The Plant World

The History and Physiology

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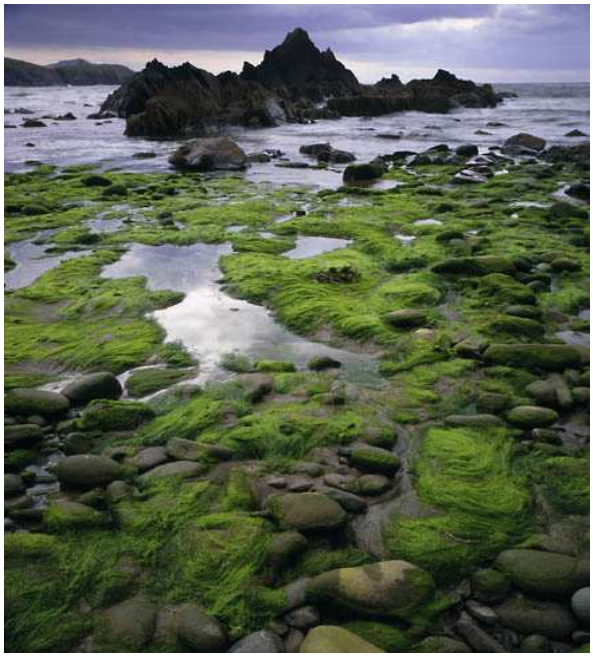
Chapter 1: Evolution of Land Plants

Among the first plants were water dwelling algae. Two types of algae, red and green, first appeared in the Proterozoic over 1 billion years ago. Algae belong to the Kingdom Protista which means they are eukaryotic, and have cell walls of cellulose. All plants or organized into groups like this, it is called taxonomy. Most algae are unicellular but some can be multicellular. They are also different from protozoa, another group of organisms classified under the Kingdom Protista in that algae produce their food through a process called photosynthesis. Plants that produce their own food are called autotrophs. The reproductive process of algae was very simple. The algae just release egg and sperm into the ocean where they meet. They form structures called zoospores which float around to find new places to live. Since every cell is able to stay in contact with the ocean, water and other important nutrients could be absorbed directly through the cell wall.

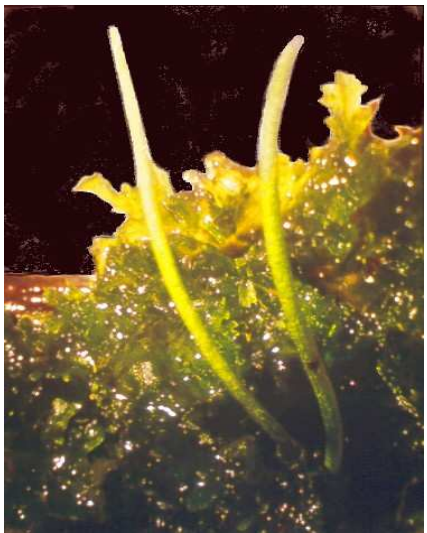


Scientists believe that green algae are the ancestors to land plants. This is because both green algae and land plants contain chloroplasts, have cell walls made of cellulose, and store food and starches.

When algae would wash up onto land, drying winds and temperature changes often killed most of them. But after millions of years, algae were able to live on for short periods of time. These algae lived on to become the ancestors of land plants.

Next in the evolutionary timeline are lichens (right) and mosses. They live on land and are part of the fungus kingdom. They are formed with a bond between algae and fungi. The fungus part of this relationship provides the protection while the algae make food with their chloroplasts. The structure that the fungus creates to house both organisms is called a thallus. Only certain types of alga and fungi can get together. Therefore, every lichen has a unique thallus. They often are found living on rocks. Since lichens have no roots, they can absorb water from rain water or from moisture in the air and provide food for animals and sometimes humans.

Along with lichens, mosses, liverworts (right), and hornworts (below) were some of the first plants to live on land. Unlike lichens, these land dwellers are part of the Kingdom Plantae. They are all bryophyta due to their lack of vascular tissue which causes them to grow very close to the ground. Bryophytes are multicellular and contain rhizoids which are long thin cells that hold the bryophytes in place. Rhizoids also help absorb water and minerals from the ground which is then moved around by osmosis. Rhizoids are NOT true roots. They reproduce through means of alternation of generations which will be discussed later. Bryophytes are also one of the first examples of an organism with specialized cells. Specialization is when different cells have different jobs in the organisms. For example, some cells in mosses may be responsible for absorption of



water while others are responsible for photosynthesis. Specialization is also called differentiation.

Hornworts are a strange group of bryophytes. After fertilization occurs, the growing sporophyte will become long and start to resemble small green horns. Also, unlike liverworts and mosses, the sporophyte of the hornwort can undergo photosynthesis.

Mosses (left); along with the two other bryophyta have structures called cuticles. The cuticle is a water resistant cover over the epidermis. The liverwort is the only land dweller without a stoma, an opening in the lower epidermis which regulates gas exchange for photosynthesis and help release water in the form of vapor, but they do have pores on their surface.

Ferns were some of the first plants that had vascular tissue. This is why they are able to grow much higher than the bryophytes. Ferns are classified as Tracheophyta. Although some ferns still have rhizoids, they also have true roots which help them grow into large plants. Some ferns can grow up to 20 feet! If you look on the backside of a fern you will see small black spots. These are sporangia or spore cases. Although ferns are much evolved from earlier plants, they still reproduce through alternation of generations and do not have seeds. Water is necessary for the reproduction of ferns. The reproduction of these plants will be looked at in detail later on. Ferns grow all over the world. They live in rainforests, deserts, and arctic conditions. Generally, ferns like a humid, shady environment.

