Plants: Roots, Stems and Leaves

Unlike animals, plants only have 3 organs, the **roots**, the **stems** and the **leaves**. Stems and leaves together form the **shoot** of a plant. These 3 organs, elaborated in different ways, make up everything that you find on a plant, whether it's the trunk of a tree, the pitcher of a pitcher plant, or the spines of a bouganvillea. Because there are only 3 organs, these are often highly modified or altered in appearance between different plants or even on the same plant. One aspect of understanding plants is to be able to figure out what is root, stem, and leaf.

Roots, stems, and leaves are produced by the activity of **apical meristems**. Apical meristems are at the tips (or apices) of plant parts. The shoot apical meristem is at the tip of the shoot, while the root apical meristem is at the tip of the root. The cells of the meristem divide actively; some cells stay to maintain the meristem, while other cells **differentiate**. In the shoot apical meristem, the differentiating cells produce the stem and the leaves, which are lateral outgrowths on the stem. The presence of leaves along the stem divides the stem into **nodes**, where the leaves are attached, and **internodes**, the part of the stem between the nodes (Figure 1).

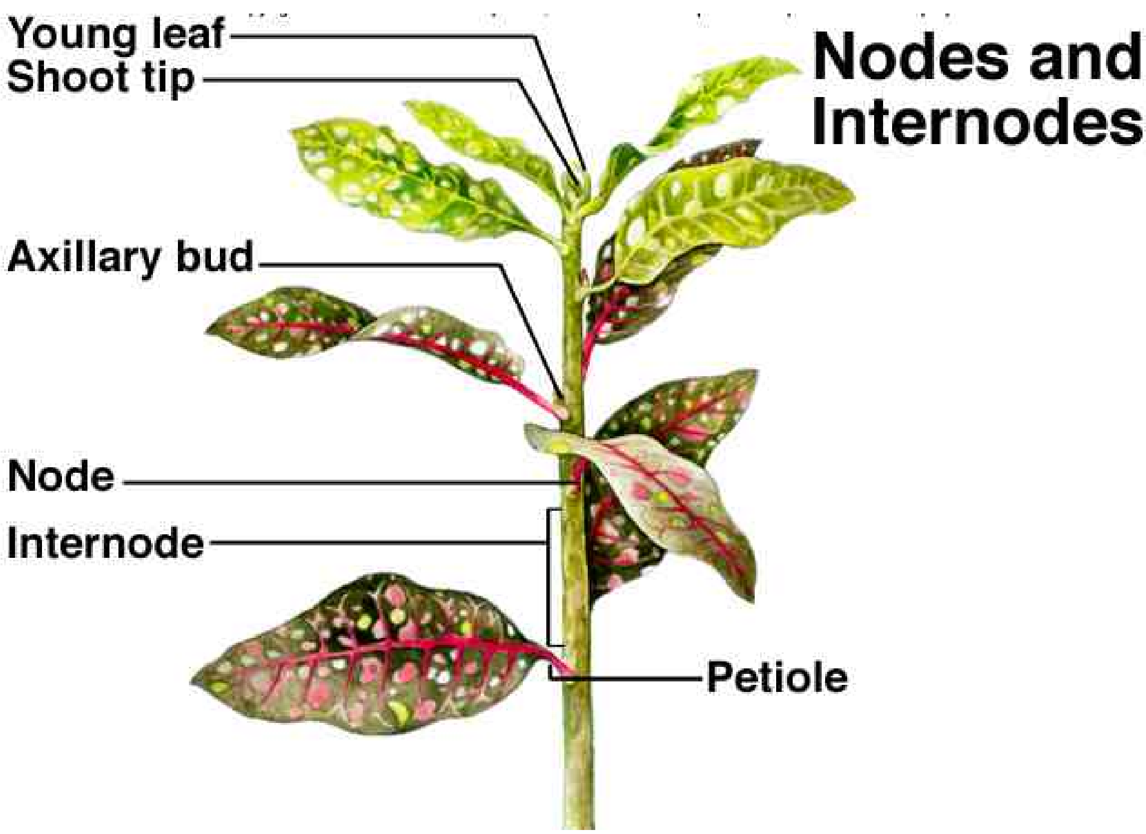


Figure 1. Shoot structure.

