CHAPTER VI

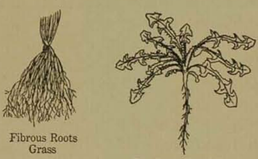
SPERMATOPHYTA. PART II

MORPHOLOGY OF ROOT, STEM AND LEAF

We have already studied the flower and the reproductive process resulting in the formation of seeds. The seed develops into a plant with three organ systems, namely, the root, stem and leaf. These organs are concerned with the vegetative or metabolic life of the plant.

A. The Root

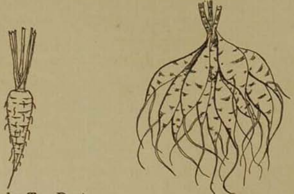
Roots usually live in the soil. They anchor the plant, absorb water and mineral salts dissolved in the soil water; they absorb oxygen and give out carbon dioxide. There is a great variety in root form but there are two main types: (*a*) *Fibrous Roots.* Grasses (Fig. 78) have such a root system. There is a thickly branching mass of small roots which grow down from the base of the stem. (*b*) The *Tap Root.* The dandelion (Fig. 78) has one main tap root which grows down into the soil. From this, branch roots develop. Carrots, parsnips (Fig. 79), beets and turnips are examples of thickened or fleshy tap roots, in which sugar and starch are stored. The dahlia (Fig. 79) has a cluster of *multiple roots* at the end of the growing season.



Fibrous Roots
Grass

Tap Root - Dandelion

Fig. 78. — Root types.



Fleshy Tap Root
Parsnip

Multiple Fleshy Roots
Dahlia

Fig. 79. — Storage roots.

The older parts of roots (tree) are tough and woody, but the very *tip ends* of the smallest roots are soft, delicate structures of vital importance to the plant. Such a *root tip* has five regions which merge into one another. (1) A *root cap* at the very tip. This consists of a covering of cells which protect the tender tissue behind it. As the root tip grows it penetrates between soil particles and in this process the outer cells of the root cap are worn away, but new cells are constantly formed underneath to take the place of the outer cells. (2) Just back of the root cap is the *embryonic region* or meristem. This is a small portion where the cells are undergoing cell division, forming new cells for the root cap and also for the important structure of the root further back. (3) Back of the embryonic region is the *elongation zone.* Here the cells, formed in the embryonic region, grow longer. Thus, increase in length of the root is provided for. (4) A little further back, these lengthening cells are assuming the form they will have when mature. (5) Still slightly further back are cells which *have* assumed this mature form. The accompanying figure (Fig. 80) representing the root tip of a young corn plant illustrates some of the features just named. For a short distance just above the elongation zone in the region of the newly matured cells, some of the epidermal cells develop long, hair-like processes (Fig. 81) called *root hairs.* They are extensions of the epidermal cells. The wall is of soft cellulose and is freely permeable. Just inside the cellulose wall is a thin layer of protoplasm which continues into the epidermal portion of the cell. In the cytoplasm is the nucleus. The cell is not entirely filled with protoplasm but has a large sap cavity. Sap contains sugar and mineral salts in solution. As the root hair develops, it pushes its way out between

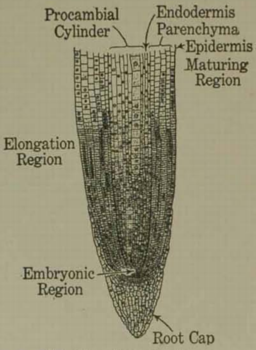


FIG. 80. — Root tip of corn.