A close relative to the fern is the horsetail.
This plant is a descendent of fernlike plants found today.
It can grow up to 18 feet or even taller and the stem is about as thick as a wrist.
They can be found growing in wet places such as small ponds of ditches.

The whisk fern has no leaves but instead small, circular, spore producing structures called synangium.

Rhizoids anchor the plant down and are also responsible for the absorption of nutrients.

Over time with the growth of all the land plants, organic matter would get mixed with the soil when the plants died and decomposed. These organic materials were broken down by bacteria so that they could be absorbed by roots.

These next plants are much different than the ones discussed before. Ferns, bryophytes, lichen, and algae were all dependent on water for their reproduction but conifers (right) do not need water for reproduction. The development of pollen destroyed the need for swimming sperm. Pollen could be carried by wind. Cone-bearing conifers have two different types of cones, female and male. When fertilization occurs, the resulting zygote is in the form of a seed. This seed could then remain dormant until conditions permitted it to grow. These cone bearing conifers are also known as gymnosperms. The first conifers appeared during the Mesozoic era.

Although there are only about 500 species of conifers, they dominate the vast forest regions of the northern hemisphere.

About 130 million years ago, the flowering plant appeared. Flowering plants are also known as angiosperms and like conifers; they also appeared during the Mesozoic era. Today, flowering plants are the most common plant on Earth. The flower of this plant is usually a very bright, vibrant color which helps in the attraction of insects and birds for pollination. Flowering plants can grow in all different kinds of locations and under a wide range of conditions. Flowering plants produce seeds which are sometimes enclosed by fruits for protection.

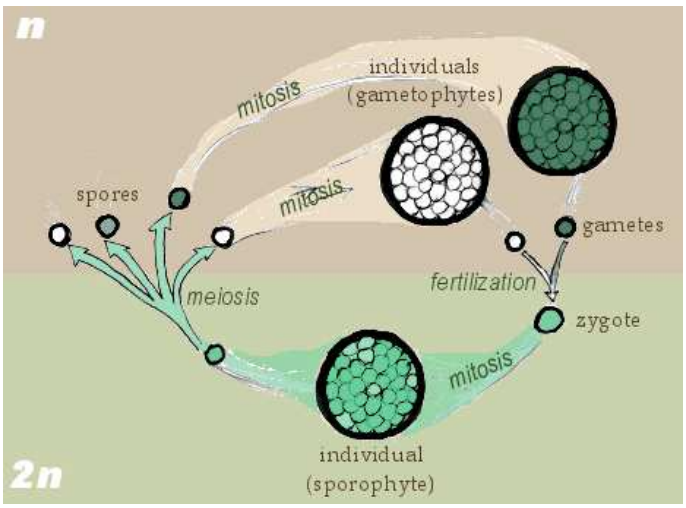
Chapter 2: Life Cycles

About Alternation of Generations:

Plants can undergo both asexual (single parent) and sexual (two parent) reproduction. The far more important of the two for plants, however, is sexual reproduction. The way in which plants undergo sexual reproduction can be difficult to understand for the young botanist who has never learned about it before, particularly because it is so different from the far more familiar process of sexual reproduction that occurs in the animal kingdom. The plant reproduction cycle is indeed a complicated process, as it spans multiple stages and differs widely between different species and groups

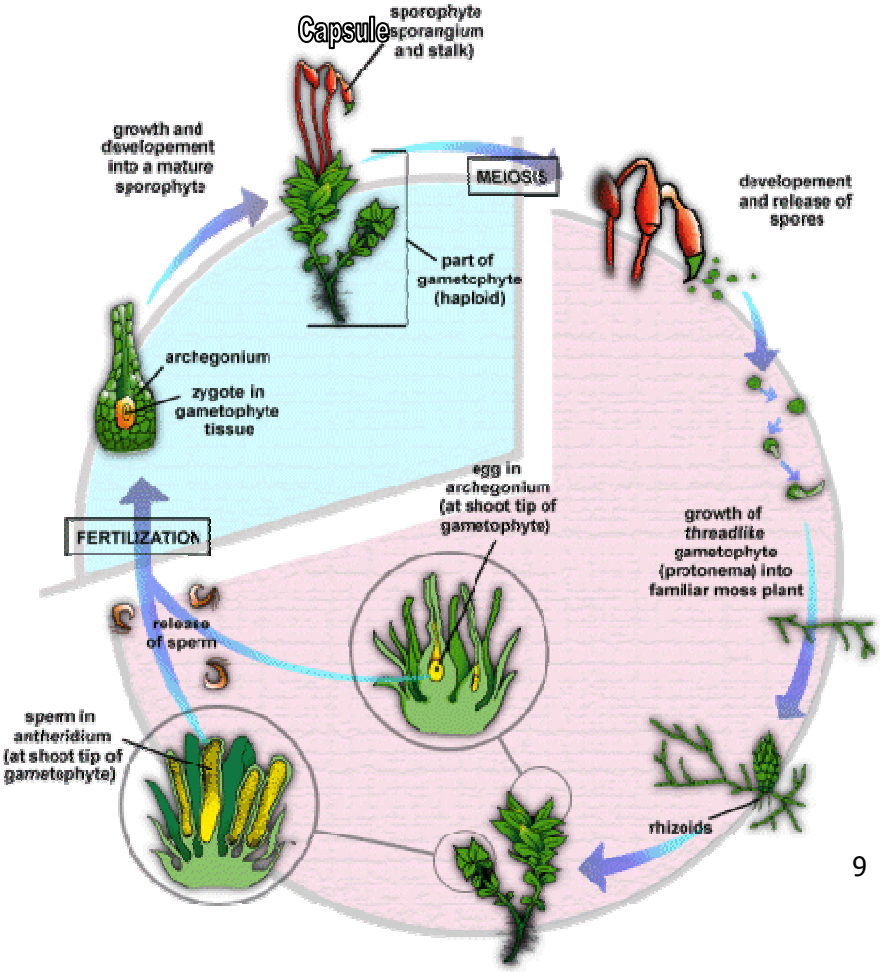
The key to understanding plant reproduction (or sexual reproduction in any scenario) lies in understanding the difference between haploid and diploid cells. **Haploid** cells are cells containing one chromosome for each part of the total set. Haploid cells constitute the early stages of the plants life, called the **gametophyte** stage. **Diploid** cells are cells containing two chromosomes (homologous pair) for each part of the total set. Notice how in the *diploid* karyotype (gene map) picture at the left, there are two chromosomes for each number. Diploid cells constitute the later stages of the plants life, called the **Sporophyte** stage. Depending on the plant type, either of these two stages may be called dominant. The dominant stage is the stage of the plants life that is longer and generally more recognizable. In mosses, the gametophyte stage is dominant, whereas in ferns the Sporophyte stage is dominant. The process through which plants change from gametophyte to sporophyte (haploid to diploid) is known as **Alternation of Generations.**

