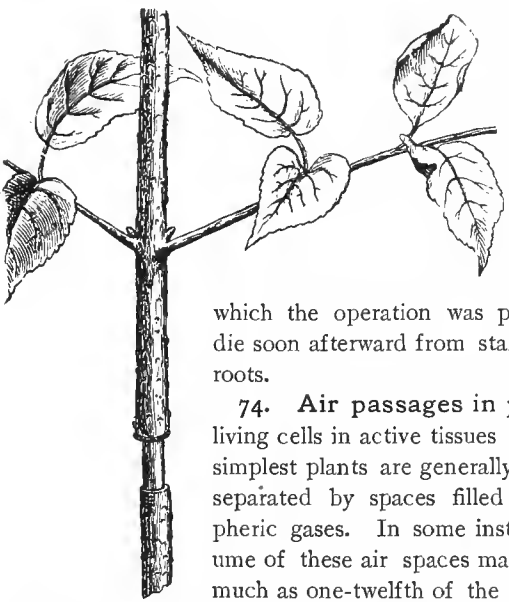


Fig. 54. — Girdled shoot of *Sambucus*. After Oels.

74. Air passages in plants.—The living cells in active tissues in all but the simplest plants are generally more or less separated by spaces filled with atmospheric gases. In some instances the volume of these air spaces may comprise as much as one-twelfth of the entire bulk of the plant, a condition prevailing in many aquatics. These spaces and passages facilitate the interchange of gases between the protoplasts and the atmosphere, and are generally most numerous in tissues not provided with ready communication with the air.

The air spaces in the loosely arranged parenchyma cells of the leaves are generally continuous with those of the cortex of the stems, and these spaces connect at many points with the vessels of the vascular system, which are usually free from liquid contents. In addition to the stomata, the lenticels also afford

direct connection between the cortical air spaces and the air. In the case of deciduous plants, the stomatal openings are lost in winter or during the resting season, the leaf-scars sealed with cork, and the lenticels are also more or less completely closed.

The large chambers found in many stems, such as those of the grasses and of other plants produced by the rupture of the pith, are results of growth and of the mechanical necessities of construction, rather than to meet any need for aeration.

Fig. 55. — Portion of branch of an oak, showing lenticels. After Bonnier and Leclerc du Sablon.

75. Air passages through stems and leaves.—Provide a small bottle with a tightly fitting stopper, and fill it about half full of water. Fit the petiole of a leaf of *Primula* or *Prunus* in the stopper, and seal tightly with gelatine which has been soaked in water for an hour. Thrust a short section of glass tubing, bent at right angles, through a second hole in the cork. With the mouth apply strong suction to the tube until bubbles are seen to pour from the end of the petiole which is submerged. Continue the process until it is ascertained whether the bubbles come from air in the stem, or air is drawn through the leaf.

76. Passage of air through lenticels and cortex.—Examine a branch of *Salix*, *Sambucus*, *Syringa*, or *Populus*, and note the number of roughened elevations to be seen on the bark. Cut a section of sufficient length to pass through the stopper, and beneath the surface of the water, in the apparatus described in the above test. Seal the upper end of the branch with wax, and fit tightly in the cork, as above. Now apply suction, and ascertain whether air may enter the lenticels and come out from the lower end of the twig. The bottle

should be filled completely with water in this test. Seal the lower end of the twig, and ascertain if air bubbles will issue from the submerged lenticels.

77. **Osmose of gases.**—Gases pass through membranes by osmose, but are dissolved in the water in the membrane during their passage through it. Membranes impregnated with waxes or oily substances, therefore, permit the diffusion of gases very slowly. On the other hand, the thin walls of the cells in the interior of the body are well adapted to rapid exchanges of gas between neighboring cells. In such saturated walls, passage of the gas can take place only by osmose, and not by filtration pressure. As soon as a membrane becomes dry, however, gas may be forced through it, and osmose ceases, or is reduced to a minimum. The continuous exchange of gases between the intercellular spaces in the interior and living cells causes great variations in the composition of

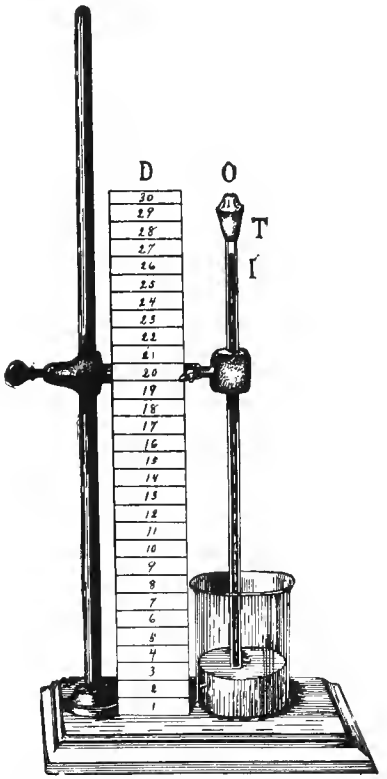


Fig. 56.—Preparation to demonstrate osmose of gases. *O*, skin of grape attached to glass tube; *T*, cork and sealing wax; *I*, level of mercury twenty days after beginning of test.

the air in these spaces, especially with regard to the proportion of oxygen and carbon dioxide present.

Smooth both ends of a glass tube about 30 to 60 cm. long, fit a cork stopper over one end, and place its upper surface nearly flush with the end of the tube. Coat the end of the cork and glass tube with soft sealing wax. Cut a small piece of coarse, strong cloth, or, better, fine brass gauze, and imbed it in the warmed wax. Now lay a thin slice from the outer rind of a squash, the cuticle of an apple, or skin of a grape, on the gauze or cloth, and apply more wax in such manner that the fitting is made perfectly tight, and no gas may pass except through the tissue. Care must be exercised to select material free from perforations and faults. Lay the tube nearly horizontal, and, after the wax is cool, run in distilled water until it is completely full and all air is expelled. Stand upright in a dish of mercury for an hour. If the fitting is properly done, the water will be held in the tube, and no air will enter through the membrane. Now displace the water with carbon dioxide or oxygen taken from a receiver or generator (Figs. 17 and 18). Note the height of the mercury column daily, as the gas diffuses out through the membrane.

CHAPTER V.

NUTRITION.

78. Composition of the body.—The body of a plant is composed of carbon, oxygen, hydrogen, and nitrogen, together with various elements which are united in the form of compounds which may be grouped under the proteids, amides, alkaloids, carbohydrates, organic acids, glucosides, fats, fixed oils, volatile oils, etc. To make a complete analysis of the composition of a plant would require the facilities of a chemical laboratory, and may not be undertaken in connection with this work; but the presence and localization of various important substances may be demonstrated by the use of simple methods.

It is important to bear in mind that the body of a plant includes not only the *plastic* substances, which may be used by the living matter in carrying on various processes, but also large quantities of insoluble *aplastic* material, which is not capable of being used except in a mechanical way.

79. Determination of organic and inorganic substances in plants.—Secure enough fresh mature leaves to make about 20 to 50 grams, and weigh carefully. Now divide into fine shreds, taking care that none of the material is lost. Place in a small crucible, and set in an oven or over a burner where it will be kept at a temperature slightly above the boiling point. Weigh a few hours later, and note amount of loss. Replace over flame, and weigh again after further exposure to heat. Note the weight from which no further decrease may be made. Subtract the weight of the crucible, ascertained before the desiccation was begun, from the total weight. This will

give the amount of the dry matter in the plant, consisting of organic and inorganic compounds. Subtract weight of dry matter from original weight of material, obtaining the amount of water originally present, which has been driven off by heat. This will also include any volatile substances originally present. Now place the crucible in the flame of a Bunsen burner, where it will incinerate. The process should be continued until the ash is nearly pure white. Some precaution must be taken that particles of the substance are not carried away by currents of air rising above the flame. Obtain the weight of the ash comprising the mineral substances in the plant, and subtract from the weight of the dry matter. The remainder will indicate the amount of organic present material in the leaves. Calculate the percentage of the three groups of constituents. Repeat with stems and fruits.

It would also be profitable to make an analysis of young and old leaves of some species to note variations in the proportions of the chief constituents.

The demonstration of starch, sugar, oil, wax, cellulose, proteids, acids, nuclein, glucosides, etc., may be accomplished by methods given in detail in text-books on micro-technique. (Directions for an analysis of the plant are outlined in MacDougal's "Practical Plant Physiology," pp. 147–174.)

80. **Food elements of plants.**—The elements used by the plant in the preparation of its food are carbon, hydrogen, oxygen, nitrogen, potassium, calcium, phosphorus, sulphur, iron, and magnesium. Carbon is obtained chiefly from the air, oxygen from the air and soil and some carbon, and all of the other elements named are derived from the soil. Oxygen is in the form of compounds in the soil and as a free gas in the air. Carbon is in the form of carbon dioxide in the air and in various compounds in the soil. The other elements occur in combination in the soil, from which they, as all soil constituents, are taken up in watery solutions.

81. Presence of substances in solution in the soil.—Take a few kilograms of garden soil and shake in a large flask with distilled water for several minutes. After standing for half an hour, filter into a large clean evaporating dish, and evaporate to dryness. If a residue is obtained, it will denote the presence of substances in the soil. Note the character of the residue. It may be of value to evaporate a similar quantity of distilled or rain water in another dish, as a control test.

82. Corrosive action of plants on minerals.—Fill a five-inch pot with clean sand to a depth of 8 cm. Now lay a small piece of polished marble or an oyster-shell on the sand, with the polished surface uppermost. Place three or four beans on the shell or marble, and cover to a depth of a few centimeters with fine soil. Set the preparation where it may receive proper care and temperature. Two weeks later, after the beans have sprouted, and attained a height of several centimeters, take out the marble or shell, wash completely clean with water, and dry. Now observe the glistening surface by reflected light, and note the etching of the surface in places which have been in contact with the roots. Test the acidity or alkalinity of the roots of the bean, using litmus paper. Not all plants are capable of corroding rock or lime compounds in the above manner.

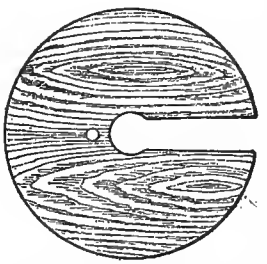


Fig. 57.—Wooden fitting for top of water-culture jar. After Detmer.

83. Water cultures.—Procure a number of jars with a capacity of one to two liters, and fit them with a wooden top with a slit cut from one edge to the center. Germinate a number of peas, beans, or the seeds of *Convolvulus*. Make a culture solution of the following substances:

6 grams calcium nitrate.
1.5 grams potassium nitrate.
1.5 grams magnesium sulphate.
1.5 grams neutral potassium phosphate.
1.5 grams sodium chloride.
600 cc. distilled water.