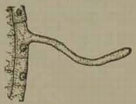


FIG. 81. — Root hair.

the minute soil spaces and comes into intimate contact with soil water. Root hairs do not live very long. As the root tips grow out, new root hairs (Fig. 82) form and the earlier ones, farther away from the tip, die. The surface exposed to soil water is enormously increased by the root hairs. The total area of all the root hairs of a single root tip is many times the area of the surface of the root tip itself. Since there are innumerable root tips in a large tree, the absorbing surface is *so much more* increased by the root-hair device. It is said that *the absorbing surface of all the root hairs roughly approximates the evaporating area of all the leaves.*

Soil fluids cannot penetrate the tough woody bark of old roots. It is the function of these thick roots to anchor the plant, and to make possible added growth in stem, aerial branches and leaves. There is a constant and great increase in numbers of root tips and root hairs. These constitute the only doorways by which water and nitrates and other compounds so essential to the plant can enter.

Root Tissues. Farther back from the root tip, tissues are being organized from embryonic cells which will provide for the annual growth in thickness of the older roots. Let us note stages in this process as may be found in dicotyledons.

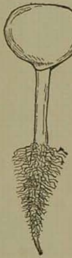


FIG. 82.—Sprouting radish seed showing zone of root hairs.

First. Just back of the root-tip region, an examination of the root reveals a certain amount of tissue differentiation (Fig. 83 *A*). (First) Externally, there is a single layer of epidermal cells, many of which develop root hairs. In the main, the *epidermis* is a protective layer. (Second) Within the epidermis is a zone of parenchyma cells in which starch may be stored. This zone is called the *cortex.* (Third) Within the cortex is the *central cylinder* or *stele,* which is separated from the cortex by a single layer of cells called the *endodermis.* Just within the endodermis (fourth) we find four (for example) *alternating* masses of *xylem* and *phloem. Xylem* consists of large, thick-walled, woody cells, giving rigidity to the root. Its cells form long ducts in which soil fluids are carried from roots to stem and leaves. Alternating with the four *xylem bundles* are four *phloem bundles.* Phloem consists of thin-walled special cells which transport sugar solutions from leaves, down through the stem to all the roots. Additional xylem cells forming centrally result in a four-pointed xylem mass. (Fifth) Between these primary xylem and primary phloem masses are groups of cells resembling those of the embryonic region in the tip. These cells also retain the *power of cell division*, and the tissue which they constitute is called *cambium.*

A branch rootlet may grow out from such a young root. If so, it arises from the cambium in the stele and grows out through the cortex and epidermis.

Second. Having studied the early histology, let us note the structure of this region later in the growing season, *i.e.*, Fig. 83 *B.* Epidermis, cortex, endodermis are shown as before. It should be stated that within the endodermis is tissue similar to that of the cortex, *i.e.*, parenchyma. The four separate masses of cambium have extended toward each other with the result that there is a complete cambium cylinder, though it is not yet exactly circular in cross-section. Added xylem, now called *secondary xylem*, is formed from the inside of the cambium and built upon the outer face of the first formed and centrally located, *primary xylem.* Wider masses of phloem have formed from the outer face of the cambium. The first four masses of phloem, *i.e.*, *primary phloem*, are pushed out further.

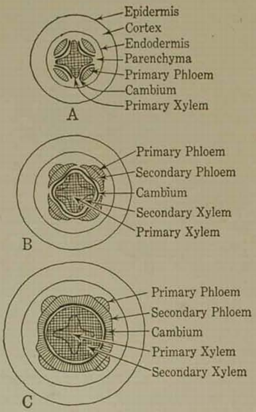


Fig. 83.— Histology of young root.

Third (Fig. 83 *C*). Now let us study the same portion of the root toward the end of the year's growth. Around the central mass of primary xylem is a still larger mass of secondary xylem. The cambium is even larger in circumference. Outside the cambium is a complete and wider *ring* of secondary phloem. The last xylem cells formed toward the end of the summer are small. When growth is resumed the next spring, large xylem cells are formed from the inside cambium cells. Later on, the xylem cells are smaller. The contrast between smaller xylem cells of late summer and adjacent large xylem cells of the next spring gives the appearance of a succession of ' rings ' of xylem or *wood*. Of course, new phloem is formed from the outside of the cambium. The older phloem is gradually pushed out toward the periphery of the ever-thickening root. Certain cells of the parenchyma inside the endodermis and later certain cells of the older phloem will form a cork which makes the ' bark ' of the root waterproof.