A Basic Overview of the Process:



When a diploid plant matures during its Sporophyte stage, some of its cells begin to undergo **Meiosis.** Meiosis is a process through which diploid cells are turned into haploid cells. The haploid product that is usually produced is called a **spore**. Spores may or may not be a significant part of the plants cycle, however, in all cases, the spore grows into the new gametophyte. In angiosperms, the spore stage is skipped and the plant produces gametophytes more directly. The purpose of the gametophyte is to produce **Gametes**, or sex cells. Either male of female gametophytes may be produced, or only one type of gametophyte with both male and female parts may be produced. The cell cells are produced through the process of **Mitosis**. Mitosis is the method through which haploid cells are created from existing haploid cells. Meiosis is not needed to produce the sex cells (as it is in humans), because the gametophytes themselves are already haploid. The sex cells created by one gametophyte will eventually combine with the sex cells of another gametophyte. This is referred to as **Fertilization**. After fertilization, the young **Zygote** is created. The zygote is diploid because it is the result of a combination of the sex cells (gametes), which were haploid. The zygote represents the first stage of the sporophyte stage in the plants life. The zygote begins to divide through mitosis after fertilization, and matures to become a multi-cellular sporophyte **Embryo**. The sporophyte embryo eventually matures into a grown sporophyte and proceeds to repeat the process by undergoing meiosis to produce more spores.

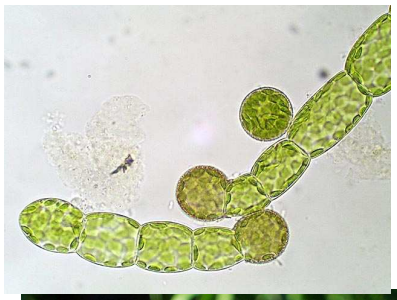
The Life Cycle of Mosses (Bryophytes):



As described in the previous chapter, mosses are a fairly basic form of plant life on earth. They cover a wide range of species across the globe. The reproductive cycle of the Moss is characterized by its *dominance of the gametophyte* stage. Mosses are one of the few plants in which the sporophyte generation is brief and sometimes overlooked. In observing the picture to the right, one can see that the mature sporophyte of a moss grows out the haploid gametophyte plant. As the Sporophyte grows, it begins to produce spores through meiosis within a sporangium

(structure for making new spores) called a **capsule**.

When development is completed, the haploid spores are released into the environment and allowed to germinate. In The first stage of growth for the new gametophyte, a thin, thread-like structure called a **Protonema** (see left picture) is produced. The protonema eventually develops thin roots called **Rhizoids**. Rhizoids anchor the developing moss plant and also allow it to absorb water. Mature gametophytes can develop two different kinds of reproductive structures. The **Antheridium**, or male reproductive organ of the gametophyte, produces haploid sperm cells through mitosis. The