Leaves differ from stems in not having an apical meristem, so leaves are **determinate** (i.e., limited in their growth), while stems are **indeterminate** (theoretically capable of growing forever). In the root apical meristem, the differentiating cells produce the **root cap**, a structure that protects the root apical meristem as it pushes its way through the soil, and the root body, which is the part of the root that we see. Thus, the apical meristems of the root and shoot differ in their structure—the root apical meristem is internal, surrounded by cells on all sides, whereas the shoot apical meristem is external and not covered by cells. You usually need to look at sections of plants under the compound microscope to see these differences, but on some plants, such as the aerial roots of aroids (members of the plant family Araceae), you can clearly see the root cap of the prop roots before they enter the ground. Examine plants on campus, identifying roots, stems, leaves, apical meristems and axillary buds.

Both roots and shoots can branch. The branches form more roots, if they are root branches, and more shoots, if they are shoot branches. Root branches are produced inside the root itself, breaking out through the root, while shoot branches form from axillary buds. **Axillary buds** are produced in the upper angle between the leaf and the stem, which is called the **axil** of the leaf (Figure 1).

Leaves are produced in a very organized manner at the shoot apex. This results in a predictable arrangement of the mature leaves on the stem. This arrangement is called the **phyllotaxis** of the leaf. Common patterns are for the plant to produce 1 leaf at a time at the apex, resulting in an **alternate** phyllotaxis. Sometimes two leaves are produced at a time at the apex, with successive leaf pairs at 90^{o} from each other. This is an **opposite** phyllotaxis. If more than twp leaves are produced at a time, the phyllotaxis is **whorled**, but this is a much more rare occurrence. See the examples in Figure 4.