We have spoken of the cambium as a ring. But the diagram shows only a cross-section of the cambium. In reality it is a cylinder, as are also the secondary xylem and the phloem. The reason the cambium remains about the same thickness year after year can now be explained.

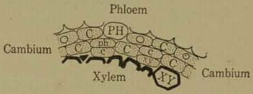


Fig. 84. — Cambium cells forming xylem and phloem cells. (Diagrammatic.)

Cambium cells (Fig. 84) are roughly rectangular in shape. The cambium cell *C* divides, as shown in the figure, into two small cells, *c* and *xy*. When formed, *c* grows into another cambium cell, *C*, while *xy* develops into a xylem cell, *XY*, on the *outside* of an older xylem cell. But elsewhere in the cambium, a cell *C* has divided into two cells, *c* and *ph*. The cell *c* develops into a cambium cell again, while *ph* develops into a phloem cell, *PH*, which is just *inside* the old phloem but on the outer side of the cambium. Any cambium cell may develop now a xylem cell and cambium cell, and the latter cambium cell may next produce a phloem cell and another cambium cell. The constant formation of new xylem and phloem increases the thickness of the stem, but the thickness of the cambium layer remains about the same. At the end of the second season we find two rings of woody xylem within the enlarged cambium cylinder. There are also two rings of phloem outside. It is evident that before long the old cortex and epidermis will be effaced. Moreover, due to the pressure of the earth, the outer (phloem) tissues are rubbed off. Old phloem decays quickly, so that roots never have very thick *bark*.

B. The Stem

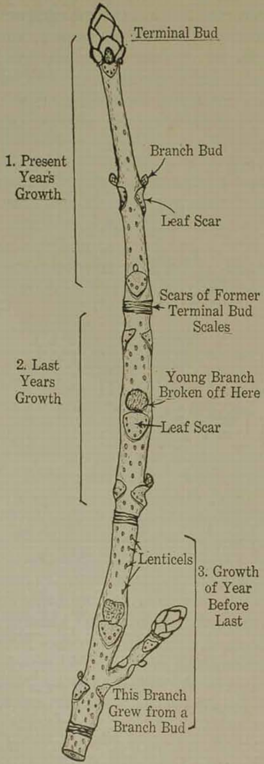


FIG. 85. — Horse-chestnut twig in autumn.

Materials are conducted from the roots to the leaves through the stem, and substances pass from the leaves through the stem to all parts of the plant. The number of leaves is increased to a great extent by the branching habit of the stem. There is a great variety in the form and structure of stems.

A Young Dicotyledon Stem. Fig. 85 is a diagram of the end portion of a *branch* of a horse-chestnut tree taken in autumn after the leaves have fallen. The terminal portion is that part formed during the current summer; the middle portion is two years old and the remaining part is three years old. At the tip end is the terminal bud. Back of it are seen shield-shaped *leaf scars*, indicating places of attachment of former leaves. Just above the scar is a *branch bud*. When the leaf was alive, the branch bud was in between the branch and the leaf petiole, that is, in the *axil* of the leaf. At the junction of the terminal and middle segments are seen scars about the branch. These were left when the bud scales of the terminal bud fell off in the spring of that year. Just back of the middle growth are similar scars marking the position of the terminal bud in the spring of the preceding year. Farther back, due to the growth of the stem in diameter, these indications of the yearly increments in length disappear.[1] The length of the internodes varies from year to year. There may be several reasons for this. One season must have been more favorable for growth than another.

The structure of the tip of a stem is similar in some respects to that of a root tip. There is no root cap, of course, but there is an embryonic region or *meristem* tissue where *cells divide* — thus providing for added growth. Back of these dividing cells is a zone of *elongation, i.e.*, where cells are elongating and assuming their permanent form; farther back is a region where the cells have assumed their permanent length and the stem increases no farther in *length* at that point, but there is an increase in *diameter* from season to season. There is no sharp line of demarcation between these zones.