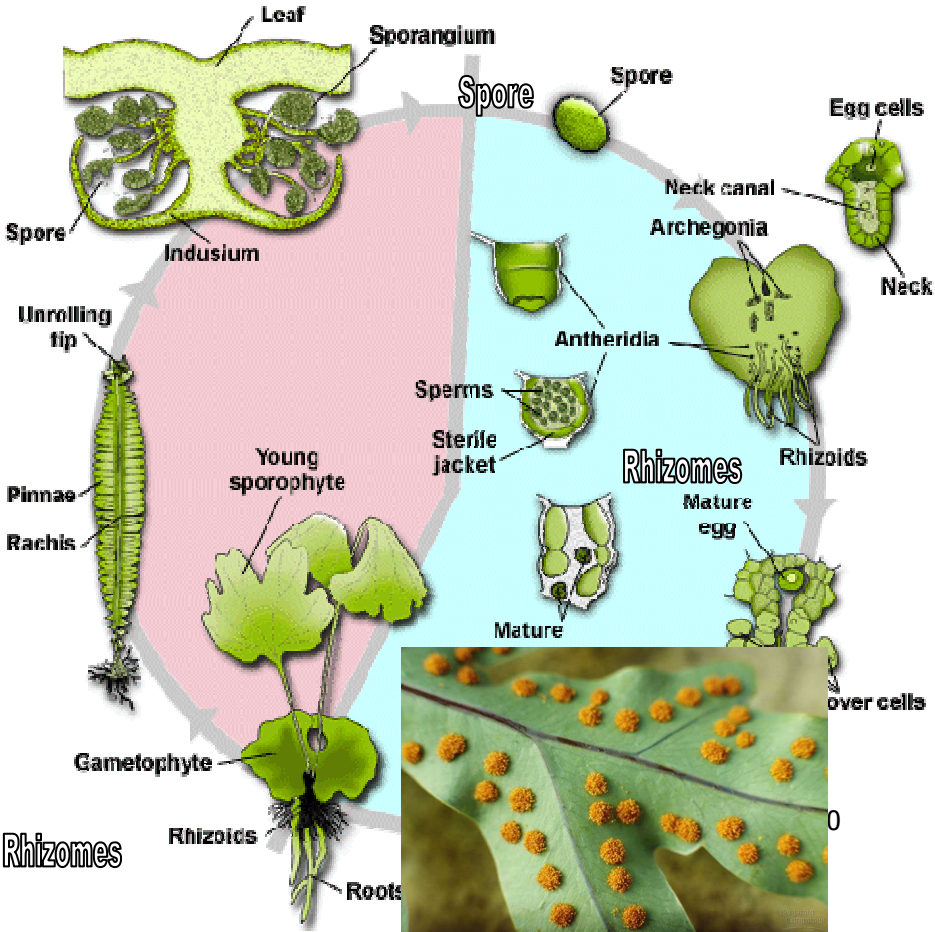
Archegonium, or female reproductive organ of the gametophyte, produces haploid **Egg** cells through mitosis.. In order for the mobile sperm cells to get from the antheridium to the archegonium, *water must be present* on the gametophyte so that the sperm may swim. In the picture on the left, notice how the moss plants are close together to allow sperm to swim from plant to plant. Upon reaching the archegonium, a sperm may enter and fertilize the egg which is present. At this point, the sporophyte

part of the moss plant begins to develop. The newly created diploid zygote begins to grow, and the sporophyte eventually sprouts from the plant (see picture). This sporophyte undergoes meiosis to produce more spores to be released into the surrounding area.

The Life Cycle of Ferns (Pterophytes):

Ferns are an important member of the plant family on Earth, and have existed for millions of years. The fern reproductive cycle is frequently studied as a good example of the system of Alternation of Generations. For the fern, the *sporophyte is the dominant phase* in the plants life cycle, because the plant spends most of its time as the familiar leafy plant recognized by

many people. As in the mosses, the mature sporophyte undergoes

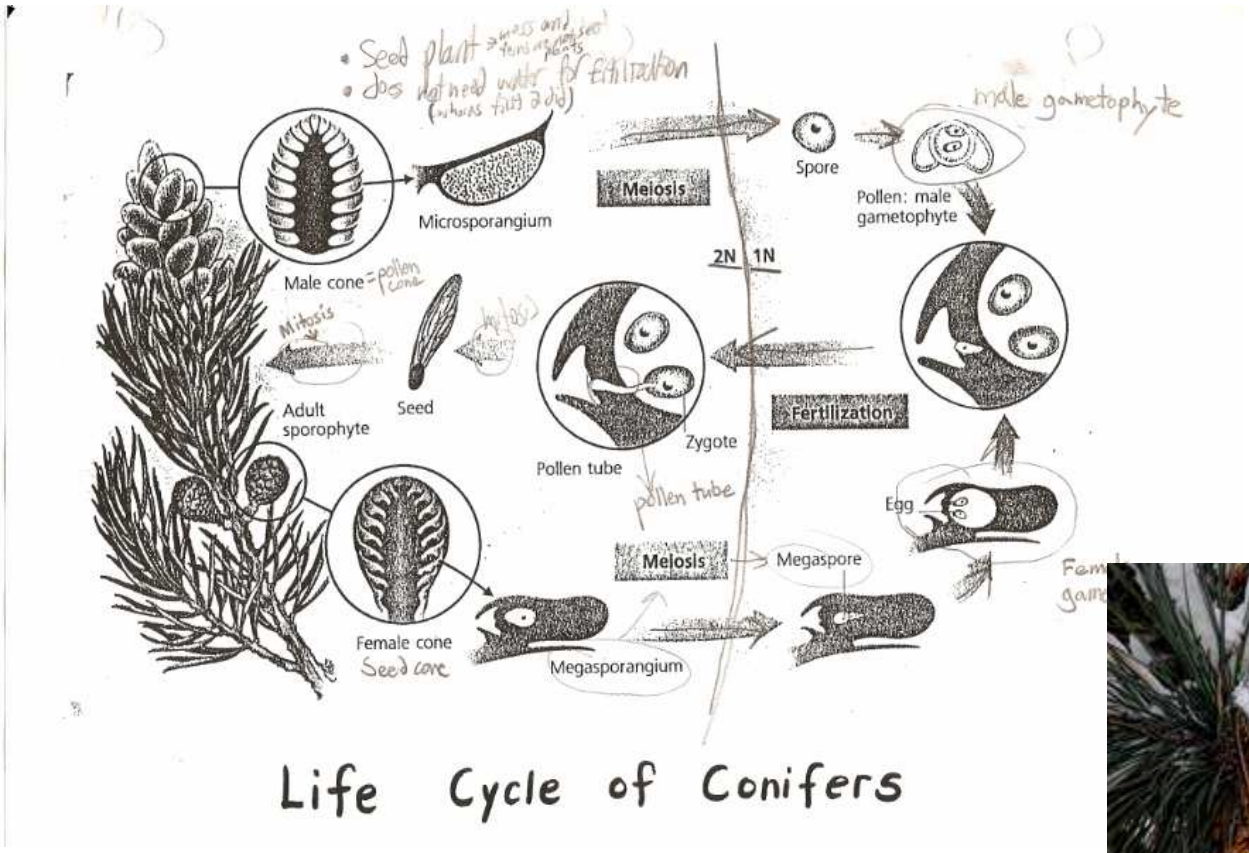


meiosis for the development of spores. The spores produced by the sporophyte fern are generally created in clusters of sporangium capsules, which gather, on one side of the ferns leaves. The clusters, called **Sori** (See picture on below), release the spores into the environment.