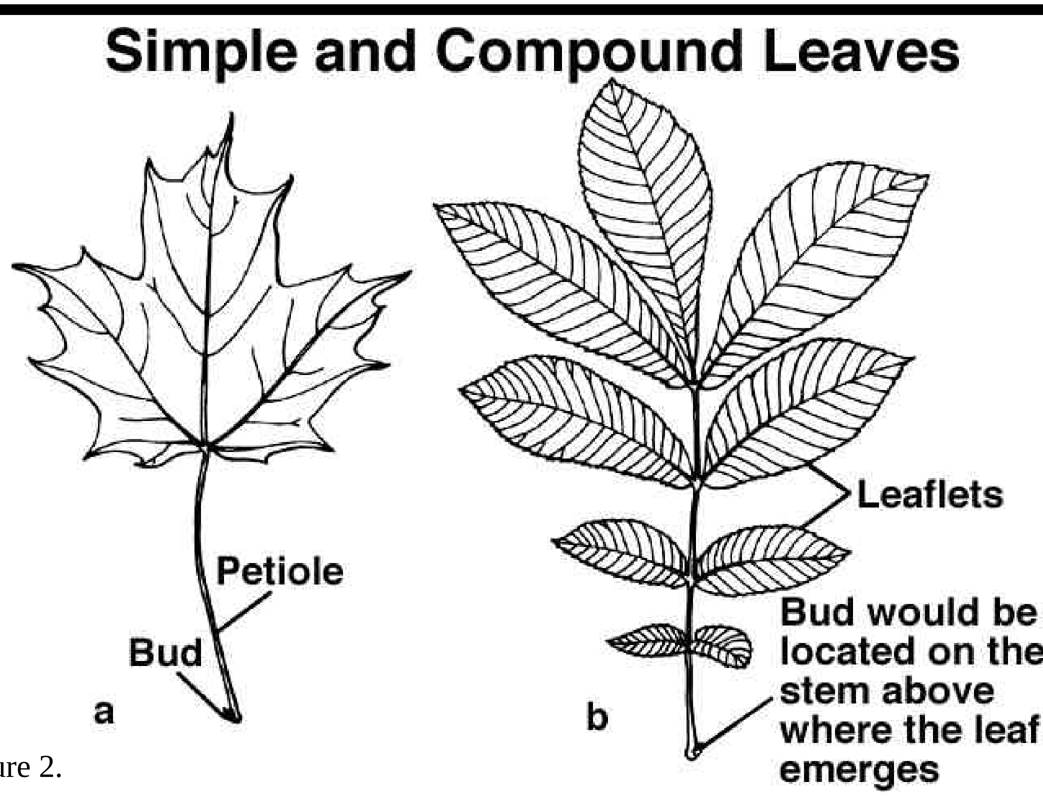


Figure 2.

The basic parts of the leaf are a leaf base, which is the region where the leaf attaches to the stem, and the leaf blade or **lamina**, which is the freely projecting part of the leaf (Figure 2). The leaf may also have a **petiole** or stalk that supports the lamina (Figure 2). The leaf base can be inconspicuous, as in many trees, or very elongated, as in palms. The shapes of leaves vary enormously both along a single plant and among plants. Leaves can be simple or compound (Figure 2). **Simple leaves** are undivided, whereas compound leaves are subdivided into leaflets or pinnae. Simple leaves can have smooth margins or be toothed or lobed. **Compound** leaves can have the pinnae attached in a single region, so the leaflets are arranged like the fingers on your hand (**palmately compound**). Alternatively, the leaflets can be distributed along the leaf **midrib** or **rachis**, producing a **pinnately compound** leaf. Being able to see these differences in leaf shape and arrangement are fundamental to being able to tell one plant from another, i.e., to identifying plants. See the examples in Fig. 4. Compound leaves can be further subdivided, i.e., the leaflets are themselves compound. A leaf that is subdivided once is once-compound, while leaves whose pinnae are subdivided are twice-compound. Some species are 3 or 4 times compound. In these more complex cases, it is important to find the axillary buds, in order to understand which part is the leaf and which part is just a leaflet.

In many plants the roots form at 180^{o} from the shoot, producing a separate root system. It is also common, however, for roots to be produced on the stem, especially when the stem is growing horizontally. These shoot-borne roots are called **adventitious roots** (Figure