Buds. At the tip of every branch will be found a bud (Fig. 86) protected by scale leaves. Inside of these at the very tip is a small area of promeristem tissue, where cells retain the power of cell division. Adjacent or lateral to this are a number of other embryonic regions. They will develop stem and leaf structures and also flowers.

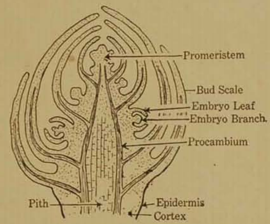


FIG. 86. — Vertical section through a terminal bud.

Stem Formation. The buds are dormant during the winter, but with the return of spring, activities become renewed. There are at least four types of activities:

1. *Cell division* in the meristem region. This will continue all through the summer. 2. *Elongation* of this portion of the stem due to the lengthening of some cells formed by division. 3. *Differentiation* of early similar cells into various tissues which when formed exhibit no further change. 4. Increase in *diameter* of the stem.

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[1] In a casual examination of a certain horse-chestnut tree, one branch showed twenty annual increments of growth by the scars of old terminal bud scales.

These changes take place as the season advances. We may obtain an idea of what occurred during the season by studying sections taken at various levels of the terminal portion of a dicotyledon stem. Only a general account can be presented here (Fig. 87).

1. The tip of the stem is a region of homogeneous tissue where the cells are small, of equal size throughout and undergoing cell division in any plane. This is *promeristem* tissue (Fig. 87 *A*).

2. Behind this — or among older promeristem cells — some become slightly elongated and more densely packed with protoplasm.

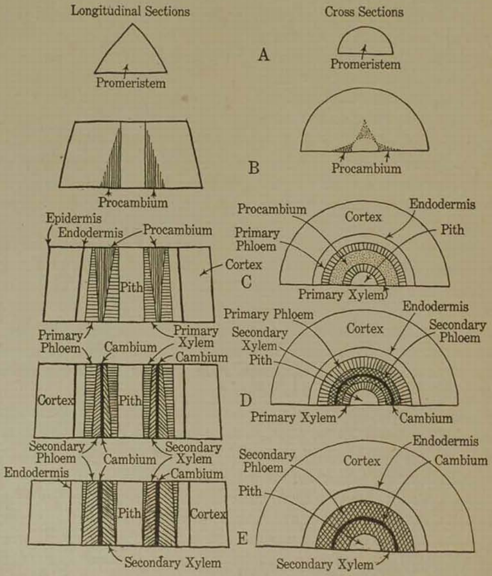

FIG. 87. — Histology of young dicotyledon stem. *A, B, C, D, E*-sections at different levels from the tip; longitudinal sections at left and half cross-sections at the right. Modified from Eames and MacDaniels' *Introduction to Plant Anatomy*, copyright 1925, McGraw-Hill Book Co., reprinted by permission.

These form in groups at regular distances from the center, as shown in diagram, Fig. 87 *B*, which shows the sections of these elongated cells, now called the *procambium.* The clear space is occupied by the promeristem cells.

3. Now the procambium cells at the *inner borders* of the procambium strands, *toward the center,* differentiate into *primary xylem* cells (Fig. 87 *C*). The procambial cells at the *outer border* of the strands, *i.e., toward the surface,* differentiate into *primary phloem* cells.

4. New procambial cells are added to the procambial strands by *differentiation* of promeristem cells, so that an entire ring of procambium is formed. It is really a hollow cylinder (Fig. 87 *C*), considering all three dimensions of the stem. The student should remember that when the word *ring* is used, he should visualize this as a sectional view of a hollow cylinder. In different stems, varying numbers of strands are formed; in some cases the entire ring may appear at once.

5. As the extension of the procambium to form a complete ring continues, the differentiation from procambium to *new xylem* and *new phloem* occurs also, so that three rings now appear: an inner ring of xylem, middle ring of procambium, outer ring of phloem (Fig. 87 *C*).