The haploid spores land and grow into the fern gametophyte plant. This structure, often referred to as a **Prothallium**, has both male antheridium and female archegonia. The prothallium has an extension of its stem into the ground called a rhizome. The rhizome is the basis for the plant's root system. Once again, water is needed for the sperm cells in the antheridium to reach the archegonium. After fertilization, the egg grows and becomes a zygote and then an embryo. The Sporophyte part of the plant soon begins to sprout from the prothallium. In the sporophyte plants early stages, it is called a **Fiddlehead** (see picture on above). When the fiddlehead becomes completely uncurled and the plant matures, the more recognizable fern plant, called a **Frond**, is created. The adult frond undergoes meiosis, creates sori, and disperses spores to repeat the cycle.

The Life Cycle of Conifers (Gymnosperms):

Conifers, or **Gymnospores** (plants that reproduce with cones) represent a truly fascinating variation of the plant life cycle. Many Americans are familiar with pinecones, which grow in almost every region of the united states. Surprisingly, however, few people actually understand what the purpose of a pinecone is. In Conifers, the *sporophyte stage is always dominant*. Both the pine tree and its cones are diploid structures. Just as is the case



in other types of plants, the mature sporophyte produces spores for the creation of new gametophytes. The way in which this occurs in conifers however, is significantly different from the previous examples.

The adult sporophyte tree produces two distinct types of cones, a male and a female (see pictures at right). In both cases, these cones produce spores through meiosis. Spores made by the male cone become male gametophytes, and spores made by the female cone become female gametophytes The male cone has within it structures called **Microsporangium**. Microsporangium produce normal haploid male spores. The female cone contains within it structures called **Megasporangium**. Megasporangium produce female spores. Spores released by the male cone quickly grow into the male gametophyte called **Pollen**. For this reason male cones are often called **Pollen Cones**` Pollen is a very basic male gametophyte in that it does not grow into a new plant, but instead produces sperm cells as a free [illegible] travels with the wind. The haploid spores made by the female cone (called megaspores) grow into the female gametophytes, which are small structures that remain attached to the cone and contain created egg cells

Male

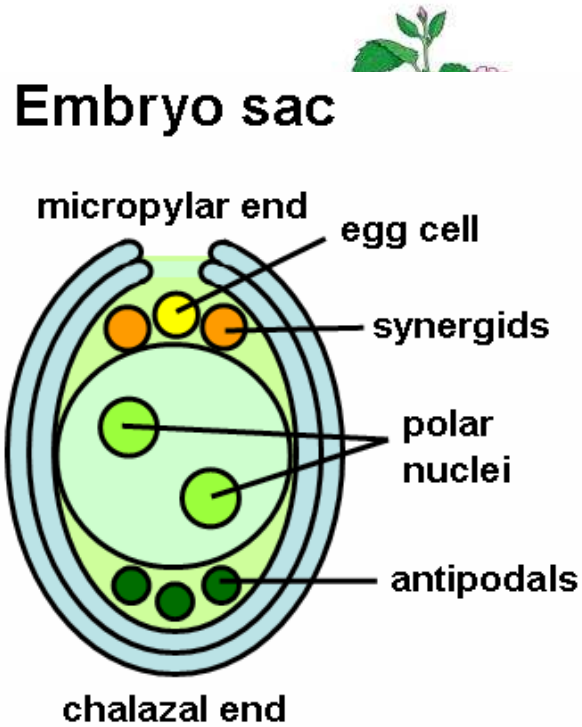
Pollen contains a **Generative Nucleus** and a **Tube Cell Nucleus**. Pollen produces its gamete (sperm) by dividing its generative nucleus, which creates two sperm cells. When the male pollen gametophyte comes in direct contact with a female gametophyte, fertilization is allowed to take place, which in this case is called **Pollination**. Pollination is unlike fertilization in mosses and ferns because it does not require water to take place. The sperm within the pollen is able reach the egg cell by way of the pollen tube, which is created by the tube cell nucleus. The pollen tube extends from the pollen particle into the female gametophyte. As usual, after fertilization, the newly made zygote (new sporophyte) begins to develop, eventually becoming an embryo. Instead of growing directly into a new pine tree however, the zygote grows into a **Seed** (see picture above). Seeds are essentially the beginnings of the new plant packed up into storage. When the time is right, the seed is dispersed into the environment, where it may remain dormant until conditions are right for growth. The seed grows into the familiar pine trees we see nearly every day. After reaching maturity, the tree begins to produce cones to repeat the cycle.