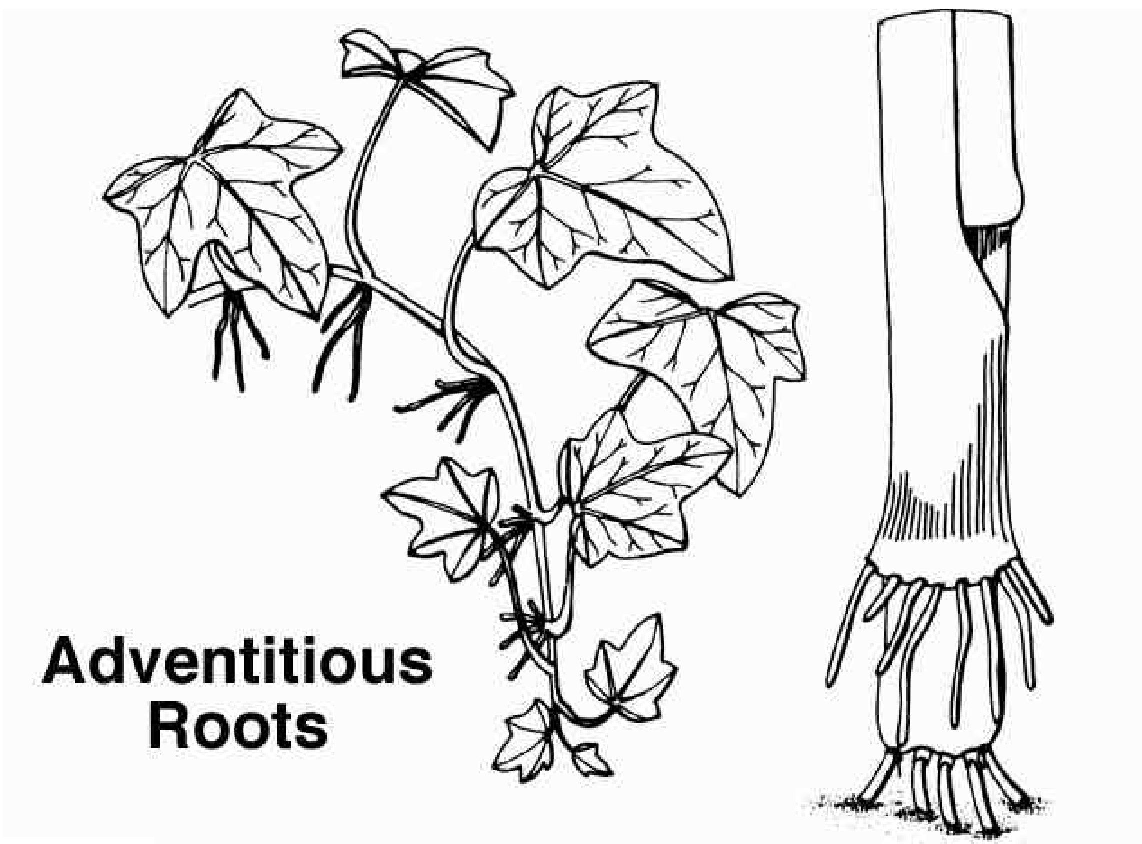


Figure 3.

3).

Flowers, and the fruits and seeds that develop from them, are modifications of stems and leaves. A flower is equivalent to a stem bearing leaves. The innermost leaves (stamens and carpels) are highly modified and bear the reproductive parts of the plant.

One way to begin to analyze what's what on a plant is to consider where different parts fit into the overall ground plan of the plant. For example, a thorn that is lateral to another structure (the stem) and has a third structure in its axil (the axillary bud) is in the right position to be equivalent to a leaf.