6. The promeristem cells inside the procambium and its primary xylem now gradually differentiate into *pith,* while those outside the procambium and the primary phloem have become *cortex* covered with one layer of cells, the *epidermis.*

7. The formation of the primary xylem and primary phloem has been at the expense of the procambium. This is finally reduced to a thin layer between the wide primary xylem and phloem (Fig. 87 *D*). The few remaining procambium cells of this layer no longer differentiate directly into xylem and phloem, but remain as *cambium,* and retain the power of cell division by which they will split off cells *within,* to become *secondary xylem,* and split off cells *without* to form *secondary phloem.*

8. At the end of the season (Fig. 87 *E*) the *oldest* portion of the current year's growth of the stem would show:

1. Pith in the center.
2. Vascular cylinder.
    - (*a*) Xylem ring inside — thick.
    - (*b*) Cambium ring between — thin.
    - (*c*) Phloem ring outside — thick.

   (*d*) Parenchyma tissue.
   (*e*) Endodermis.
3. Cortex.
4. Epidermis.

A Study of the Structure of the Two-Year-Old Stem (Fig. 88). The stem remains dormant during the winter. The last xylem cells formed in summer are small and rigid. Now with the spring awakening, the cambium forms large *water-conducting* xylem cells for a time. But as the season advances it forms the narrower, more rigid cells. Of course, cambium also forms phloem cells outside, *i.e.*, on the inner side of old phloem cells, pushing out the latter. The contrast between the small summer xylem cells of one season and the large spring xylem cells of the next season gives the appearance of concentric rings of wood. And in general, the number of wood rings seen in cross-section indicates the age of the tree. These are not always of equal width, which indicates variations in the nature of the seasons, some being favorable to growth, others not. A season of drought in midsummer followed by a warm, wet, late summer might cause two rings to be laid down. Photomicrographs of sections of one-year, two-year and three-year-old linden stems are shown in Fig. 89.

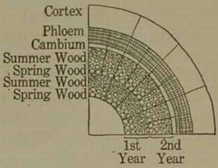

FIG. 88. — Diagram of section of stem two years old.

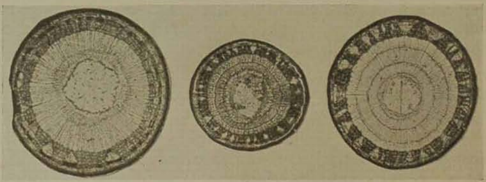

FIG. 89. — Photomicrographs of (left) one-year; (middle) two-year; and (right) three-year-old linden stems. One, two, and three rings of wood (xylem) can be seen. Radiating lines are sections of vascular rays. Phloem is thick dark band outside xylem, and cambium between phloem and adjacent xylem. Triangular-shaped masses in phloem ring are expanded masses of vascular rays with phloem between them. Pith is in center of stem.

Tissues of a Woody Stem. *Epidermis.* This is a single layer of cells protective in nature. The cells may contain chloroplasts and starch may be made. Special cells guard the stomata or air pores. Later the epidermis disappears.

Cortex. This is a zone of parenchyma cells underneath the epidermis. It is later crushed by the increasing phloem inside. Moreover in some stems the epidermal cells or some of the outer cortical cells develop into a special meristem, called the cork cambium. This forms waterproof *corky* cells outside and a few parenchyma-like cells inside of it. Portions outside this cork cambium dry, shrivel up and peel off as seen on the trunk of the cherry or birch. New bark of this sort is constantly formed. In other trees the cork cambium continues to form deeper into the cortex and splits off pieces of ' bark,' and invades the old dead phloem. Thus there is no cortex in older branches, and since pieces are constantly falling off, the bark does not seem to increase in thickness. In many trees as the corky bark replaces epidermis, the cork cambium forms masses of cells *loosely arranged* near old stomata, thus leaving an air passage to the inner tissues. These are called *lenticels* and are characteristic of smooth bark trees like the cherry and birches. (See Fig. 85.)