Shake thoroughly, and keep in a tightly stoppered bottle. Wash out the culture jars with water to which a little nitric acid has been added, then rinse with distilled water. Fill the jars to within 1 or 2 centimeters of the top by adding 1 part of the original solution to 10 parts of distilled water. Put a small bit of iron chloride in the solution in the culture jars. Place the seedling in the center of the cover, with its roots depending in the water, and wedge in position with asbestos fiber or cotton, taking care that the packing should be kept dry. Provide a wooden rod for a support when the plant shall have attained a height of a few centimeters. Set in a room with sunlight and the

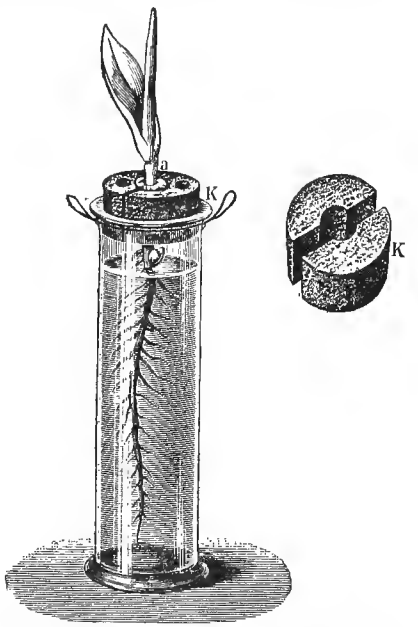


Fig. 58.—Apparatus for water culture. *K*, cork stopper divided and furnished with apertures for ventilation when in place; *a*, cotton or asbestos wool. After Hansen.

proper temperature. The solution in the bottle should be renewed at least once a week. It will be found advantageous to imbed the culture jar in soil, and it should be shielded from the direct rays of the sun. Compare the growth of the seedling in the above culture with one grown in soil in a pot placed near it. The solution contains all the elements which the plant is supposed to derive from the soil.

84. Growth of plants in solutions lacking nitrates.—Make up the following solution:

1.5 grams neutral potassium phosphate.
1.5 grams magnesium phosphate.
1.5 grams potassium chloride.
600 cc. distilled water.

Dilute as above with ten parts of water to fill culture jar, and add a small bit of iron chloride. In this the plant is given no nitrogen, that in the air not being accessible to it.

Compare growth of seedlings of corn, sunflower, or wheat in this solution with others grown in soil or in normal complete culture solutions. Can the plant attain development without nitrates? (See "Practical Text-book of Plant Physiology.")

85. Growth with distilled water as a nutritive fluid.—Set up a water culture, using all the precautions given above, but filling the jar with distilled water only. The seed contains an amount of food sufficient for limited growth, and the seedling depends upon this until its absorbent and chlorophyl-bearing organs are developed under normal conditions. In this instance the stage will soon be reached where the supply will be exhausted and growth will cease.

86. The food-forming power of green leaves.—Germinate a number of seeds of corn, sunflower, or bean, and grow three seedlings in each of two pots. Place one pot in a position where it may receive sunlight, and the other in a room from which light is wholly excluded. Note the difference in the appearance and form of the two seedlings from

time to time. Can the seedling in the darkness live as long as the one in light? The plants in darkness are said to be etiolated, and have not formed chlorophyl. The lack of chlorophyl, and of its action in the presence of sunlight, results in the starvation of the etiolated specimen.

87. Growth of plants in air free from carbon dioxide.—Chlorophyl is active in the use of the carbon dioxide of the air in the formation of foods in the leaf. It will be profitable to observe the behavior of the plant when placed in a condition in which it may not have access to carbon dioxide. To accomplish this, make the following preparation: grow seedlings of corn or sunflower in two small pots, and provide two large bell jars with a tubulure at the top or on the sides. Set the pots containing the seedlings on separate sheets of glass. One is to be used as a test, and the other as a control. A shallow dish containing several sticks or fragments of potassium or sodium hydrate should be placed under the bell jar with the test object. Fit a perforated rubber or cork stopper tightly to the opening in the bell jar, and insert a drying tube filled with sodium hydrate in the perforation. Omit hydrate from control experiment. The hydrate in the bell jar will take up all the carbon dioxide in the chamber, and all the air entering through the drying tube is similiarly acted upon. Renew the preparation at least once a week. After a week or two, note action of plant in an atmosphere free from carbon dioxide, and compare with the control plant under a second bell jar, in which no sodium hydrate has been placed.

It will be necessary to shield the plants from the direct rays of the sun, since the temperature in the confined chambers, which are not well ventilated, would be raised above the normal.

88. Properties of chlorophyl.—Place 100 grams of freshly chopped leaves in a flask, and cover with water. Test with litmus paper, and, if acid, add enough sodium carbonate to neutralize. Boil for half an hour. Pour off the water, and wash

repeatedly. Press out the water from the fragments, and return to flask. Cover with alcohol, and set in a dark place until the following day. Now pour some of the extract into a narrow test tube, and hold up to the light. The solution appears green, but the edges show a blood-red color, due to the fluorescence of chlorophyl, which has the power of changing the length of the waves of light in such manner as to give the red color.

If a portion of the solution is examined by the aid of a spectroscope, it may be seen that some of the rays are absorbed. The absorbed rays are converted into other forms of energy in the plant and used to perform the work of food formation.

89. Formation of chlorophyl in light and darkness.—Germinate some seeds of pine, and also some acorns, in a dark chamber. Note the formation of chlorophyl in seedlings of the conifers in darkness. After the seedling oaks have appeared and are a few centimeters in height, remove to a shaded corner of the laboratory, and follow the appearance of a green color.

90. Absorption of light by tissues of plants.—Secure two shot-gun cartridge shells, one of ten caliber and the other of twelve. If uncapped, the closed end will show a small perforation. Cut circular pieces from the leaf blades of any convenient species, and fit over end of smaller shell. Slip the larger shell over the smaller one, and thus hold the section of leaf between the closed ends of the two. Apply the eye to the open end, and direct toward a strong light. Note the amount of light that penetrates the leaf. Add one or more sections of the leaf to the preparation, and test permeability to direct rays of sun. How many layers of leaf blades will sunlight penetrate? It will be interesting to test the outer layers of young twigs and bark of other plants in the same manner.

91. Red color in leaves.—Boil a number of red leaves of *Amarantus* (cockscomb) in water, and note the extraction of the coloring matter. Do red leaves contain chlorophyl?

Cut sections of the leaf, and ascertain the location and condition of the substances to which the red color is due.

Repeat this test with autumnal colors of leaves of maple, oak, or sumac. What differences are to be found between the colors of such leaves as *Amarantus*, *Coleus*, and *Achyranthes*, and the autumnal colors?

92. Arrangements for concentrating rays of light upon chlorophyl layers.—Cut a cross-section of a leaf of *Coleus*, or any leaf with a velvety surface, and note the outline of the epidermal cells and their effect upon rays of light striking the surface at various angles. Test such leaves with the apparatus described in § 90 to ascertain their permeability to light. Make similar tests with some species having a thick leathery leaf.

93. Exhalation of oxygen by green plants.—Fill a funnel with green sprigs of *Philotria*, *Myriophyllum*, or *Cabomba*, and immerse in a beaker of fresh spring water. Fill a small test tube with spring water, and invert it over the small end of the funnel in such manner that no air is allowed to gain access to it. Place the preparation in bright sunlight. Observe the rate at which a gas is collected in the uppermost end of the test tube. After an amount sufficient to displace half of the water in the test tube has been collected, close the lower end with the finger, under water, remove the tube, and bring to an upright position. Strike a match, or ignite a splinter of wood in a flame. After a good length of the wood is burning well, extinguish the flame, remove the finger from the end of the test tube, and

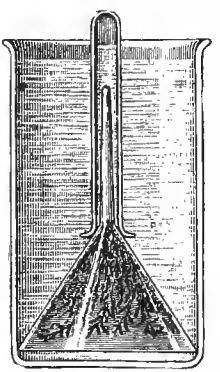


Fig. 59. — Preparation for collecting gases liberated by aquatic plants. After Detmer.

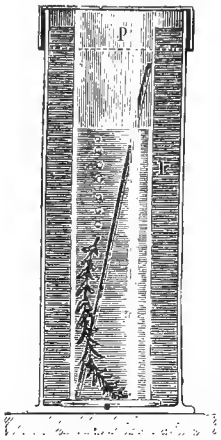


Fig. 60.—Apparatus for testing influence of light which has passed through colored solutions upon liberation of gases by green plants. *k*, colored fluid in outer cylinder; *p*, inner cylinder, containing plants and water. After Oels.

thrust the glowing wood into the gas. If it glows more brightly, the presence of oxygen is denoted.

94. Portion of spectrum by aid of which green plants exhale oxygen. — Provide two large cylinders about 25 cm. in height, and two of about the same height, but smaller diameter. Set the smaller inside the larger ones, and ballast with a weight of about a kilogram. Fill the outer cylinder around the smaller one, in one instance, with a saturated solution of potassium bichromate. Fill the other with a solution made by adding strong ammonium hydrate to a saturated solution of copper sulphate as long as the forming pre-

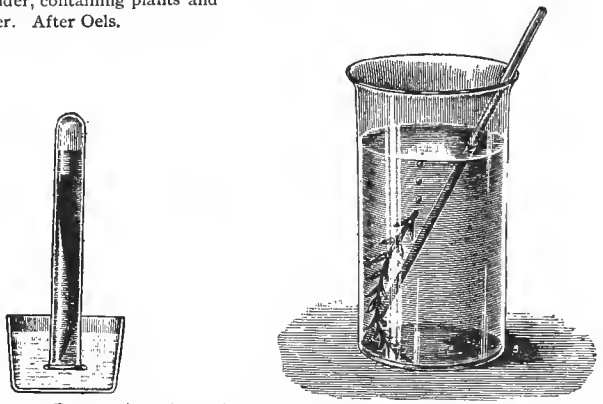


Fig. 61.—Preparations for estimating rate of liberation of gases by counting number of bubbles. A sprig of an aquatic plant is fixed to a glass rod, with the excised end of the stem uppermost.

cipitate is redissolved. This will permit, chiefly, red and yellow rays to pass in one preparation, and blue-violet in the other. Now make up two preparations of algæ, or aquatic plants, as in §93, and set inside of each inner cylinder, and cover the top with some opaque body, so that only the light which has passed through the solutions may strike the plants. Set in sunlight. Note amount and quality of gas collecting in the tubes in the two instances. Care must be taken that the same amount of material is placed in the two test tubes (Fig. 60).

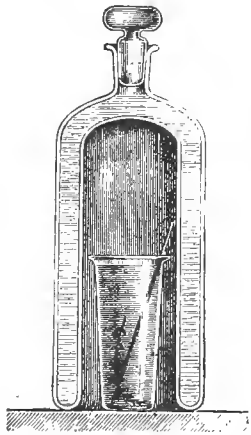


Fig. 62.—Bell jar with double walls, for testing effect of colored light on liberation of oxygen. After Sachs.

Double-walled bell jars may be obtained, which facilitate the performance of this demonstration.

A box with blackened inner surfaces, and the open ends suitable for holding sheets of ruby, yellow, and blue glass, may also be used to expose plants to a portion of the spectrum (Fig. 63).