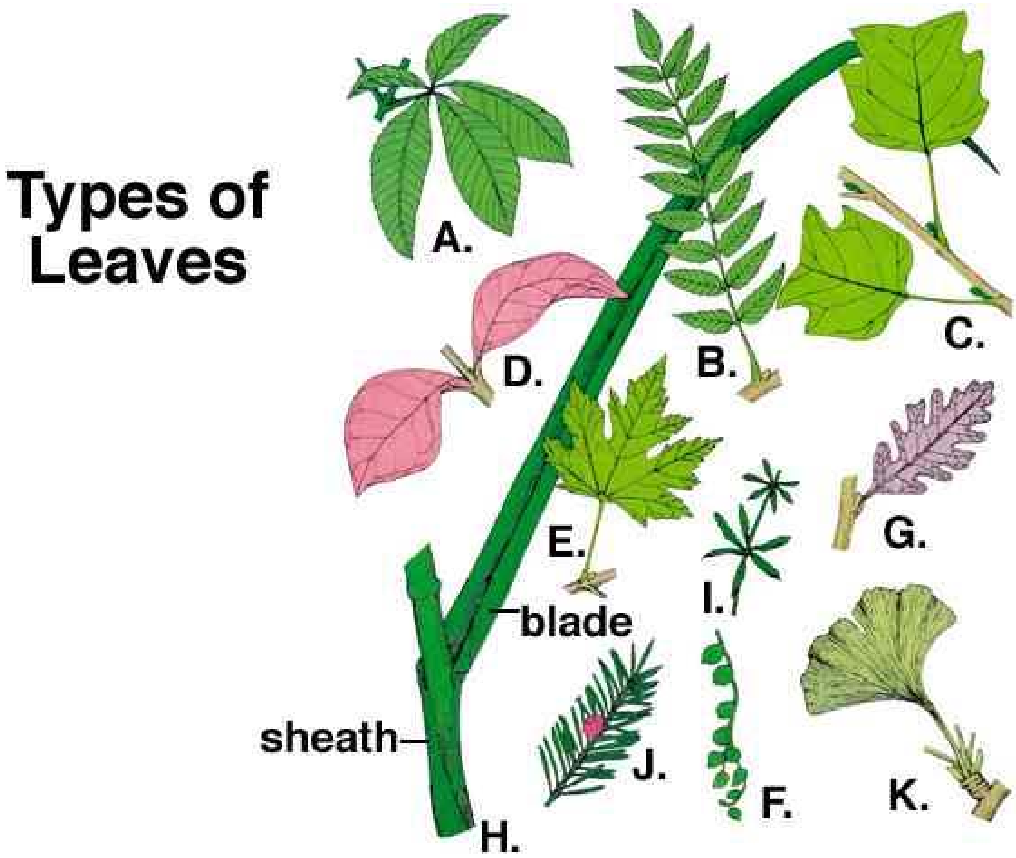
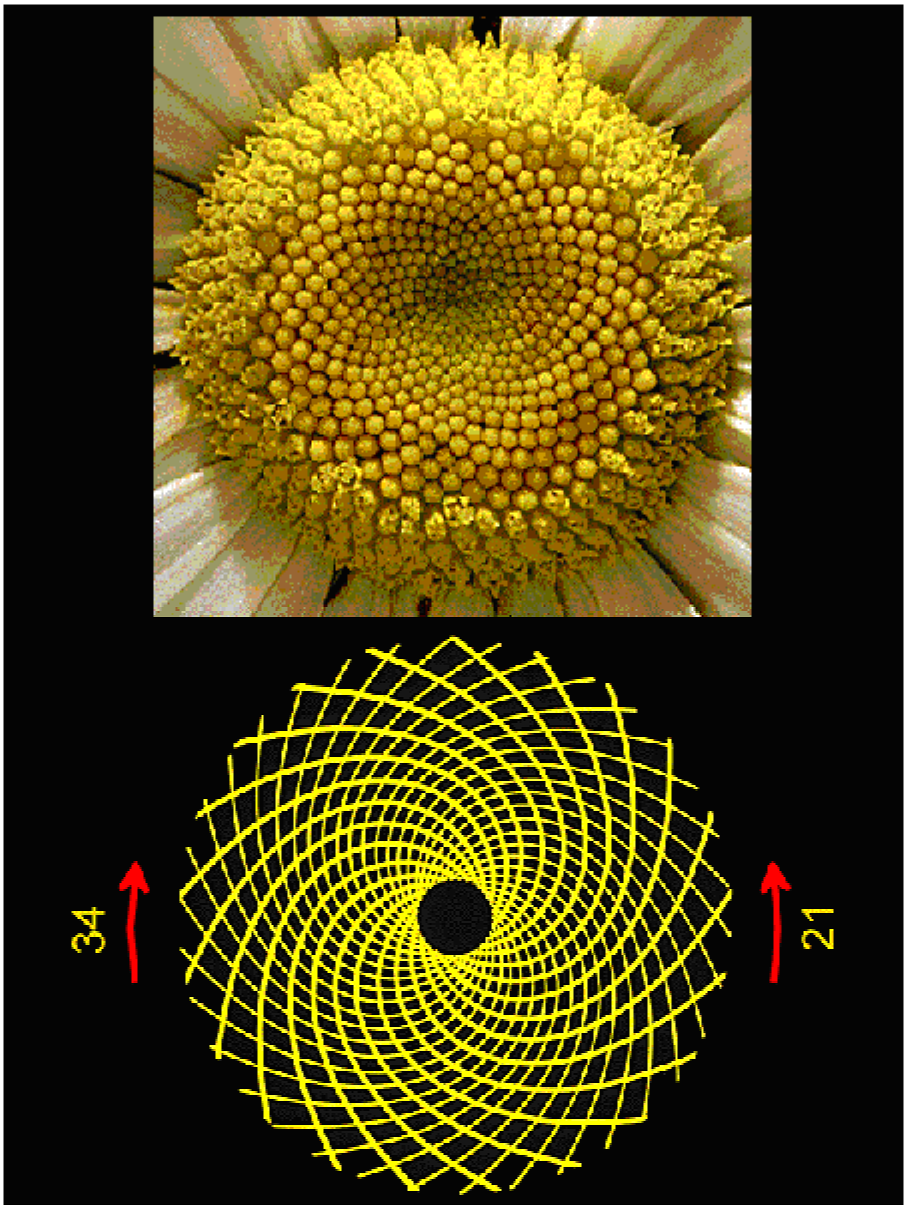