Phloem. Inside the cortex is the phloem. This consists of sieve tubes (Fig. 90), special cells for the conduction of proteins, fats and carbohydrates in solution down the stem. The ends and lateral walls of these cells are sieve-like. Alongside them are companion cells with cytoplasm and a nucleus. They are thought to control the activity of the sieve tubes. Phloem also contains fibers and phloem parenchyma cells.

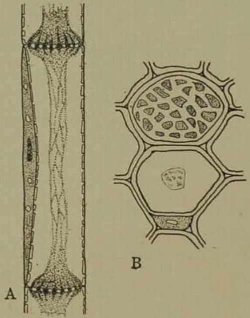

FIG. 90. — *A.* Side view of a sieve tube with slender companion cell on the left. *B.* Sectional view of sieve-tube end (above); through middle of another sieve tube and its companion cell (below). From Sinott, *Botany*, McGraw-Hill Book Co., reprinted by permission.

Cambium. The activity of the cambium has been explained in our study of the root. Cell division in promeristem can take place in any plane. In cambium it is restricted.

Xylem is inside the cambium. It is known as wood. In general it is supporting tissue, but also conducts soil water up the stem. The cell walls of cellulose become hard and rigid, *i.e.*, lignified. Various cells are formed in this tissue (Fig. 91). *First.* Long, slender, thick-walled cells with almost no cavity, becoming wood fibers adapted for rigidity. *Second.* Long wood parenchyma cells. *Third.* Tracheids are long cells whose walls are lignified and pitted. Pits are thin places through which fluids can easily diffuse. *Fourth.* Vessels, the chief water-conducting elements of higher woody stems. Some are short, wide cylinders with lignified pitted walls; drum-shaped and fitted end to end to form long ducts for passage of water. Both tracheids and vessel elements die when mature.

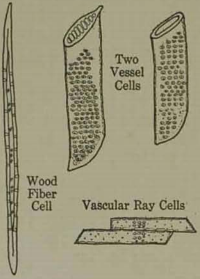

Fig. 91.—Xylem cells. From Sinnott, *Botany*, McGraw-Hill Book Co., reprinted by permission.

Vascular (*wood*) *Rays* (Fig. 91). The cambium also forms vertical and radiating plates of living cells which connect xylem with the phloem, making possible lateral transfer of plant fluids in and out. These have often been called medullary rays, but are now known as vascular rays. They give " quartered oak " its peculiar quality.

Old wood rings are usually dead and do not conduct water and are called *heart wood.* The newer xylem that transports water is called *sap wood.* The number of xylem rings composing sap wood varies in different stems.

Spring wood consists chiefly of water-conducting vessels, while *summer wood* consists chiefly of the more rigid and strengthening elements of wood, such as the fibers.

Monocotyledon Stem. The above account of root and stem structure, involving a cylinder of cambium and annual "rings" of xylem and phloem, applies to dicotyledons. The stem of monocotyledons has a different structure. In the stem of the corn (Fig. 92) there is an outer epidermis, while parenchyma is the ground substance in which are found *scattered* vascular bundles. When examined, *each bundle* (Fig. 93) is seen to consist of a ring of bundle-sheath cells, more numerous toward the peripheral and central borders of the bundle. The xylem consists of a *few large* cells just peripheral to the central bundle-sheath cells. One xylem cell lies in a large space. External to the xylem cells is the phloem composed of sieve tubes and companion cells. Parenchyma cells are also present. Most perennial forms such as the palm and bamboo have no provision for increase in thickness of stem except by the delayed maturing of early formed cells. The principal growth is apical, thus forming long, slender trunks as that of the bamboo.

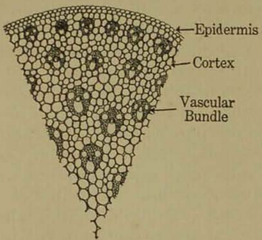

FIG. 92. — Portion of cross-section of corn stem.

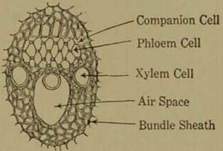

FIG. 93. — Vascular bundle of corn stem.