95. Relations of plants and animals to the atmosphere.—Enclose two or three living mice in a small wire cage, and place on a ground-glass plate of the proper size to receive a bell jar. Invert a large bell jar, and fill it loosely with fresh, leafy shoots, or set a plant with many leaves beside the cage. Place the bell jar over the cage, and seal to the plate with vaseline. The cage should be in such position that the animals may be easily observed through the glass. Place the whole preparation in a dark room, or cover completely with a photographer's focussing cloth, to exclude the light. Note the condition of the mice at the end of a period of half an

hour or more. As soon as the animals appear to become inactive, sluggish, or asphyxiated, because of lack of oxygen, uncover the bell jar and expose it to direct sunlight. Note effect on

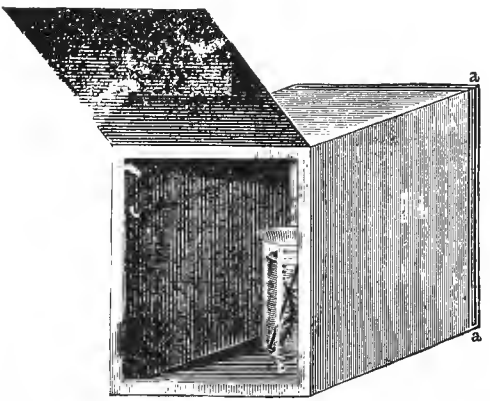


Fig. 63.—Box with door at one end, and plates of colored glass, *aa*, at the other. After Oels.

animals. The test may be repeated, and should be attempted only on days in which good illumination may be secured.

96. Changes produced in the air by a flame and by green plants.—Provide a large bell jar with tubulure at top, and a glass plate upon which it may rest. Bore a hole in a block of wood to receive and hold a small candle firmly. Fasten a strip of wood to one side of this block, with its upper end below the level of the exposed wick of the candle. Glue a strip of sanded paper to the side of this strip nearest the candle. Set the candle with its holder, prepared as directed, in the center of the glass plate, and near it a plant growing in a pot. Close the tubulure of the bell jar with a cork or rubber stopper, through which a glass rod extends down to the block in which the candle is fastened. A short section of the lower end

should be bent at right angles, and a match wedged in it, with 1 or 2 centimeters of the tip exposed, and the head in contact with the sanded paper. When all is in readiness, lift the bell jar, set the candle burning, and replace. Arrange the rod bearing the match in the manner described. Seal all joints with vaseline. After a minute or two the candle will have used so much of the oxygen, and given off so much carbon dioxide, that combustion is impossible, and the flame is extinguished. Allow the preparation to stand in the light for several hours. Pull the glass rod upward through the cork, drawing the match-head along the sanded paper. After igniting the match, twist the rod, and place the flame in contact with the wick. The relighting of the candle denotes that the carbon dioxide of the air has been absorbed by the plant,

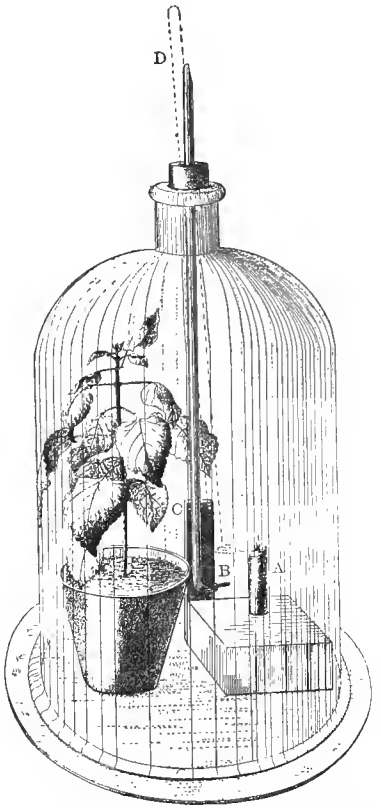


Fig. 64.—Preparation for testing relations of plant to atmosphere. *A*, candle; *B*, match; *C*, strip of sanded paper on wooden support; *D*, glass rod holding match; the dotted line shows position when the match is applied to the candle.

and that oxygen enough to support combustion has been given off. The test may be repeated a number of times.

97. **Formation of starch in light.**—Place a good specimen of some plant with thin leaves in darkness for a day or two, until but little starch can be detected in the leaves by the use of iodine solution. Bring the plant out into light, and cover one leaf completely with aluminum or tin-foil. Place a thin section of cork on the lower side of another leaf, and a second exactly opposite it on the upper side, and drive a pin through both corks and the leaf to hold them together. After the plant has been exposed to bright sunlight for four to six hours, take an untreated leaf, the one that has been covered with tin-foil, and the one to which the corks have been fastened, and plunge into boiling water for a few minutes. Next place in a porcelain dish containing alcohol (75 per cent.) and warm gently, renewing the alcohol from time to time until all of the chlorophyl is extracted. Remove all the alcohol, and wash with distilled water poured over the leaves in the dish. Pour off the water, add enough of a solution of iodine in potassium iodide to cover

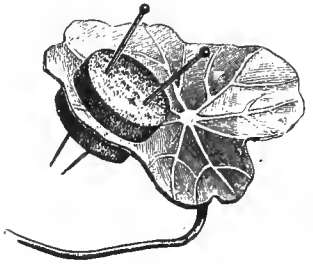


Fig. 65.—Method of exclusion of light from portion of a leaf.

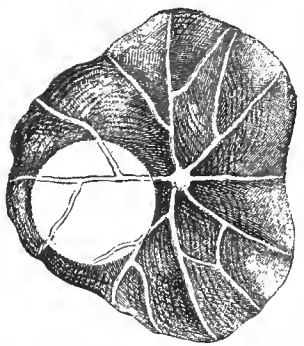


Fig. 66.—Leaf treated with iodine solution, showing uncolored portion which had been darkened in Fig. 65.

the leaves. The solution should be of such concentration as to appear a dark wine color. The portions containing starch should be stained a dark blue color by the iodide, and the relation of the action of chlorophyl to light will be indicated by the results. Repeat the test with single leaves in reddish and blue light, as in §94, and ascertain what rays are concerned in the food formation.

Starch is not the direct product of the activity of the chlorophyl in photosynthesis. Some form of sugar is probably built up in the leaf, and when it begins to accumulate or reaches a certain concentration in the sap, some of it is condensed into starch. Starch may be taken to indicate an accumulation of the products of the photosynthetic activity of chlorophyl.

98. Relation of stomata to food formation.—Procure a living specimen of some species, with the upper surfaces of the leaves free from stomata, and place in dark room until the leaves are shown to be free from starch. Now place in the light. Cover the entire under side of one leaf with warm cocoa butter in such manner as to close all of the stomata. Treat one-half of the lower side of a second leaf in the same manner. Cover the entire lower side of a third leaf with the butter, and then carefully cut through the upper epidermis in three or four long lines. After exposure to sunlight for a few hours, remove one of the treated leaves and one of the normal, extract the chlorophyl and test with iodine, as in §97. Is the leaf able to carrry on sufficient food formation to accumulate a surplus which is

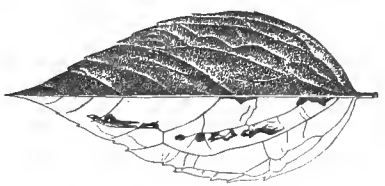


Fig. 67.—Leaf after treatment with iodine. The stomata of the unshaded portion have been closed with cocoa butter while exposed to light. After Stahl.

converted into starch in leaves in which the stomata are closed?

99. Nutritive relations of a parasite.—Secure some living specimens of *Cuscuta*, or dodder, to be found as yellow cord-like stems, attached to *Impatiens* and other plants on the margins of swamps and in meadows in late summer. Examine fresh material, and place remainder in formalin or alcohol. Note manner in which the dodder is attached to the host plant. Cut thin sections through the organs of attachment and the stem which they penetrate, and make out the anatomical relations of the two plants. It will be profitable to secure seeds of the parasite and grow them in a pot containing young plants of tomato, or other herbaceous species, and note the manner in which the parasite attacks and attaches itself to the host plant.

Fig. 68.—*Cuscuta* attached to stem and leaves of an aster. After Johnson.

Cut a section of a leaf of any seed plant which has been attacked by a parasitic fungus,

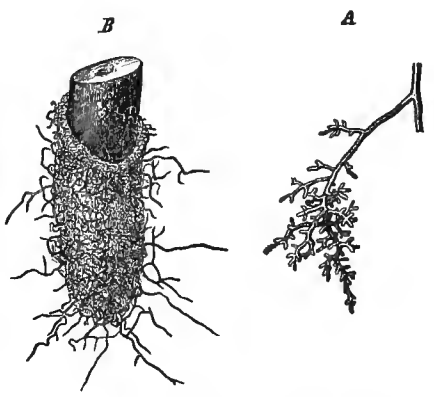


Fig. 69.—*A*, roots of beech (*Fagus*) covered with a symbiotic fungus; *B*, terminal portion of root enlarged. After Frank.

and note the manner in which the fine hyphal threads of the parasite penetrate the cells of the host, or show devices for drawing nutritive material from them. Rusts, mildews, and molds will offer many accessible examples for such studies.

100. Symbiosis of a seed plant and a fungus.—Cut sections of the apical portions of the roots of any coniferous tree, and note the presence of a fungus which may enwrap the root in some species, replacing the piliferous layer, while in others it penetrates the cortical cells, sending hyphæ out into the substratum either through the root-hairs or through the walls of the epidermal cells.

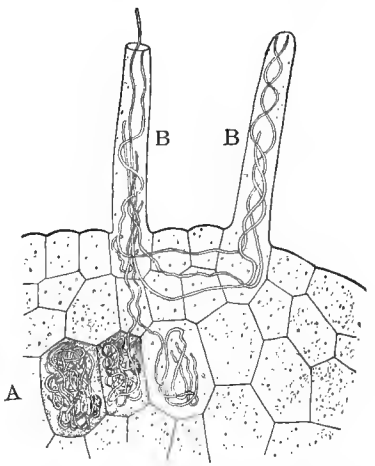


Fig. 70.—Transverse section of portion of root of *Listera*. *A*, clumps of fungal hyphæ in cortical cells from which filaments pass out into the soil through the root-hairs *B B*. After Chodat.

101. Tubercles of leguminous plants.—Dig up the roots of any species of the pea or bean family, and observe characters of nodules, or tubercles. Make careful anatomical examination of the tubercles, and cut thin sections with a razor. Numbers of globular or ovoid organisms will be found in the parenchymatous tissues. Stain with iodine, and ascertain nature of other substances present. The bacterial organism enters a young root in a filamentous form, through the hairs, and its presence stimulates the formation of the tubercles. Seed-

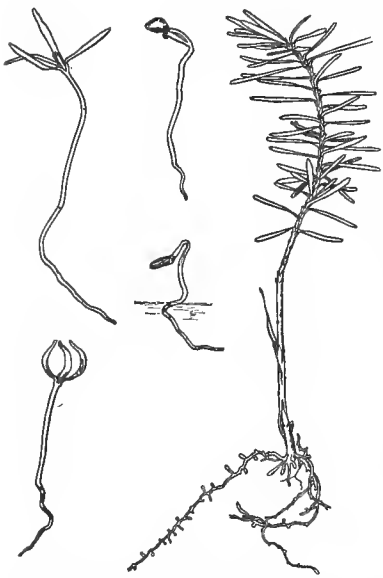


Fig. 71.—Seedling of hemlock (*Tsuga Canadensis*) with mycorrhizal roots. After Lloyd.

lows: place under a bell jar for two days a fragment of bread which has been moistened with water. A number of slender hyphæ of a mold may be seen arising from the bread. Tear apart a bit of the bread, and examine with a magnification of about 60 diameters. The absorbent branches of the mycelia may be seen ramifying through the bread. These submerged hyphæ take up sugars and other plants with such tubercles can fix and make use of the free nitrogen of the air.