Figure 4. A = palmately compound leaf, opposite leaf arrangement; B = pinnately compound leaf, alternate leaf arrangement; C = simple, lobed, petiolate leaves, alternate leaf arrangement; D = simple leaves, opposite leaf arrangement; E = simple, lobed and toothed, petiolate leaf, opposite leaf arrangement; F = simple leaves, alternate leaf arrangement; G = simple lobed leaf, alternate leaf arrangement; H = simple linear leaf with sheathing leaf base, alternate leaf arrangement; I = simple leaves, whorled leaf arrangement; J = simple needlelike leaves, alternate leaf arrangement; K = simple bilobed leaf, alternate leaf arrangement.

Tasks: Identify leaf, stem (node and internode), and, if possible, roots, on three plants on campus. Determine the phyllotaxis (i.e., arrangement) of the leaves. Then decide whether the leaves are simple or compound, and if they are compound, whether they are pinnately or palmately compound and how many times compound. Once you have completed this practice, look at the plant with a modified organ (tendril or thorns) that your TA supplies. Based on its position in the general ground plan of the plant, what organ do you think this modification is?

Phyllotaxis and Fibonacci Numbers

Interestingly, alternate phyllotaxis of plant parts is often associated with spiral patterns. These patterns can be easily observed in the arrangements of sunflower seeds in a sunflower head, florets of daisys, scales of pinecones, and segments of pineapples. In these patterns, two types of spirals are apparent to the eye: clockwise spirals and counterclockwise spirals. Surprisingly, the number of spirals in each direction are usually adjacent numbers in the Fibonacci sequence of mathematics. The Fibonacci sequence has the following form: 1, 1, 2, 3, 5, 8, 13,... where each succeeding number is the sum of the two before it. This remarkable connection between botany and mathematics has been studied by botanists, mathematicians, and physicists for over 100 years.



reproduced from: http://ccins.camosun.bc.ca/~jbritton/fibslide/fib31.gif

Wood

Wood is secondary xylem. **Xylem** is the plant tissue that conducts water and mineral nutrients. The conducting cells of xylem (tracheids and vessels), which are dead at maturity, have secondary cell walls with **lignin** in addition to **cellulose** (the main component of primary cell walls). Lignin is a complex polymer that is strong and resists decay. Some wood also has lots of **fibers**, which don't conduct but have VERY thick, lignified, secondary cell walls. These cells provide additional strength to wood.

Secondary xylem is produced by a meristem that is on the sides of the stem or root, so it is called a **lateral meristem**. These completely surround the stem or root. Not all plants have lateral meristems. For example, most monocots, such as palms, grasses, and orchids, do not. The primary meristems are the apical meristems. They cause the plant to lengthen, while the lateral meristems cause the plant to increase in width (Figure 5). There are 2 lateral meristems. The lateral meristem producing wood is the vascular cambium; the other lateral meristem makes the outer part of the bark, called cork.

