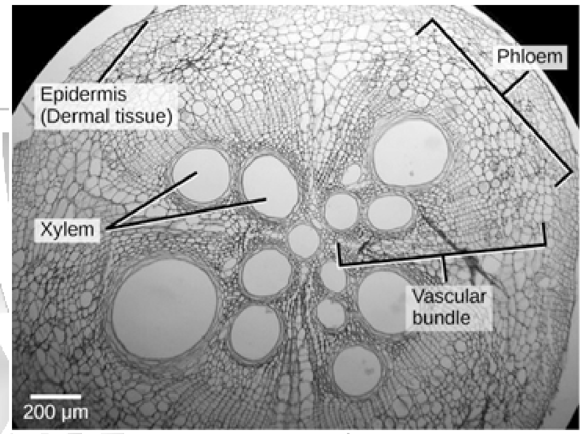
Plants are made up of meristematic and permanent tissues and are supported by shoot and root organ systems.

PLANT TISSUES

Plants are multicellular eukaryotes with tissue systems made of various cell types that carry out specific functions. Plant tissue systems fall into one of two general types: meristematic tissue and permanent (or non-meristematic) tissue. Cells of the meristematic tissue are found in meristems, which are plant regions of continuous cell division and growth. Meristematic tissue cells are either undifferentiated or incompletely differentiated; they continue to divide and contribute to the growth of the plant. In contrast, permanent tissue consists of plant cells that are no longer actively dividing. Meristematic tissues consist of three types, based on their location in the plant. Apical meristems contain meristematic tissue located at the tips of stems and roots, which enable a plant to extend in length. Lateral meristems facilitate growth in thickness or girth in a maturing plant. Intercalary meristems occur only in monocots at the bases of leaf blades and at nodes (the areas where leaves attach to a stem). This tissue enables the monocot leaf blade to increase in length from the leaf base; for example, it allows lawn grass leaves to elongate even after repeated mowing. Meristems produce cells that quickly differentiate, or specialize, and become permanent tissue. Such cells take on specific roles and lose their ability to divide further. They differentiate into three main types: dermal, vascular, and ground tissue. Dermal tissue covers and protects the plant. Vascular tissue transports water, minerals, and sugars to different parts of the plant. Ground tissue serves as a site for photosynthesis, provides a supporting matrix for the vascular tissue, and helps to store water and sugars.

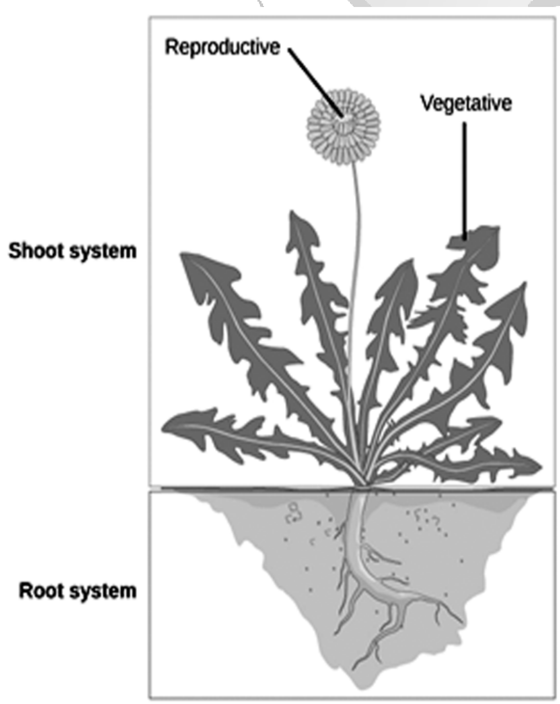


Cross section of a squash stem showing a vascular bundle

Plant tissues are either simple (composed of similar cell types) or complex (composed of different cell types). Dermal tissue, for example, is a simple tissue that covers the outer surface of the plant and controls gas exchange. Vascular tissue is an example of a complex tissue. It is made of two specialized conducting tissues: xylem and phloem. Xylem tissue transports water and nutrients from the roots to different parts of the plant. It includes three different cell types: vessel elements and tracheids (both of which conduct water) and xylem parenchyma. Phloem tissue, which transports organic compounds from the site of photosynthesis to other parts of the plant, consists of four different cell types: sieve cells (which conduct photosynthates), companion cells, phloem parenchyma, and phloem fibers. Unlike xylem-conducting cells, phloem-conducting cells are alive at maturity. The xylem and phloem always lie adjacent to each other. In stems, the xylem and the phloem form a structure called a vascular bundle ; in roots, this is termed the vascular stele or vascular cylinder.