102. Nutrition of a saprophyte.—No independent saprophytes, or species which live on dead organic matter, are known among the seed plants. The fungi comprise a large number of species which obtain their nutriment in this manner. Their method of growth and absorption of food may be observed as fol-

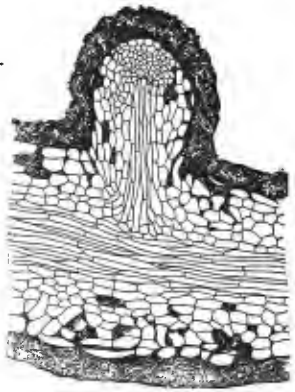


Fig. 72.—Longitudinal section of root of hemlock (*Tsuga Canadensis*). The outer, shaded layer is inhabited by a fungus. After Harlow.

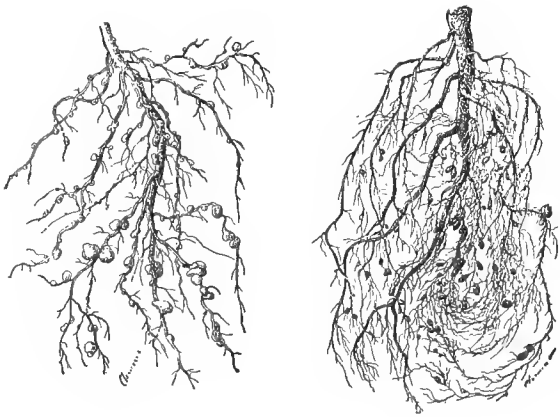


Fig. 73.—*A*, root system of pea with tubercles; *B*, root system of lucerne with tubercles. After Belzung.

organic matter from the bread in much the same manner as the root-hairs absorb mineral solutions from the soil.

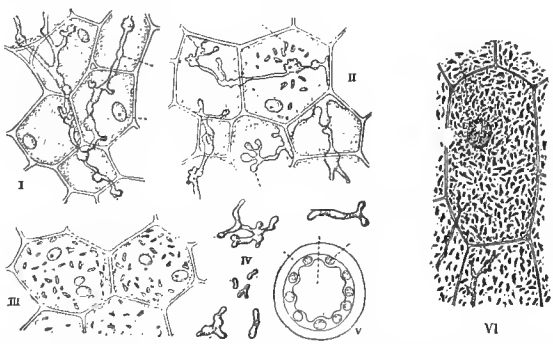


Fig. 74.—Bacterioidal organism in tubercles of leguminous plants. *I*, filaments in parenchyma cells; *II*, formation of bacterioids from filaments; *III*, bacterioids in cells; *IV*, various forms of bacterioids; *V*, section of a tubercle; *VI*, cell containing bacterioids and fragments of filaments.

CHAPTER VI.

RESPIRATION, DIGESTION, AND FERMENTATION.

103. Release of energy.—A large number of complex substances are formed in the plant as a result of photosynthesis and other synthetic processes. All such construction results in the storage of energy in a potential form, and the food material acquired by the plant represents so much potential which must be liberated to furnish energy for growth, construction of organs, movements of the body, movements of fluids in the body, and, in exchange with the substratum and atmosphere, maintenance of position, and rigidity of the body. The plant, therefore, only makes use of its food material when it builds up tissues, or liberates the energy which is held in the food.

The liberation of energy is accomplished by respiration and fermentation. Many types of respiration may be recognized. In one of the best known forms, the material in living matter is oxidized and carbon dioxide is set free, in exact opposition to photosynthesis, which is a reducing process. The proportions of the gas exchanged in respiration show the greatest variation. In a modification of the above form of respiration the oxidation is incomplete, and no carbon dioxide is liberated. In another method, respiration is effected without the intervention of external oxygen.

Energy may be released in the plant by fermentation, by the action of a group of substances known as enzymes, which have the power of inciting chemical changes in compounds with which they are in contact, without entering into

chemical combination with either the original substance or any of its derivatives. Fermentation may also serve an important purpose in digestion, in which its chief purpose is to reduce the foods to soluble and diffusible form.

104. Exhalation of carbon dioxide by germinating peas.—Fill a glass cylinder, of a capacity of about a liter, one-third full of peas which have lain in water at a proper temperature for a day. Cover tightly with a glass plate or wooden top sealed with vaseline. Twelve or fourteen hours later provide a section of candle 2 or 3 centimeters long with a holder of bent wire. Carefully slide the cover to one side without creating currents of air, and lower the burning candle into the jar. Note result. Repeat two or three times. Make the test also with a jar containing the same quantity of dry peas.

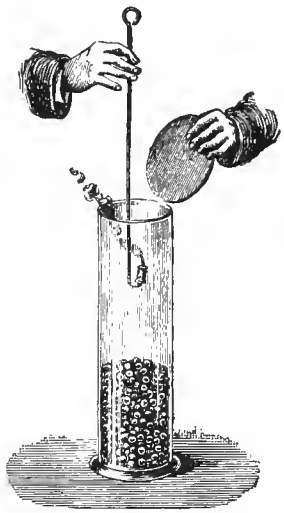


Fig. 75.—Method of testing gas liberated by germinating peas. After Sachs.

Make a fresh solution of lime or baryta water. Pour some into clean dishes. Set one inside the cylinder containing the growing seeds, and another in one with dry seeds. Cover carefully as before. Examine a few hours later. The liberation of carbon dioxide will be denoted by the formation of a film of carbonate of calcium or barium in the liquid. The series of tests given above may be repeated with a quantity of flowers of clover or sunflower.

105. Estimation of the amount of carbon dioxide

given off in respiration of germinating wheat.—Support a small retort by means of a clamp, and stand with the end of the delivery tube immersed in a dish of mercury. Soak a handful of grains of wheat in water for a day, then place in the bowl of the retort, and cover with a moist piece of filter paper. Pass a few fragments of potassium hydrate through the mercury, up into the tube of the retort, and then pour enough water down the tube from the stoppered opening to dissolve the potash. Measure exact level at which the liquid stands on opposite sides of the tube. Close the stoppered aperture, and seal with vaseline. Set the preparation in a room where it may be kept at a temperature of 15° to 20° C. The potassium solution should absorb all of the carbon dioxide in the air in the retort at the beginning of the experiment, and also all of that given off by the seeds. Note the level to which the liquid has risen in the tube a day later, and mark exactly as before. This marking should be done when the experiment stands at the same temperature as at the first marking. Now dismount the preparation, empty the retort, and support in an inverted position at the same angle as before. Fill with water to

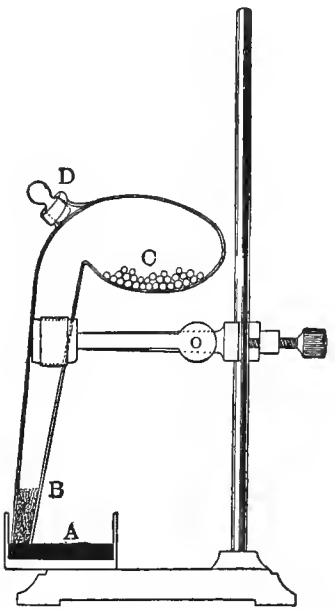


Fig. 76.—Apparatus for estimating amount of carbon dioxide given off by germinating wheat. *A*, mercury; *B*, level of water; *C*, seeds; *D*, stopper.

the last marks made on the tube. Now carefully pour in water from a graduated burette to fill the tube up to the first mark made. The amount of water used from the burette will then represent the volume of carbon dioxide given off by the seeds and absorbed by the potassium. The results are only generally approximate, and rest upon the supposition that the amount of carbon dioxide given off and the oxygen absorbed by the seeds are equal, which is not always true. (Fairly accurate volumetric methods for respiration are given in "Practical Text-book of Plant Physiology.")

Respiration tubes may be used also in this test. In this case both the potash and water may be introduced into the lower end of the tubes after the preparation is set up.

106. Incomplete oxidation of oily seeds.—Soak a handful of oily seeds, such as those of hemp, in water for an hour, and put in apparatus described above, from which the potassium solutions have been omitted. Note the behavior of the seeds as indicated by the level of the mercury in the tube. A decrease in the volume of the air in the tube or retort would denote the absorption of one or more of the gases by the seeds, with an exhalation not equal to it in amount (§103). Note rise and fall of column. When the column returns to its original level, introduce the potassium solution, and ascertain whether an exhalation of carbon dioxide has begun. Describe the course of respiration in oily seeds.

107. Respiration without external oxygen.—Soak a few peas in water for a day. Fill a five-inch test tube with mercury; invert, and support with its lower end immersed in a small dish of mercury. Select five sound peas, take off the outer coating, and slip under the edge of the tube, and allow them to rise to the top of the tube. Introduce a small wad of filter paper in the same manner. Care must be taken

that no air is introduced in the operations mentioned. Observe twelve and twenty-four hours later.

Test the gas exhaled by the seedlings, by pushing a small stick of potassium hydrate under the edge of the tube as before. If it absorbs the gas, and the mercury again rises to the top of the tube, it will demonstrate that the seeds of the pea are capable of carrying on respiration without external oxygen, exhaling carbon dioxide during the process.

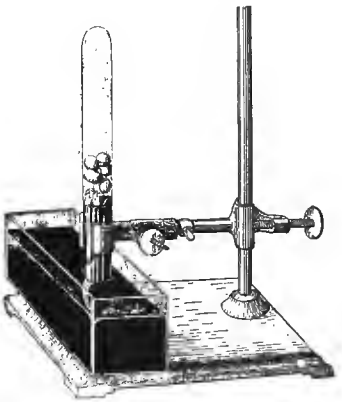


Fig. 77.—Liberation of carbon dioxide without external oxygen.

108. Influence of temperature upon respiration.—Set up two experiments as above, fixing the tubes firmly in place. Now leave one to endure ordinary room temperatures, and set the other one in a large pail or dish. Pour water into the pail until the test tube is completely immersed, then put several large pieces of ice into the water. Add more ice as needed, and note the temperature of both preparations four or five times during the next twelve hours. Compare the amount of gas given off as denoted by the fall of the mercury column in the test tube. The actual amount of gas exhaled in the above tests may be found by marking the limits of the column of gas in the tube, and then afterward noting the amount of water taken from a graduated burette to fill the tube to the levels indicated. Repeat the tests given above, using wheat or corn, and ascertain if these seeds may also carry on respiration by this method. What is the difference in chemical com-

position of the storage substances in the various seeds tested ?

109. Products of fermentation.—Make up 1,000 cc. of a 10 per cent. solution of cane sugar, and add to it a package of compressed yeast, or make a Pasteur's solution by adding to 838 cc. distilled water, 10 cc. ammonium tartrate, 150 cc. saturated solution of grape sugar, and 2 grams each of magnesium sulphate, calcium phosphate, and potassium phosphate. After the ingredients are thoroughly mixed, fill a tall glass cylinder about one-third full, and cover tightly. Introduce a package of compressed yeast. Test the air above the solution for carbon dioxide, as in §104, a few hours later. Taste the solution. The sugar originally present is split up by the action of an enzyme secreted by the yeast cells into carbon dioxide, water, and alcohol.