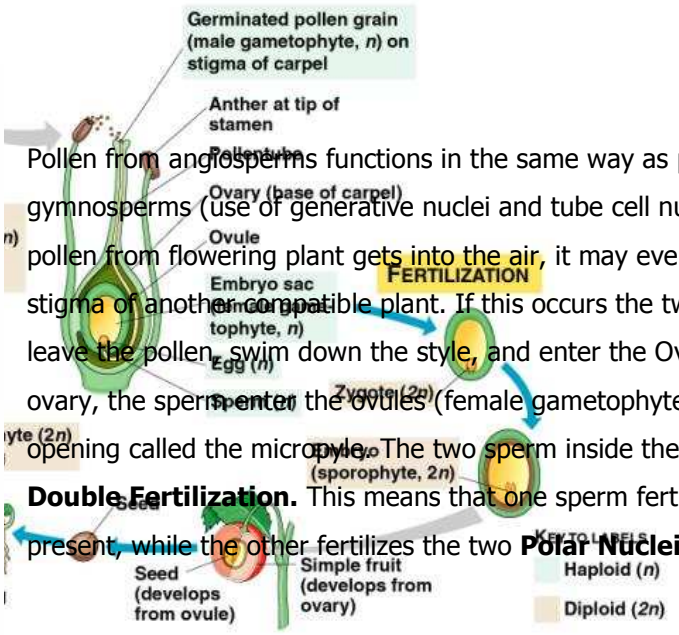
The Life Cycle of Flowering Plants (Angiosperms)

The last life cycle to be observed is the life cycle of **Angiosperms,** which are flowering plants. Angiosperms represent the most complex of the all the plant reproductive cycles. This is because, as mentioned in chapter one, the angiosperms were the last to evolve of the four plant groups we are studying, and thus have developed a very intricate way of propagating themselves. In flowering plants, *the sporophyte stage is dominant*. The commonly seen flower with its stem, petals, etc… is the sporophyte. In a manner similar to that of the

conifers, the sporophyte flower creates male and female gametophyte offspring. The difference is that with flowers, the spore stage is skipped.

Most flowers contain both male and female parts. These **Perfect Flowers**, as they are often called, fertilize each other through the use of numerous different structures. The Male part of the plant is called the **Stamen**. The stamen's purpose is to create haploid pollen directly. The pollen of the flower is created within the anther, which is a structure where meiosis takes place in the flower. The anther is attached to the center of the flower by way of a long filament (observe in picture above the white bulbs protruding out). The female part of the flower is called the **Pistil**. The pistil consists of a centralized structure with three parts. The **Ovary** (very large bulb in picture) is where the female gametophyte, called the **Ovule** (or embryo sac) is found which houses the egg cells. The second part of the pistil is the style. This is the tube which comes out of the ovary that sperm cells pass through to reach the egg. At the tip of the style is the last part, called the stigma. The stigma is the sticky spot where pollen in the air may land to pollinate the flower



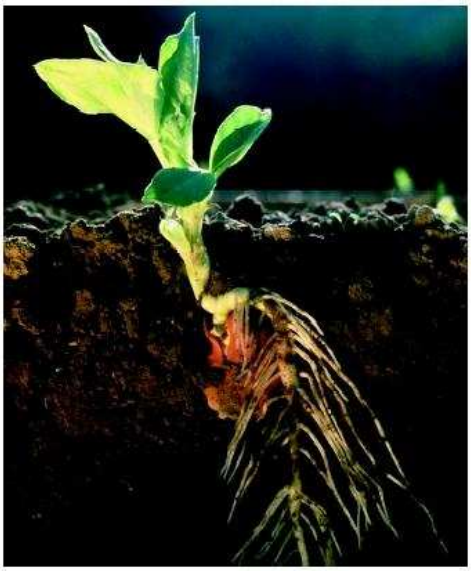


Pollen from angiosperms functions in the same way as pollen from gymnosperms (use of generative nuclei and tube cell nuclei). When the pollen from flowering plant gets into the air, it may eventually land on a stigma of another compatible plant. If this occurs the two sperm will leave the pollen, swim down the style, and enter the Ovary. Once in the ovary, the sperm enter the ovules (female gametophytes) through an opening called the micropyle. The two sperm inside the ovule create a **Double Fertilization.** This means that one sperm fertilizes the egg present, while the other fertilizes the two **Polar Nuclei** present. The

result is an ovule containing a new sporophyte zygote as well as a **triploid** (three chromosomes per part of total set) cell from the merging of the sperm and polar nuclei. The significance of this is that as the zygote matures to form an embryo and eventually a seed, the triploid cell will begin to undergo mitosis and eventually form the Endosperm (or food) to be stored within the seed for the young plant. When the seed is released by the plant, it grows into a new sporophyte flowering plant, ready to undergo meiosis and begin the process again.

Chapter Three: Roots and Stems

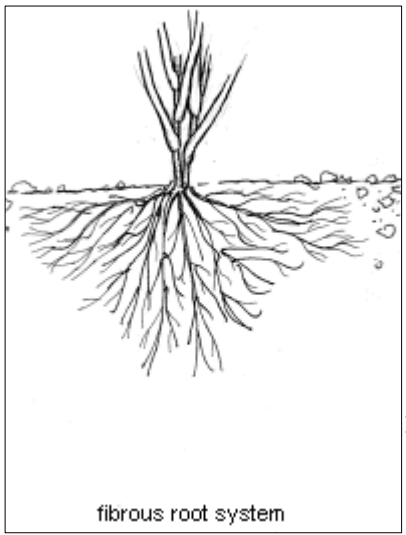
Roots



The root is one of the three organs on plants and it is the most commonly forgotten part of the plant. Many people look at a plant and talk about its foliage if it is a tree or a bush and if it is a flowering plant they talk about the flowers. You don't often hear a person talking about look at the spreading root foundation of that beautiful sugar maple (*Acer saccharum)* due to its extensive fibrous root system. Those people neglect that without the root system the tree or other species of plant would cease to exist. The roots are one of the most important parts of a plant.