PLANT ORGAN SYSTEMS

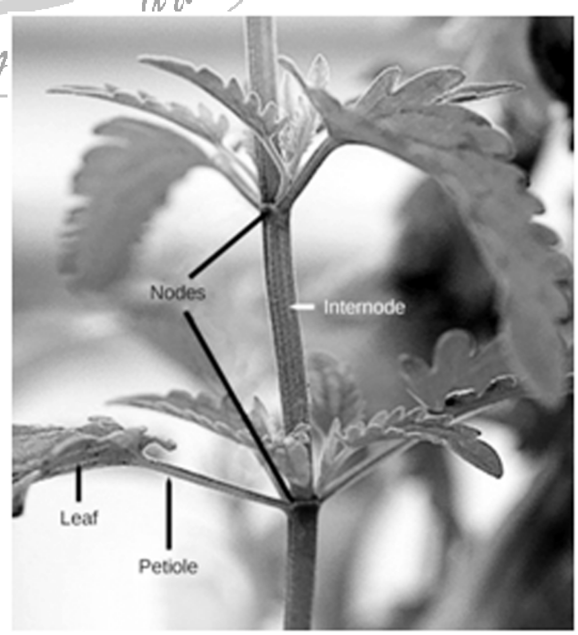
In plants, just as in animals, similar cells working together form a tissue. When different types of tissues work together to perform a unique function, they form an organ; organs working together form organ systems. Vascular plants have two distinct organ systems: a shoot system and a root system . The shoot system consists of two portions: the vegetative (non-reproductive) parts of the plant, such as the leaves and the stems; and the reproductive parts of the plant, which include flowers and fruits. The shoot system generally grows above ground, where it absorbs the light needed for photosynthesis. The root system, which supports the plants and absorbs water and minerals, is usually underground.



Example plant organ systems

Stems

A stem connects the roots to the leaves, provides support, stores food, and holds the leaves, flowers, and buds. Stems are a part of the shoot system of a plant. They may range in length from a few millimeters to hundreds of meters. They also vary in diameter, depending on the plant type. Stems are usually above ground, although the stems of some plants, such as the potato, also grow underground. Stems may be herbaceous (soft) or woody in nature. Their main function is to provide support to the plant, holding leaves, flowers, and buds; in some cases, stems also store food for the plant. A stem may be unbranched, like that of a palm tree, or it may be highly branched, like that of a magnolia tree. The stem of the plant connects the roots to the leaves, helping to transport absorbed water and minerals to different parts of the plant. The stem also helps to transport the products of photosynthesis (i.e., sugars) from the leaves to the rest of the plant. Plant stems, whether above or below ground, are characterized by the presence of nodes and internodes . Nodes are points of attachment



Parts of a stem

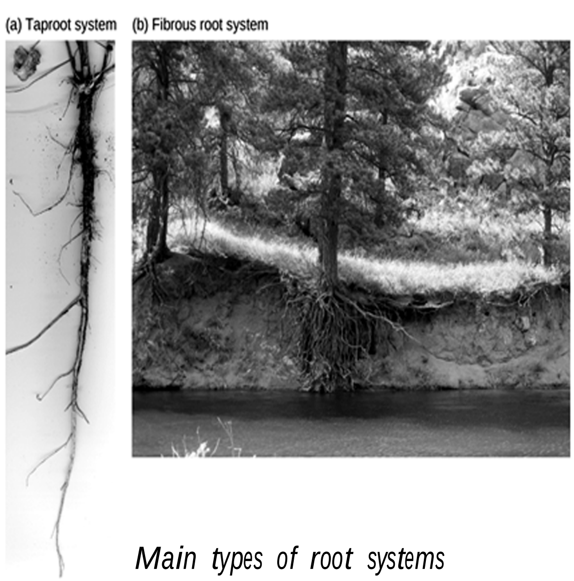
for leaves, aerial roots, and flowers. The stem region between two nodes is called an internode. The stalk that extends from the stem to the base of the leaf is the petiole. An axillary bud is usually found in the axil (the area between the base of a leaf and the stem) where it can give rise to a branch or a flower. The apex (tip) of the shoot contains the apical meristem within the apical bud.