110. Influence of various factors on fermentation.—Repeat the test given in the previous experiment, but introduce a few cubic centimeters of chloroform into the solution. Note effect. Repeat the test again, but set the cylinder containing the solution and yeast in a larger vessel containing water. Add large pieces of ice to the water, and renew. Take temperature of water occasionally. What effect does the low temperature have upon the fermentative action ? What is the action of yeast in the rising of dough in bread-making ?

111. Action of diastase and associated enzymes.—Place 10 grams of seeds of barley in a germinator for thirty-six hours, or until the radicles are about 5 mm. in length. Grind fine in a mortar or in a new coffee mill. Collect the mass in a clean glass vessel, and add 30 cc. distilled water, and stir. A half hour later filter, receiving the filtrate in a large test tube or small bottle. Make a starch paste by adding 1 gram starch to 100 cc. water, which should give

a blue reaction when a drop of it is treated with iodine solution. Set aside part of the starch solution as a control, and add the filtered extract of barley, which contains a solution of the enzyme diastase, to the bulk of the solution. Take a sample of the solution fifteen minutes later, and note the iodine reaction. Repeat a half hour, an hour, two hours, and three hours later. What is the fate of the starch? Compare taste of the solution at beginning and close of the experiment. Repeat the test, using ungerminated seeds of barley in one series, and fresh leaves of barley, finely ground, in another, and compare results.

112. Digestive action of scutellum of corn.—The enzymes play a very important part in digestion, and special layers for the secretion of these substances are to be found in the aleurone layers of seeds of grasses, and also in the outer layer of the embryo. The action of the digestive secretions may be demonstrated as follows: grate the white portion of a potato into a smooth pulp, and fill the cavities in a dozen culture slides. Dissect out the embryos of an equal number of seeds of corn that have been in a germinator for two days. Lay one of these embryos on every one of the masses of grated potato, and put all of the preparations in a moist chamber, which should be kept at about 40° C. A control slide with grated potato alone should be added to the series. Examine some of the grated potato with a magnification of about 400 to 500, and note the appearance of the starch grains. Note microchemical reaction with iodine. Now apply the iodine test to a separate slide at the end of every hour. What is the fate of the starch grains as indicated by the color reactions and by the microscopic examinations?

Test some of the fresh potato for sugar, and some of the material treated several hours with Fehling's solution. (See "Practical Plant Physiology.")

113. Digestion of cellulose.—Take a number of seeds from the dried dates of commerce, and put in moist soil or sawdust. Germination will take place in about six weeks. Two weeks later make dissections of the seeds, and compare the embryo of resting seeds with the plantlet two weeks old. What effect has the germination exerted on the hard cellulose walls of the seed? Cut a thin cross-section, and stain with iodine. What variations from the typical reactions of cellulose are to be seen? What is the fate of the cellulose? The digestion of the cellulose is accomplished by means of *cytase*, which is also secreted by parasitic plants, and used for dissolving the walls of the host.

114. Catalase and other oxidizing enzymes.—Take fresh tissues of any convenient plant and cut up finely. Put the minced material in a test tube, and cover with water. Add a few drops of hydrogen peroxide. The formation of bubbles of oxygen will denote the presence of catalase, one of the most important of the oxidizing enzymes. A familiar example of the action of this substance is to be seen in the browning of the exposed surfaces of apples, peaches, pears, and other fleshy fruits. In some instances the presence of these enzymes may be detected by moistening a cut surface with a 2 per cent. solution of gum guaiacum in alcohol. If oxidizing enzymes are present, the surfaces treated will turn blue.

115. Translocation of food material.—A familiar example of translocation of material in the plant is to be seen in leaves. Food is formed in these organs during exposure to sunlight about ten times as fast as it may be removed by diffusion. As a consequence, the surplus accumulating is converted into an insoluble form as starch, in which it does not affect the absorbing or dissolving power of the sap in the leaves. During the night, or at any time when the leaf is not exposed to light, the slow but continuous process of diffusion

may empty the cells of the leaf of soluble contents, and then the starch is reconverted into a soluble form. This is accomplished by the action of diastase, as demonstrated in §111. The main channels of conduction of food material are found to be the elongated elements in the phloem, principally the sieve and companion cells. These cells are adapted to the diffusion of solutions much more quickly than the neighboring cells of shorter axes, such as the sheath cells, which were once supposed to carry on this function.

116. Translocation of carbohydrates from leaves.—Expose any convenient living specimen to a strong sunlight during an entire day, and examine the tissues for starch in the evening. If the leaves are richly loaded with this substance, suitable conditions for the test are found. Cut off a few of the leaves, and place in a moist chamber. Set the plant and the moist chamber in a dark room, and allow them to remain until the following day at 10 A.M. Now examine leaves from the plant, and those that have lain in the dark chamber, for starch. In what way may the difference in amount in the severed leaves and those still remaining attached to the plant be accounted for? It would be well to carefully cut the main veins of one of the leaves attached to the plant before being placed in the dark chamber, in such manner as to break the conducting cells around them, and note what effect the operation has upon the translocation of starch from the leaf. Definite results may not always be seen, however.

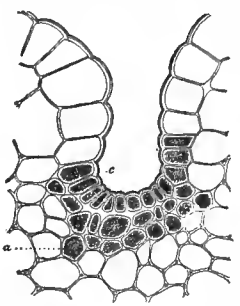


Fig. 78.—Transverse section of nectary of *Aloe vera*. *c*, cuticle. After Schniewind-Thies.

117. Excretion of nectar.—Examine a number of plants that are being visited by honey-gathering animals, and

ascertain exact location of nectarial organs. A large number will be found in floral structures. Well-developed nectaries may be found outside the floral circles in *Passiflora*, *Cassia*, *Ricinus*, and many species grown in conservatories. Make an examination of the structure of the nectaries. Draw a section made at right angles to the secreting surface, and note structure of secreting cells. Ascertain rate of secretion by removing the nectar from a gland and noting length of time necessary for its replacement. Carefully remove the nectar from another gland, and then wash well with distilled water, and wipe dry by means of a minute portion of linen cloth. What effect does it have on the rate of secretion?

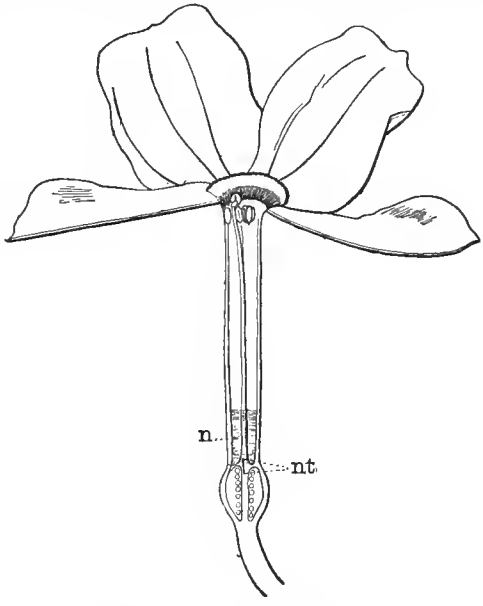


Fig. 79.—Diagram of flower of Narcissus. *nt*, nectary; *n*, excreted nectar. After Schniewind-Thies.

118. Action of glandular hairs.—Examine the glandular hairs of the pansy (*Viola tricolor*), horse-chestnut (*Æsculus*), *Primula Sinensis*, hop (*Humulus lupulus*), and note structure of the glandular organ, and make various tests, including

taste, to determine the nature of the secretion (Figs. 80, 81). Make a careful examination to ascertain the manner of extrusion of the secretion. In many instances it will be

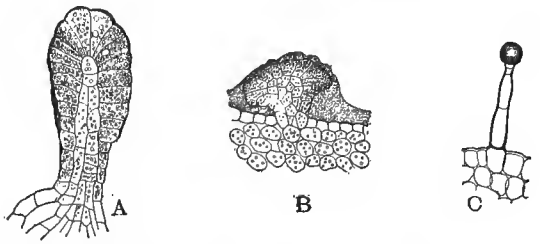


Fig. 80.—*A*, glandular hair from stipule of pansy (*Viola tricolor*); *B*, glandular hair from scale of *Æsculus hippocastaneum*, covered with excreted substance; *C*, glandular hair from petiole of *Primula Sinensis*.

found to be held between the outer walls of the gland and the superficial layer of cuticle, and is only set free when the cuticle bursts. *Cypripedium* and *Primula* will offer interesting material for the study of this point.

119. Secretions serving as a protection.—Many of

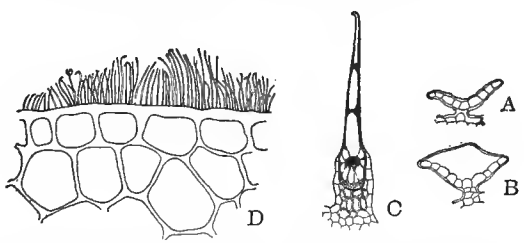


Fig. 81.—*A*, glandular hair from inflorescence of the hop (*Humulus*); *B*, same after the cuticle has become distended by secretion; *C*, stinging hair of nettle (*Urtica dioica*); *D*, waxy secretion on stem of sugar-cane (*Saccharum officinarum*).

the secretions formed by external glands are of such a nature as to serve to repulse the encroachments of animals, and thus damage to the body of the plant is avoided. The glandular

secretion of *Cypripedium* has been found to be irritable to the skin, the volatile secretions of poison ivy have a marked poisonous effect, and the unpleasant effects from the stinging hairs of nettle are well known. In the latter instance the secretion is contained in the stiff hairs borne on the leaves and stems; and when the walls are broken, the jagged edges penetrate the skin, allowing the action of the irritating contents to act more strongly. Secure fresh stems and leaves of *Primula, Cypripedium*, or nettle, and make tests to ascertain the presence of oils or acids in the glandular hairs.

CHAPTER VII.

STIMULATION AND CORRELATION.

120. General irritability of plants.—The plant may carry on its functions only under a certain range of conditions or intensities of certain external forces or agencies, of which light, moisture, temperature, food, substratum, and gravity are the most important. Any change in the relations of any one of these factors to the organism sufficient to alter the behavior of the plant in any of its functions constitutes a *stimulus*, and the response to the action of the stimulus, or to *stimulation*, is termed a *reaction*. Reactions are not produced by variations in environmental forces alone, however. The parts of the body are most intimately connected, and any change in the manner of performance of a function in one organ acts as a stimulus on other parts of the plant. Thus the cessation of growth, the reception of an injury, or the inception of a new activity in an organ stimulates tissues in distant parts of the body to variations in their behavior. This correlation of all the organs of an individual exists in a much higher degree among plants than among animals. Familiar and marked examples of irritability or reaction to stimulation are to be seen in the movements made in bending toward the source of light rays, and the closure of the pinnules in the pinnules of *Mimosa*.