Roots have two major functions; the first is to absorb water and nutrients dissolved in the water. The second purpose is to anchor the plant to the ground. Water is needed in profuse amounts throughout the plant to survive and without anchorage a tree like the sugar maple, which averages a height of 90-120 feet tall, would topple. Roots are classified into three major groups; the fibrous and the taproot systems and the tuberous.

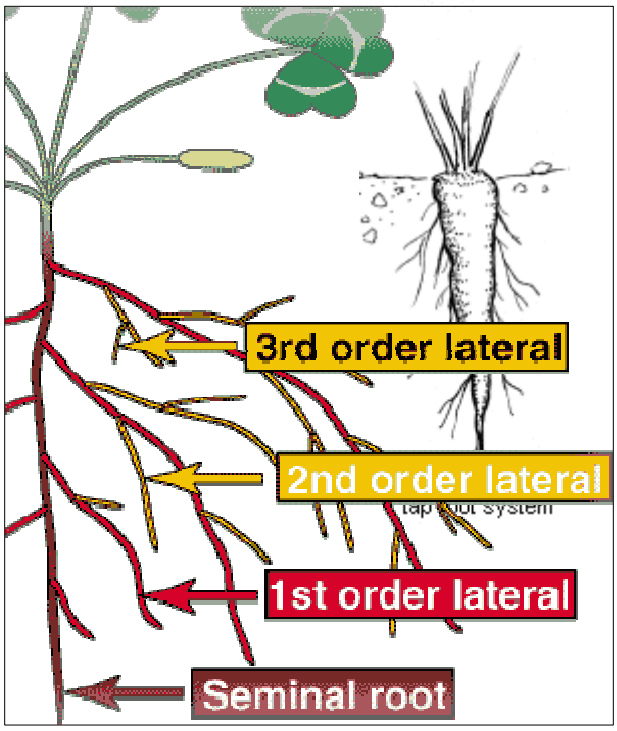
The fibrous root system is somewhat self explanatory its structure because it has many roots and they appear like fibers. Their growth is like strings out from the plant seeking out their constant need for water and nutrients. Fibrous roots are generally all the same size within the same plant. This means that on a fibrous plant all the roots coming from that plant are the same size. Fibrous roots come in many sizes depending on the species of plant. Almost all monocots have fibrous root structures. The sugar maple has very large fibrous roots that spread in all directions. Some of the fibrous roots from the maple can be 3 or more inches in diameter. On the small scale grass can have roots that are less than a millimeter in diameter (Plant Roots). Roots grow from a central root



called seminal or adventitious root. The first root off of that centralized is called the 1st order lateral and a root off of that is called a 2nd order and another root from that is called a 3rd order. They follow in this order many times off the central root and all the levels of roots have root hairs which help even more to anchor the plant

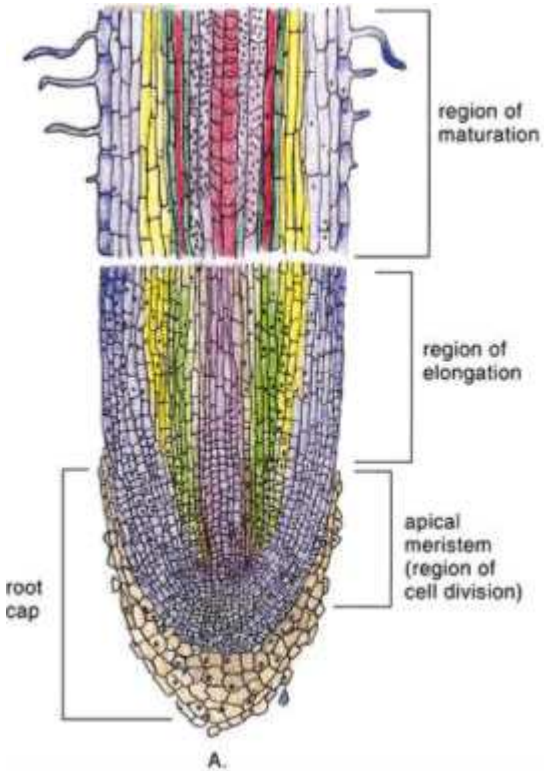
Fibrous roots have the interesting quality that they are not merely seeking nutrients and water but they are also storing photosynthetic food. An example is the sweet potato which is storage of food. The fibrous root is used commercially for the purpose of preventing erosion of soil. Its spreading roots are capable of holding soil in place so in areas of erosion plants with fibrous roots are planted.

Below: The picture indicates how the fibrous roots branch off.



Below: The sweet potato is one of the storages of food that can be attached to the fibrous roots.