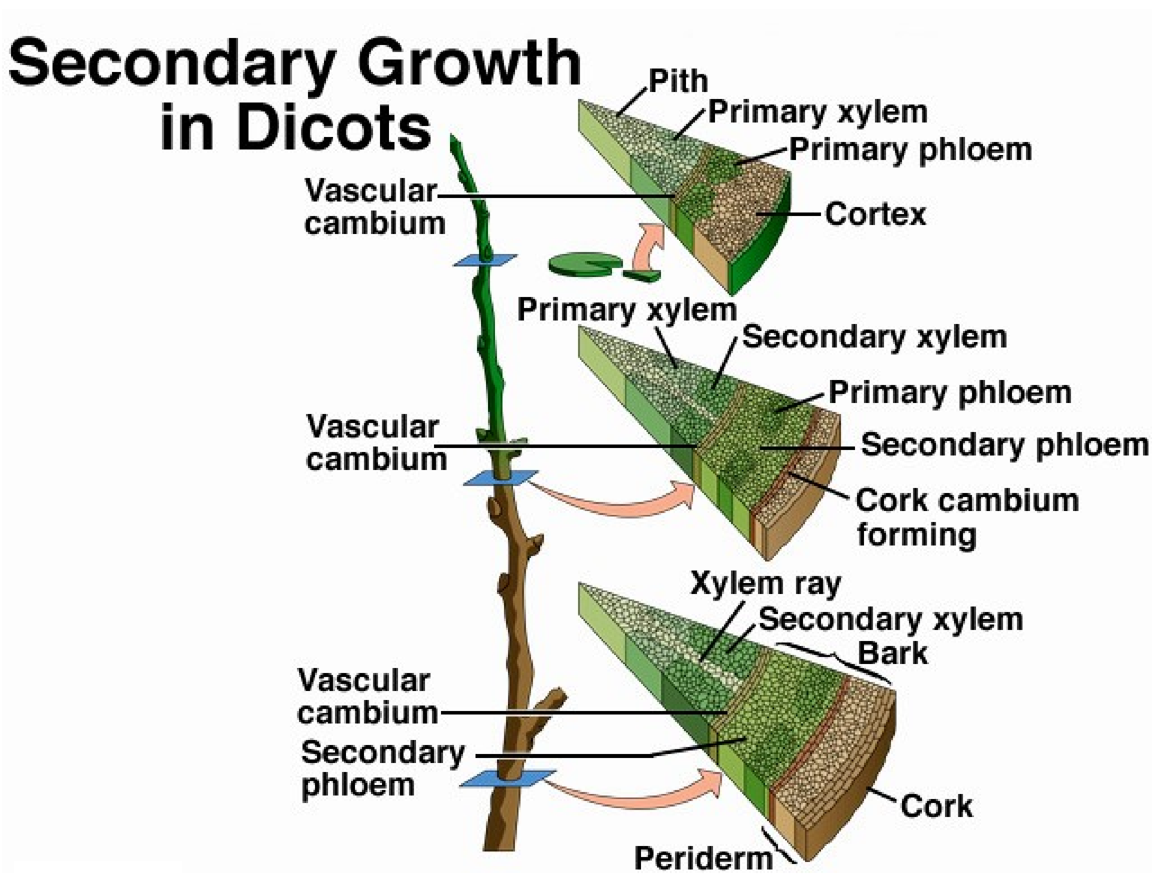


Figure 5.