121. Sensory organization of the plant.—Changes in external or internal forces constituting a stimulus often do not directly affect the organs or tissues in which the reaction ensues. The stimulus may be received by the outer layer of

protoplasts, which thus serve a perceptive function, and some form of energy constituting an impulse is transmitted to the organ concerned, in which the reaction takes place. In some instances the reaction is a movement, and special structures for producing the motion are differentiated, being known as *motor organs*. The method by which impulses are transmitted is not known, nor have any transmitting organs been definitely located. Perceptive tissues or organs are differentiated in a few instances only. The action of a stimulus is supposed to be received by the ectoplasmic layer of the cells, and transmission takes place through these layers into adjacent cells connected by interprotoplastic threads. Nearly all reactions have for their direct purpose the placing of the organ in a condition of better adjustment with the other organs of the plant or with the environment, either for the better performance of the functions or the avoidance of injury. The mechanism developed, however, may be set in action by other forces than those to which they are designed to react.

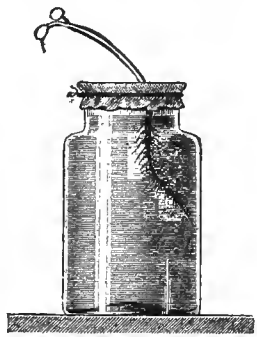


Fig. 82.—Curvatures of a seedling of mustard in response to rays of light from left. After Detmer.

122. General reactions of a plant to light.—Germinate seeds of mustard, pea, or bean, and when the roots are a few millimeters long, place on a piece of netting fastened over the mouth of a bottle or dish, as in Fig. 82. Cover with a cardboard box, and set near a window in a room kept at ordinary temperatures. Cut a slit in the box on the side nearest the window. A few days later lift off the box, and note the position of the root

and shoot. What connection is shown with the habit of growth of the plant?

123. Prophototropism.—Germinate a number of seeds of oats or wheat in a shallow dish of moist soil, and, when the leaves begin to appear, set in a cardboard box. Cut a circular hole in one side of the box, at the level of the seedlings. Roll up a sheet of paper into a tube, and fasten to the box in such manner that light enters through the tube only. Cover the box to exclude light, except through the tube. Note the

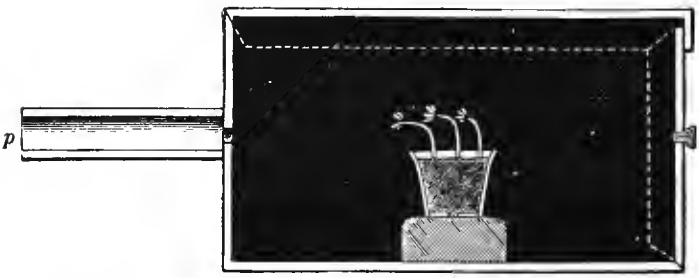


Fig. 83.—Phototropic chamber. *p*, tube through which light enters. After Schleichert.

position of the leaves a day or two later. In this instance the leaves are placed with their apices directed toward the source of the rays of light, with their axes parallel to the rays.

124. Diaphototropism.—Place in a pot a *Malva*, *Helianthus*, or *Geranium* grown in the open air, and place near a window with a southern exposure. Note the position assumed by the younger leaves a few days later. How does this reaction compare with that shown by leaves of grasses?

The same form of reaction may be seen if a leafy shoot of sunflower is bent down to a horizontal position and fastened. Note the position of the leaf blades before and two days after the operation.

125. Perceptive region in leaves of grasses.—Grow a number of seedlings of oats or wheat or canary grass

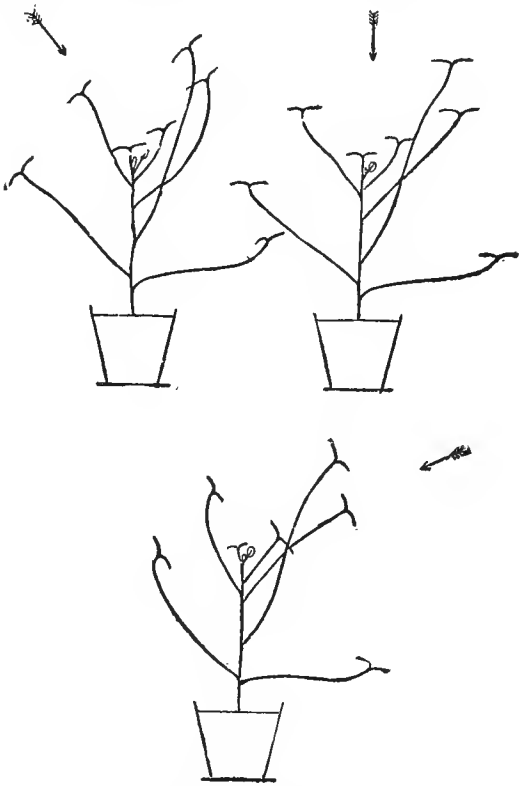


Fig. 84.—Positions assumed by blades of leaves of mallow. The arrows denote direction of rays of light.

(*Phalaris*) in a shallow dish of moist soil or sawdust. Make several cylinders of tin-foil of sufficient size to fit snugly over the leaves. To do this, wrap a strip of tin-foil round a match

Fig. 85.—Positions assumed by leaves of sunflower when placed horizontally. The blades are perpendicular to the rays of light. After Oels.

and twist the end, or tie around it with a thread. Cover two of the seedlings with these caps in such a manner as to totally exclude the light. Cover two more with short caps extending downward a distance of 6 to 8 mm. only from the tip. Slip cylinders over two more in such manner that the basal portion only is covered, leaving a length of a centimeter at the tip exposed. Set the preparation in a dark chamber, as described above, leaving the aperture open at the level of the seedlings. Note positions a day or two later. (See "Practical Plant Physiology.") What portion of the leaf must light strike to set up a reaction?

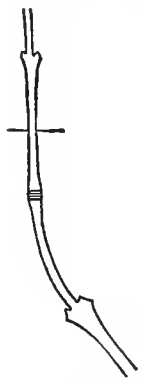


Fig. 86.—Diagram of stem of *Coleus*, to show region of curvature when illuminated at tip, above horizontal line. After Rothert.

126. Motor zone in Coleus.—Select a rapidly growing specimen of *Coleus*, and strip it of the leaves. Wrap the stem with sphagnum, or cover with tin-foil to within a centimeter of the tip, or leave one internode free. Place in a dark chamber arranged as above. Two days later note the region

in which curvature has ensued. This demonstration may also be repeated with seedlings of bean or stems of grass.

127. Influence of light on form.—Grow two lots of seedlings of pea or bean in pots. Place one lot near a window where it will receive the greatest amount of sunlight possible, and set the other in a dark corner of the room, where it will be exposed to only a weak diffused light. Take precautions that the two preparations are kept at about the same temperature. Two weeks later take up the plants from the two lots, and note the differences between specimens grown in intense and in faint illumination. Measure the length and thickness of the stems, the area of the leaves, and note difference in texture of leaves.

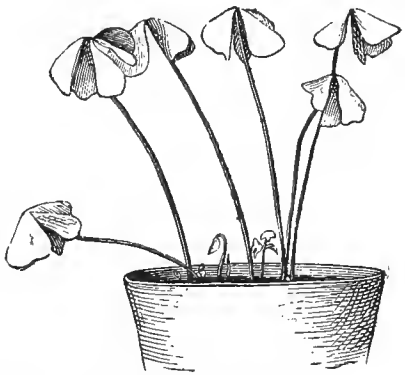


Fig. 87.—Oxalis in darkness, showing adaptive positions of leaflets.

128. Movements due to intensity of light.—Observe the positions of the leaflets of seedlings, of bean, or of *Oxalis* in the morning, mid-afternoon, and late in the evening, in a room kept at ordinary temperatures. On a second day cover the plant with a box which shall totally exclude light, and note positions of leaves as before. Repeat on a second, third, and fourth day.

The leaflets will be found to exhibit periodic movements, assuming certain positions at regular portions of the day. These movements are protective in their purpose and are designed to shield the leaves from the effects of intense

insolation in the middle of the day, and from rapid cooling and loss of water at night. The plants used have been accus-

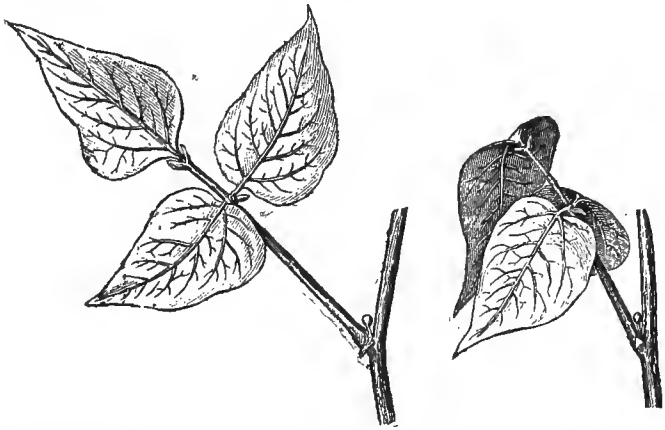


Fig. 88.—Positions of leaflets of bean in daylight and in darkness. After Detmer.

tomed to regular alternations of periods of darkness and light until they have acquired a rhythm or habit, in accordance with which the movements will be repeated a number of times, even when kept under continuous darkness or illumination. After a time, however, the rhythm will be lost in many species. After becoming fully acquainted with the behavior of the plant used in the above test, place it in sunlight, and raise the temperature of the air around it, or of the soil, and note effect on movements of leaves.

Fig. 89.—Position of pinnules of *Mimosa pudica* at night.

129. Geotropism: reaction to gravity.—Bend over

a stem of oats or wheat, and fasten the stem in a horizontal position. Place a shade over the stem so that it may not receive direct light from above. Note the movement of the stem in assuming an erect position in response to the stimulation of gravity.

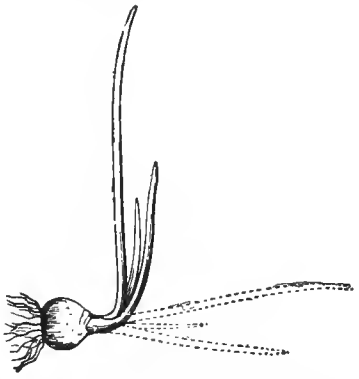
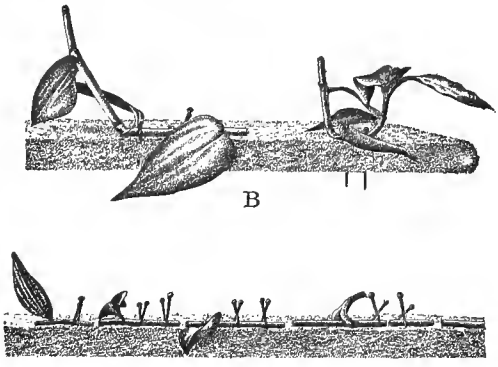


Fig. 90.—Upward curvature of leaves of onion (*Allium*) placed in a horizontal position. After Frank.

Secure a few stems of wandering jew (*Tradescantia*), and fasten with crossed pins to a thin sheet of wood or cork. Float on water in a dish, and cover with a bell jar, or lay a sheet of glass over the top of the dish to make a moist chamber. Note the movements of the stem and the location of the motor zones.