C. The Leaf

Woody trunks with their extensive branching habit expose a great mass of leaves to the sunlight. Gager has given us a most profound statement concerning the importance of the leaf. "There is no more important fact in botany," he says, "nor indeed in all natural science, than that all the food of the world is primarily manufactured in the chlorophyll-containing cells of the leaf." Someone has estimated that an elm tree of average size possesses about 7,000,000 leaves with a total surface of about five acres, over four hundred times the area of ground occupied by the tree. The leaf habit, first clearly indicated in

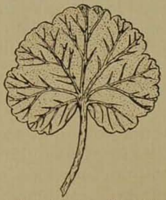

FIG. 94 *A*. — Geranium leaf. At end of leaf stalk or *petiole* is undivided *blade*.

Pteridophytes, is carried to a climax in the great leafy expanse exhibited by trees. A typical leaf has a flat, thin *blade*, where work of vital importance to the plant is carried on. This is supported by a small stem-like structure called the *petiole*. There is great variation in the size, shape and many other characteristics of leaves. For example (Fig. 94 *A*), there may be one single blade in *simple* leaves, or the blade may be divided into a number of small leaflets. Such leaves are called *compound* (Fig. 94 *B*). The leaves of monocotyledons (corn) usually have parallel veins. The leaves of dicotyledons, on the other hand, usually have a network of veins. The petiole is a small stem with vascular bundles. The veins of the leaf are also miniature continuations of stem structure ramifying throughout the leaf, carrying vascular or circulating tissue out to the leaf cells.

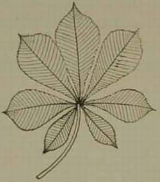

Fig. 94 *B.* — Horse-chestnut leaf. At end of petiole is divided blade.

Figure 95 shows the structure of the leaf. On the upper surface is a row of protective epidermal cells. The lower surface of the leaf is also protected by another layer of similar epidermis. There is no chlorophyll in most cells of the epidermis. Between the two epidermal layers is the *mesophyll*. The cells here are divided into two regions. In the first place, there is a layer of long cells at right angles to the upper surface, the *palisade parenchyma*. Beneath these cells is the *spongy parenchyma*, where the cells are arranged irregularly with air spaces here and there. The cells of the palisade and spongy parenchyma contain chlorophyll bodies. Palisade and spongy parenchyma form the mesophyll. It is in the mesophyll that starch is made.

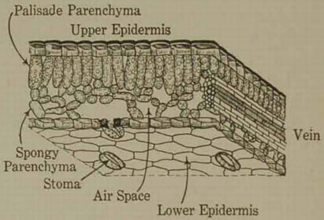

Fig. 95. — Histology of leaf. From Sinnott, *Botany*, Revised Edition, McGraw-Hill Book Co., reprinted by permission.

In the *lower epidermis* are air pores. These are called *stomata,* through which gases can pass in and out and through which water vapor escapes. Each stoma (Fig. 96) is a slit between two special, somewhat crescent-shaped epidermal cells called *guard cells.* Unlike the ordinary epidermal cells, they contain chlorophyll bodies. Scattered in the mesophyll are veins, each being a vascular bundle. Each vein is surrounded by a bundle sheath inclosing xylem and phloem cells. The very smallest veins possess but one or two ducts composed of these cells. The epidermis is coated with a non-cellular, waterproof layer called *cuticle.* This is thicker in some leaves than in others. It has been claimed that the difference in thickness of leaves is due chiefly to the variations in thickness of epidermis and not of the mesophyll, which in all leaves is more constant.

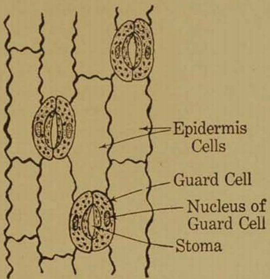

Fig. 96. — Stomata of leaf.

(Selected References at end of Chapter VII.)