Types of Root Systems and Root Growth and Anatomy

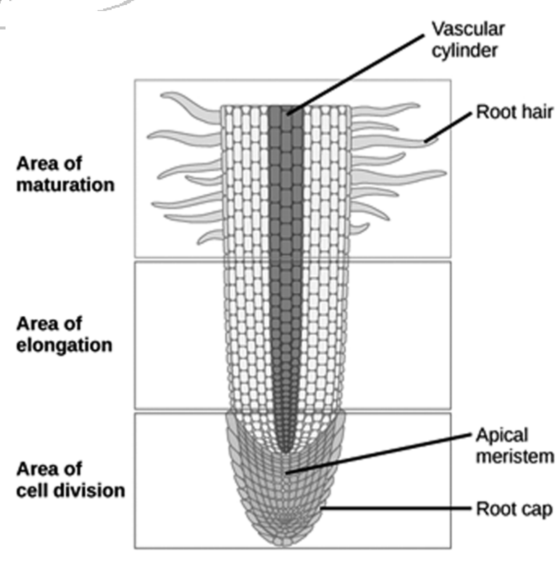
The root tip has three main zones: a zone of cell division, a zone of elongation, and a zone of maturation. There are two main types of root systems . Dicots have a tap root system, while monocots have a fibrous root system, which is also known as an adventitious root system. A tap root system has a main root that grows down vertically, from which many smaller lateral roots arise. Dandelions are a common example; their tap roots usually break off when these weeds are pulled from the ground; they can regrow another shoot from the remaining root. A tap root system penetrates deep into the soil. In contrast, a fibrous root system is located closer to the soil surface where it forms a dense network of roots that also helps prevent soil erosion (lawn grasses are a good example, as are wheat, rice, and corn). Some plants have a combination of tap roots and fibrous roots. Plants that grow in dry areas often have deep root systems, whereas plants that grow in areas with abundant water are likely to have shallower root systems.

ZONES OF THE ROOT TIP

Root growth begins with seed germination. When the plant embryo emerges from the seed, the radicle of the embryo forms the root system. The tip of the root is protected by the root cap, a structure exclusive to roots and unlike any other plant structure. The root cap is continuously replaced because it is easily damaged as the root pushes through soil. The root tip can be divided into three zones: a zone of cell division, a zone of elongation, and a zone of maturation . The zone of cell division is closest to the root tip and is made up of the actively-dividing cells of the root meristem, which contains the undifferentiated cells of the germinating plant. The zone of elongation is where the newly-formed cells increase in length, thereby lengthening the root. Beginning at the first root hair is the zone



Main types of root systems



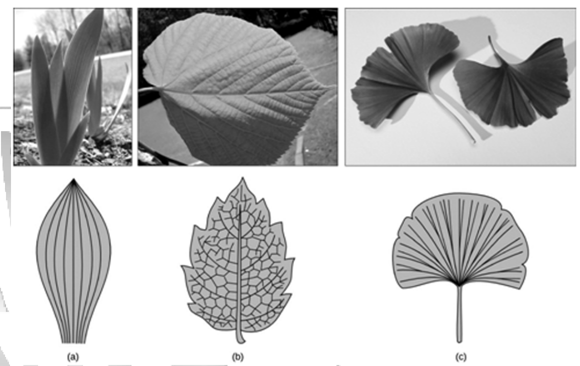
Zones of a Root Tip

of cell maturation where the root cells differentiate into specialized cell types. All three zones are in approximately the first centimeter of the root tip.