B

A

Fig. 91.—*A*, portions of stems of *Tradescantia* fastened to sheets of cork by pins; *B*, upward curvature of free ends. After Kohl.

Fit a section of glass tubing 2 cm. in diameter and 10 cm. long with cork stoppers. Perforate one cork with a hole sufficient to receive the base of the main root of a seedling of pea which has a stem a few centimeters in length. Split the cork, and place round the base of the root, and thrust into the end of the tube. Fasten the tube in an inverted position, and fill with water. Fit a perforated cork to the upper end of the tube. Note position of roots and stem at beginning of experiment and twenty hours later (Fig. 92).

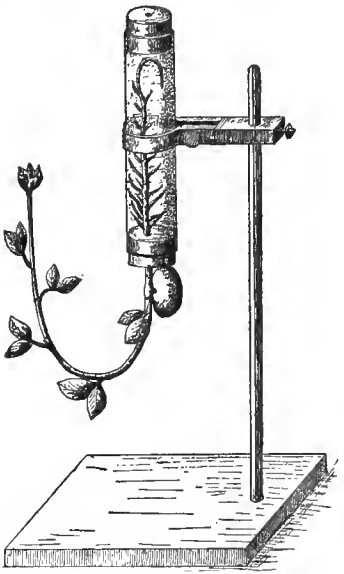


Fig. 92.—Plantlet of pea with root in a small moist chamber, in an inverted position, to demonstrate geotropic irritability of root and shoot.

130. **Progeotropism.**—Germinate a number of seedlings of pea or bean, and when the roots are 1.5 cm. in length, take several of them and fasten by means of pins to a sheet of cork or wood, with the tips of the roots directed upward vertically. Float the cork in a dish of water, and cover with some opaque object, such as a board, making a moist chamber into which light enters from the sides only. Note the positions of the roots a day and two days later. The roots are seen to react to the stimulation of gravity by a motion which has for its purpose the directing of the roots toward the center of the earth or downward into the soil.

131. Location of the motor zone.—Germinate a number of peas or beans until the main roots are about 15 mm. long. Mark off into 2 mm. intervals by means of a fine thread held by a bent wire and saturated with india ink. Lay a few of the seedlings which have been treated in this manner in moist sawdust, with the roots extended horizontally. Two days later take up and note the region in which curvature has ensued.

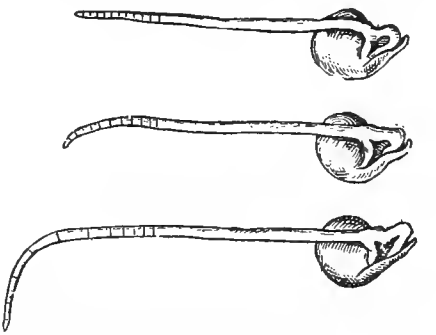


Fig. 93.—Showing successive positions of root seedling of pea placed horizontally. After Pfeffer.

132. Diageotropism of roots.—Grow a number of seedlings of pea or bean in a box of moist sawdust, one side of which has been replaced with a sheet of glass to permit inspection of the contents. After the roots have attained a length of a few centimeters, and lateral branches have been given off, tilt the box at an angle of 45 degrees, and allow it to remain in this position a day or two. Now examine the positions of the apical portions of the roots. What is the general position of the branches of the main root? What reactions ensue in the main root when it is moved from the vertical position, and in the lateral roots when moved from the horizontal? After the inclined position has been maintained a proper length of time, the glass may be removed and the sawdust taken from around the roots, with a minimum of disturbance, in such manner that their true positions may be made out.

133. Movements in response to a combination of geotropism and phototropism.—Force into bloom a number of bulbs of *Narcissus*, which may be obtained from dealers. Set one upright on a table, and cover with a cardboard box with an opening in one side, at the level of the opening flowers. Note the position taken by the flowers. The pedicels will be found to move to a horizontal position, with the axis of the flower directed toward the source of light.

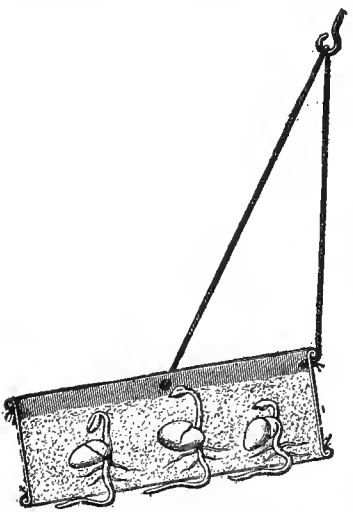


Fig. 94.—Box with perforated bottom, filled with sawdust, to demonstrate hydrotropic reaction of roots. After Detmer.

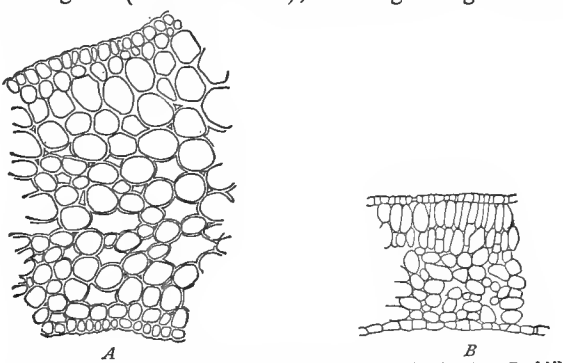
Take a second plant, in which the flowers have already assumed the horizontal position, and lay the plant inclined or horizontally, fastening the scapes in such manner that the pedicels lie in various planes. Note the exact positions of half a dozen flowers. Examine a day later, and describe the movements entailed.

134. Hydrotropism of roots.—Secure a small wooden box which will hold sufficient moist sawdust to germinate seedlings of peas or beans. Take away the top and bottom, and replace with wire or cloth gauze. Fill the box with sawdust thoroughly saturated in water, and imbed seedlings in the sawdust. Attach cords to the box in such manner that it may be suspended from a support, or provide means of tilting it at an angle of 45 degrees. The box must be so shallow that the roots in the natural course of growth

would soon reach the bottom of the sawdust. After the preparation has been made, set the box in a position where its lower side will be inclined 45 degrees from the horizontal, and follow behavior of the roots. If these organs are directed by gravity alone, they will emerge from the lower side of the box, into the air, depending vertically. If curvatures occur, to what force or agency are they due? Care must be taken, in this demonstration, that the roots are not subjected to the action of strong illumination.

Fig. 95.—Water crowfoot (***Ranunculus***) with two forms of leaves.

135. Influence of water on form of leaves.—Collect a number of plants of *Ranunculus aquatilis*, *Cabomba*, or water marigold (*Bidens Beckii*), found growing in shallow



A *B*

Fig. 96.—Transverse sections of leaves of water marigold (*Bidens Beckii*). *A*, aërial leaf; *B*, submerged leaf. After Pieters.

ponds or along the margins of streams. Note the difference between the form of the leaves which arise from the submerged and from the aërial portions of the stems. Cut sec-

tions, and note differences in structure. It would also be of interest to cultivate some of these plants in an aquarium, and observe the manner of formation of the leaves on submerged and on aërial portions of the same stem.

Fig. 97. — Positions assumed by leaves of *Mimosa* in response to stimulus applied to tip of leaflet on right.

136. Chemotropic movements of pollen tubes.—Add 1 gram of gelatine and 4 or 5 grams sugar to 50 cc. distilled water. Warm until all are dissolved together. Place a drop of the solution on a glass slip, and add a number of pollen grains of *Narcissus*, *Lilium*, *Fritillaria*, or *Lathyrus*. Cover with a thin circle of glass, such as is used in mounting objects for the microscope, and keep in a room at about 18° C. for eight or ten hours. Examine with magnifications of 60 and 400 on the following day. Note the germination of the pollen cells, and also the direction which the tubes have taken. All seem to be directed away from the edge of the cover glass. It would be profitable to make a second preparation and keep it with the first, carefully sealing the edges of the preparation with

vaseline. The pollen tubes are generally directed away from contact with air, being negatively chemotropic to oxygen.

137. Movements in response to shock.—Secure seeds of *Mimosa* from a florist, and germinate in a pot of rich, loose soil in a warm room. As soon as the seedlings have begun to develop foliage leaves, cover the pots with a bell jar, and ventilate in such manner that the air is kept in a humid condition. It will be still more convenient if the seeds are planted in several small pots. Keep the plants under observation, and note positions of the pinnules at various times in the day. All experiments should be made with the temperature at 20° to 25° C. Select a plant with expanded leaves, and jar it by striking a quick, sharp blow on the pot in which it is growing. Note result. How long is the reaction position maintained? Touch the tip of an expanded leaflet lightly with a pencil, and follow the resulting movements. Repeat this test in another form by snipping the terminal pinnules with a pair of scissors. Allow an ample length of time after each stimulation, and observe the extent of the reactions. Does a reaction take place in any part of the plant which has not been directly stimulated? If so, make careful note of the time necessary for the impulse or effect of the stimulus to be transmitted from the point at which the stimulus was given to the distant part of the plant in which the reaction occurs. Test various forces as stimuli, such

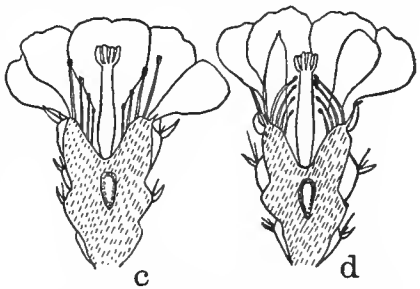


Fig. 98.—*c*, flower of *Opuntia* with stamens in normal position; *d*, with stamens after stimulation. After Toumey.

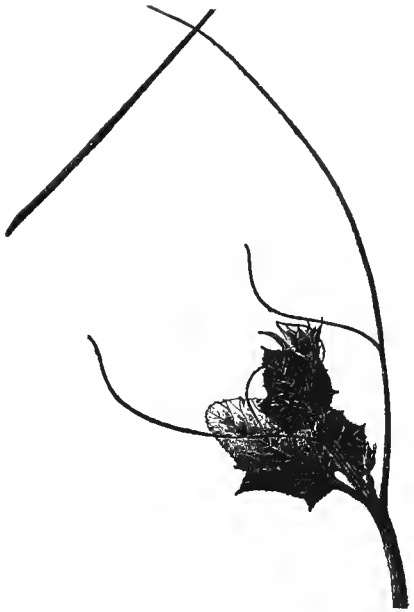


Fig. 99.—Tendril of squash a few seconds after contact with a wooden rod. A slight curvature has been formed.

as an air current, a shower of water drops, and the fumes of ammonia or chloroform (Fig. 97).

Mimosa affords an excellent example of the daily movements shown by so many plants.

138. Movements of stamens, etc., in response to shock.—Secure flowering specimens of *Berberis*, *Opuntia*, *Cereus*, *Portulaca*, or purslane, and make various tests of the irritability of the stamens by touching

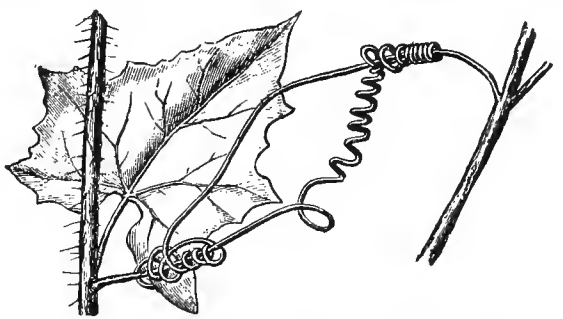


Fig. 100.—Tendrils of bryony after grasping a support. After Kerner.

with a pencil, noting the resulting movements. What advantage to the plant would movements of the stamens give? (Fig. 98.)