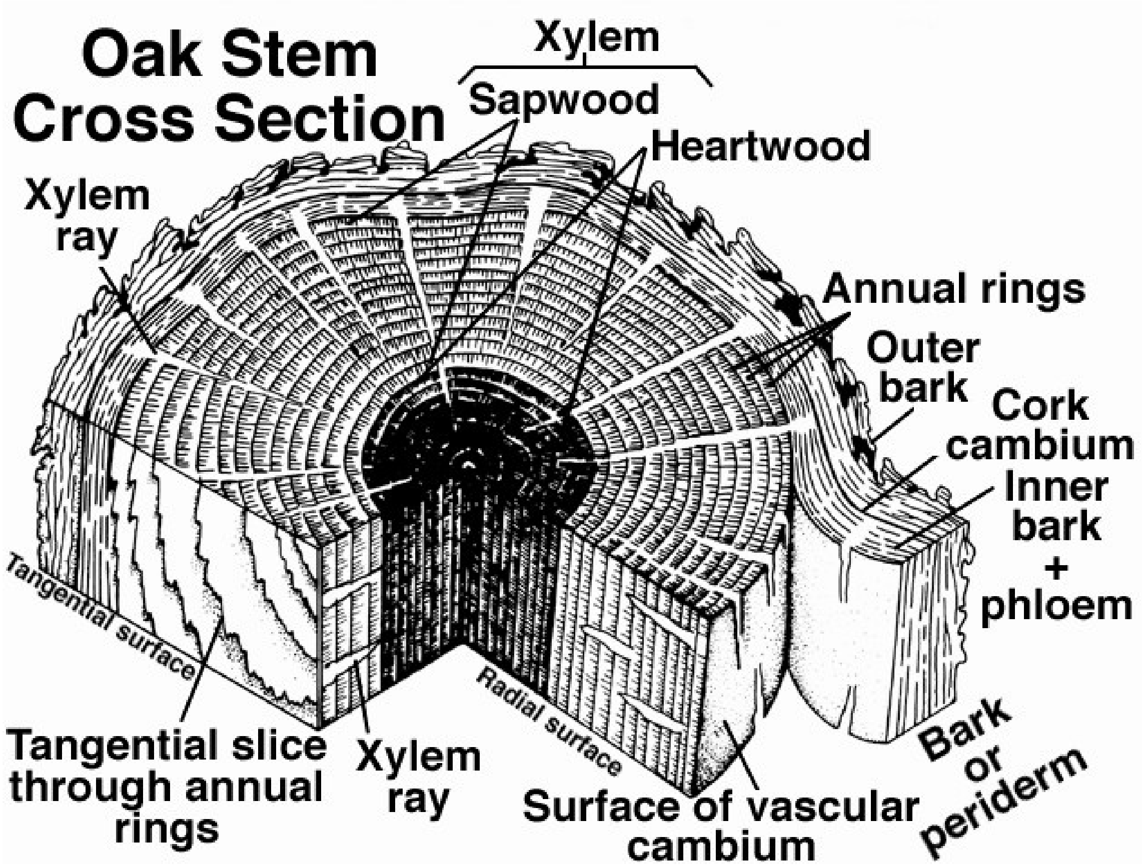


Figure 6.

The **vascular cambium** produces xylem cells to its interior and phloem, or carbohydrate-conducting cells, to its exterior (Figure 6). The phloem does not have many lignified cells, and because it is to the outside of the growing xylem and vascular cambium, it is continually crushed by their growth. Thus, the secondary phloem is not persistent, becoming part of the bark. The secondary xylem, however, can last for many years, with the rest of the plant growing like a skin outside of it.

In addition to conducting cells and fibers, the wood can have **parenchyma** cells, which are living cells. It can also have other specialized cells, such as ones that make resin in pine trees. Most of the cells of wood are elongated parallel to the direction of growth. Some cells, however, run radially, making up the rays of the wood. When you cut a piece of wood, it looks very different, depending on the orientation of the cut. If you cut a cross-section or transection, you look down on the ends of the elongated cells. If you make a longitudinal cut along a radius, you parallel the rays and can see the length of the elongated cells. If you make a longitudinal cut tangential to the stem, you see the elongated cells, but you also look end-on at the rays (Figure 5). The arrangement and types of cells in wood define its grain. Different species have different grains. Two major differences are **softwoods**, which come from conifers, and **hardwoods**, which come from angiosperms. The wood of softwoods has **tracheids** but no fibers or vessels and little parenchyma, except in the rays. The wood of hardwoods has tracheids, **vessels**, parenchyma and fibers. Thus, softwoods have a very homogeneous look to the wood, whereas hardwoods have a more heterogeneous look.

In very seasonal climates, such as temperate regions or tropical wet-dry forests, the vascular cambium goes dormant for part of the year. The conducting elements produced as the cambium goes dormant are usually smaller than those produced when the cambium comes out of dormancy. We see this difference as a "ring" in the wood. Where the seasonality of the environment is annual, these rings can be used to age wood by counting the number of annual rings. Many tropical trees, however, produce more than 1 such ring a year, so aging tropical woods can be more difficult.

Roots, like stems, can have secondary growth. A carrot gets large because of secondary growth, as does a sweet potato. These root tubers have been selected to increase the amount of parenchyma, which stores starch, and decrease the lignin content in their secondary growth.