Structure of a Typical Leaf and Leaf Arrangement

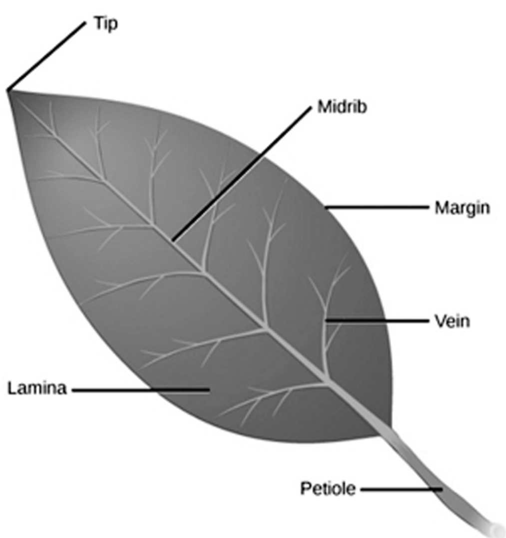
Most leaves have similar essential structures, but differ in venation patterns and leaf arrangement (or phyllotaxy).Each leaf typically has a leaf blade called the lamina, which is also the widest part of the leaf. Some leaves are attached to the plant stem by a petiole. Leaves that do not have a petiole and are directly attached to the plant stem are called sessile leaves. Leaves also have stipules, small green appendages usually found at the base of the petiole. Most leaves have a midrib, which travels the length of the leaf and branches to each side to produce veins of vascular tissue. The edge of the leaf is called the margin . A leaf may seem simple in appearance, but it is a highly efficient structure. Petioles, stipules, veins, and a midrib are all essential structures of a leaf.

Within each leaf, the vascular tissue forms veins. The arrangement of veins in a leaf is called the venation pattern. Monocots and dicots differ in their patterns of venation . Monocots have parallel venation in which the veins run in straight lines across the length of the leaf without converging. In dicots, however, the veins of the leaf have a net-like appearance, forming a pattern known as reticulate venation. Ginkgo biloba is an example of a plant with dichotomous venation.



Venation patterns

(a) Tulip (*Tulipa*), a monocot, has leaves with parallel venation. (b) The netlike venation in this linden (*Tilia cordata*) leaf distinguishes it as a dicot. (c) The Ginkgo biloba tree has dichotomous venation.



Parts of a Leaf

Leaf Arrangement

The arrangement of leaves on a stem is known as phyllotaxy. The number and placement of a plant's leaves will vary depending on the species, with each species exhibiting a characteristic leaf arrangement. Leaves are classified as either alternate, spiral, opposite, or whorled. Plants that have only one leaf per node have leaves that are said to be either alternate or spiral. Alternate leaves alternate on each side of the stem in a flat plane, and spiral leaves are arranged in a spiral along the stem. In an opposite leaf arrangement, two leaves arise at the same point, with the leaves connecting opposite each other along the branch. If there are three or more leaves connected at a node, the leaf arrangement is classified as whorled.

DEFENSE RESPONSES AGAINST HERBIVORES

Plants defend against herbivores with mechanical wounding, barriers, secondary metabolites, and attraction of parasitoids. Herbivores, both large and small, use plants as food and actively chew them. Plants have developed a variety of strategies to discourage or kill attackers.

Mechanical Defenses

The first line of defense in plants is an intact and impenetrable barrier composed of bark and a waxy cuticle. Both protect plants against herbivores. Other adaptations against herbivores include hard shells, thorns (modified branches), and spines (modified leaves) . They discourage animals by causing physical damage or by inducing rashes and allergic reactions. Some Acacia tree species have developed mutualistic relationships with ant colonies: they offer the ants shelter in their hollow thorns in exchange for the ants' defense of the tree's leaves .

Modified Leaves on a cactus

The spines on cactus plants are modified leaves that act as a mechanical defense against predators.

Chemical Defenses

A plant's exterior protection can be compromised by mechanical damage, which may provide an entry point for pathogens. If the first line of defense is breached, the plant must resort to a different set of defense mechanisms, such as toxins and enzymes. Secondary metabolites are compounds that are not directly derived from photosynthesis and are not necessary for respiration or plant growth and development. Many metabolites are toxic and can even be lethal to animals that ingest them. Some metabolites are alkaloids, which discourage predators with noxious odors (such as the volatile oils of mint and sage) or repellent tastes (like the bitterness of quinine). Other alkaloids affect herbivores by causing either excessive stimulation (caffeine is one example) or the lethargy associated with opioids. Some compounds become toxic after ingestion; for instance, glycol cyanide in the cassava root releases cyanide only upon ingestion by the herbivore. Foxgloves produce several deadly chemicals, namely cardiac and steroidal glycosides . Ingestion can cause nausea, vomiting, hallucinations, convulsions, or death.

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