139. Movements of tendrils in response to contact of solid objects.—Secure vigorous specimens of a pas-

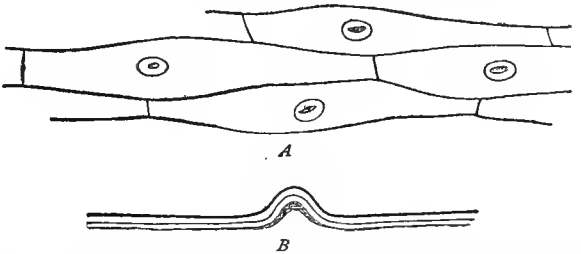


Fig. 101.—*A*, surface view of sensory cell of tendril of squash; *B*, profile of external wall of same. After Detmer.

sion flower, bryony, or squash, and observe the form of the slender tendrils at various stages in their development. Note behavior of these organs as exhibited by their attachment to various objects or supports. Select an extended and nearly mature tendril, and touch the concave surface near the tip with a pencil or some hard object. Before doing this, place a sheet of paper back of the tendril in such manner as to mark the position and outline of the tendril. Now follow the change in form exhibited. Estimate the length of time necessary to carry out the full movement, and also the period over which the resumption of the original form extends. Fasten a small stick or cord in a position where it will be in contact with the concave surface of a ten-

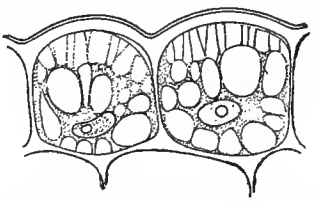


Fig. 102.—Transverse section through sensory (epidermal) cells of tendrils of *Entada scandens* (West Indian filbert).

dril, and follow the movements of the tendril in coiling around it. If the observation is continued over two or three days, the formation of free coils in the free portion of the organ may also be followed. Coat a glass rod with soft gelatine, and touch the tendril. Does a reaction follow? Allow the gelatine to harden, and repeat test. Compare results. Jar the tendrils of a vine by striking the stem. Does a reaction follow? Compare with results obtained by similar tests with *Mimosa* (Figs. 99–102).

140. Circumnutation of growing organs.—Plant

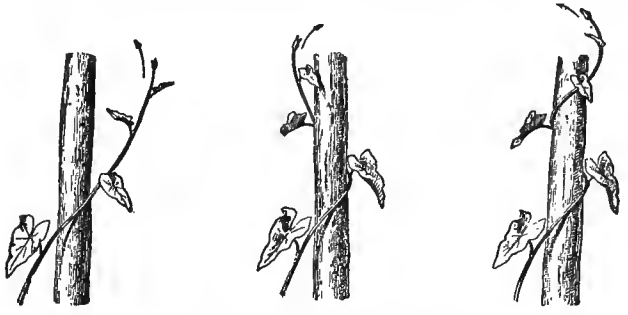


Fig. 103.—Successive positions of stem of bindweed in twining around a support. After Bonnier and Leclerc du Sablon.

four seedlings of bean or morning-glory around the margin of a large box or pot full of earth, and set a rod or support upright in the center. As the stems elongate select a bright, warm day, when the plant is growing rapidly, with the soil well watered, and observe the successive positions occupied by the tips of the stems. Support a sheet of glass over one of the plants, and mark the positions of the apex of one of the stems hourly during half a day. What length of time is necessary for the stem to make a complete revolution and return to a position corresponding most nearly to its original position?

The circumnutatory movements are due to a combination of forces of which the stimulation of gravity, followed by a reaction known as lateral geotropism, is the most prominent. (See "Practical Text-book of Plant Physiology.") Note direction of movements in a number of species that may be available in a greenhouse.

141. Carpotropic movements.—The movements of flowers by which these structures adapt themselves to changes in temperature and illumination are fairly well known. Familiar illustrations are to be seen in the wild carrot (*Daucus Carota*), which curves the main flower scape in such manner that the flat-topped umbel of flowers which faces the sky in the daytime is reversed and hung downward during cool nights; the pansy performs similar nocturnal movements, both plants returning the flowers to an upright position during the daytime. In another type of the daily movements the flower opens or closes at certain periods of the day. Thus the tulip closes on cool nights and reopens during the warmer part of the day. *Tussilago*, *Claytonia* (spring beauty), purslane, and many others exhibit similar adaptive reactions by which the flower is protected from the effects of changes in temperature and undue loss of moisture.

In addition to such induced movements which depend upon external forces for their inception, a second series is shown, which are set up by internal forces, and which depend entirely upon the developmental stage of the flower. Such reactions may be classed under carpotropic movements, and have for their purpose the adjustment of the flower to such position as will best promote pollination and ripening and dissemination of the seeds.

Carpotropic movements are seen to be of the most diverse character. The undeveloped flower buds may be erect and the ripened fruit pendent, or the reverse; the unopened bud may be pendent, the open flower erect, and the

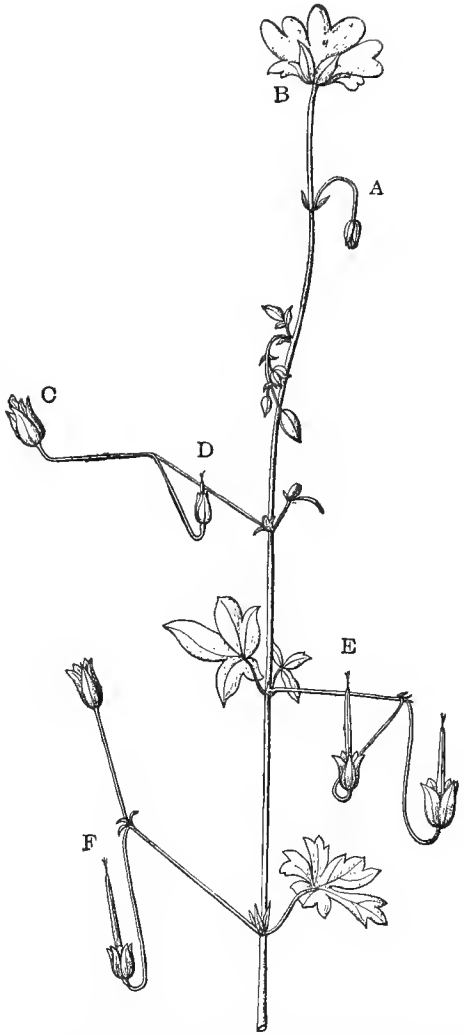


Fig. 104.—*A*, *B*, *C*, *D*, *E*, *F*, successive positions of buds, flowers, and pods of *Geranium pyrenaicum*. After Vöchting.

fruit pendent, and various combinations of growth and movement of the separate parts may be made in order to accomplish the purposes of pollination and seed dissemination. The character of these movements may be best understood by discussion of the following types:

142. Carpotropic movements of pedicels of Claytonia Virginica.—The unopened flower buds are held in a drooping position by a general curvature of the short pedicel. The advanced stage of development of the bud is the signal for the straightening of this curve until the open flower is held erect, while the mature flower is subject to the daily opening and closing, as described above. As soon as fertilization ensues, the signal thus set up starts two activities in the pedicel. The pedicel begins a rapid elongation which doubles its length, and a curvature ensues in the extreme basal portion by which the ripening pod is held in a pendent position most suitable for the dissemination of the seeds. (See Figs. 104 and 105.)

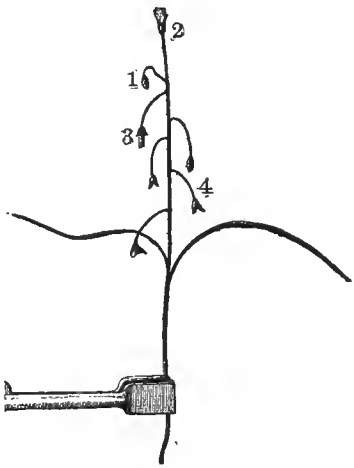


Fig. 105.—1, 2, 3, 4, successive positions of flowers of *Claytonia Virginica* (spring beauty).

Examine the position of the flower buds, open flower, and seedpods of any plants accessible, and sketch positions. Note stages in which movement occurs.

143. Carpotropic curvatures of Streptocarpus.—*Streptocarpus Rexii* bears a number of striking flowers, each

on its separate peduncle, which is curved in such manner that the unopened bud is held in a drooping position, or variously inclined, as in Fig. 106. As the development of the flower proceeds, and the stamens and pistils mature, the opened corollas are held in a horizontal position until fertilization is accomplished, when the apical portion of the peduncle again takes up a motion by which its curvature is straightened until the capsule is held in an approximately erect position. The signal or stimulus for each of these motions is set up by the plant itself. Thus the growth and enlargement of the flower bud stimulates the peduncle in such manner that it performs a straightening of the curvature until the corolla tube is held in a horizontal position. At this point the movement ceases, and the flower is held firmly in this position until pollen has been deposited on the pistil, and presumably the growing tubes from the germination of the pollen have reached the egg cell. The fusion of the nucleus from the pollen tube and that of the embryo sac sets up another signal or alarm, which again sets the peduncle in motion, and the pod is slowly erected into the position shown in the figure.

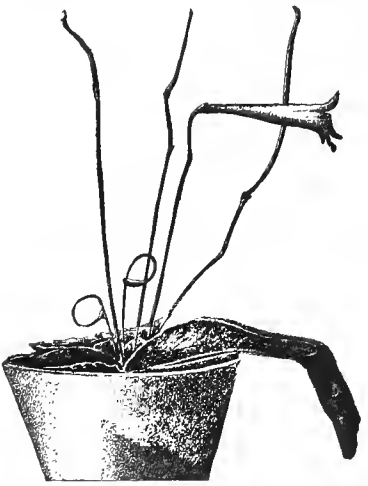


Fig. 106.—Positions of buds, flowers, and pods of *Streptocarpus Rexii*.

144. Complex movements of inflorescence of Allium.—The inflorescence of *Allium Neapolitanum* is enclosed in sheathing bracts and supported in a drooping position on

the scape. As the development of the numerous flowers proceeds, the curve in the scape is straightened and the inflores-

Fig. 107.—Positions of inflorescence of *Allium Neapolitanum* in earlier stages.

cence is finally held erect. Meanwhile the pedicels exhibit a series second of independent movements. These structures

Fig. 108.—Positions of flowers of *Allium Neapolitanum* in advanced and final stages.

acquire a sensitiveness to gravity, by which they tend to curve upward independently. After the scape has assumed a final

erect position, the pedicels, which, as has just been described, tended to curve upward, now take on separate and individual positions, by which each is separated from its neighbors equidistantly, in which position they remain until fertilization has been accomplished, when a further movement results in still wider separation—a movement due apparently to the growth of cushions of tissue at the bases of the pedicels.

INDEX.

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