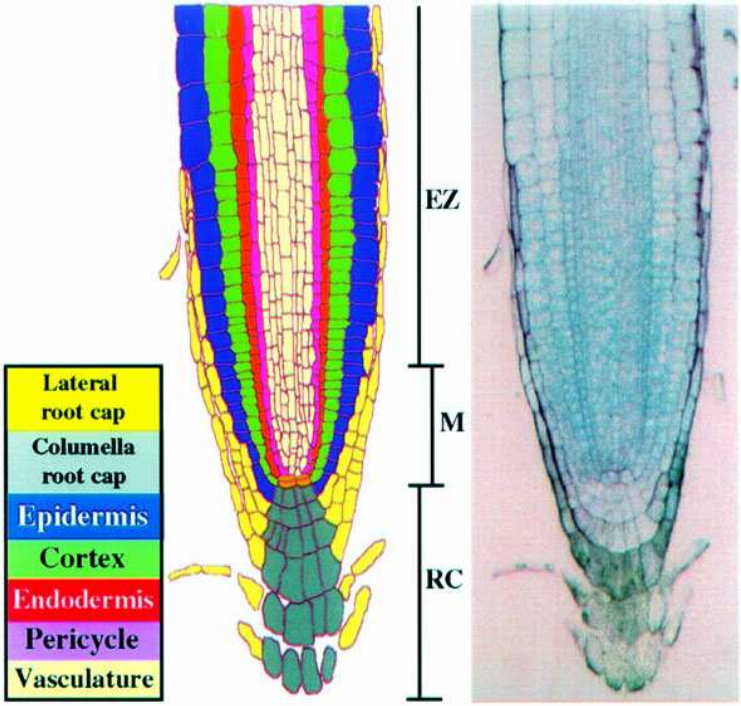
Taproots are the second kind of root. The taproot is a type of root that relies on a primary root (root). From the main primary root come branches off that act as secondary roots. This is not to be confused with fibrous because these roots are not the same size nor are they as numerous. The taproot is formed when a seed first germinates and the radical, which is the first root formed, grows into the taproot. Taproots can store food within themselves unlike the fibrous system which creates large objects like sweet potatoes. Within this root it forms one deposit of photosynthetic food. An example of this is the carrot or sugar beat. The taproot proves to be very effective at finding water that is deep in the earth .



There are definite differences between the fibrous and the taproot, but they both have the same physiology. The root can be described in 4 areas; the Zone of Cell Differentiation, Zone of Elongation, Zone of Cell Division, and the Root Cap.

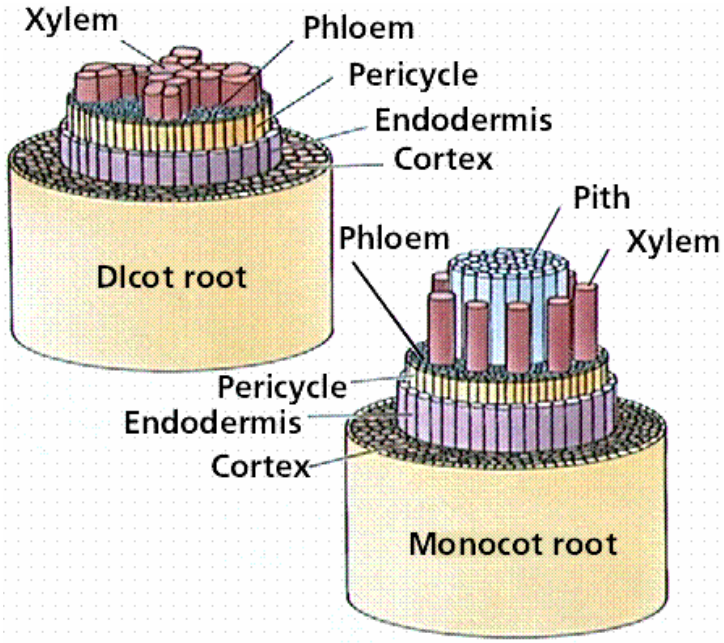
The root must push its way through the soil in its search for food and to do this there must be protection for the root. The protection for the root comes in the form of the root cap. The root cap grows in the rootcap meristem which pushes the cells into root cap zone. The cells then differentiate in columella cells which contain amylopasts. Amylopasts are responsible for the detection of gravity. Columella cells can further detect light and pressure coming from soil particles
.
Once the columella cells are pushed into the root cap tip they redifferentiate into peripheral cells. These cells are special because they secrete a chemical called mucigel which is a hydrated polysaccharide formed in dictyosomes. The dictyosomes contain sugars, organic acids, vitamins, enzymes, and amino acids. The purpose of the mucigel is to protect the root from drying out. The other purpose of the mucigel is to lubricate the root so that it can slide easily through the soil. Some plants contain a special mucigel that contains inhibitors that prevent plants from competing with them. Another purpose of mucigel is in the absorption of water and nutrients by creating more surface contact. Mucigel acts as a chelator and by doing so frees up ions that can be absorbed into the root. Within the mucigel itself there are nutrients that help to setup symbiotic relationships with bacteria in the ground.

Directly behind the root cap area is what is called the quiescent center which contains inactive cells. These cells replace the root cap meristematic cells if the meristematic cells die or become damaged.



Above: The picture shows the setup of roots with the different layers to the roots. It is shown in the image how the root is more complex than it first appears.

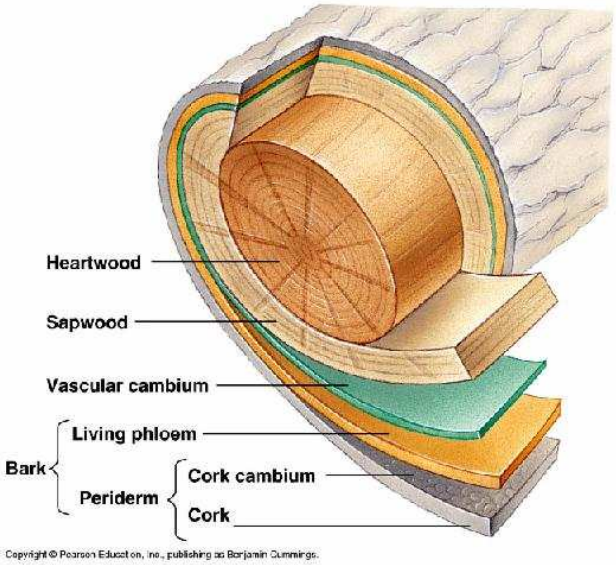
Behind the quiescent center is the subapical region. The zone contains the other three zones of the root. The other zones are the Zone of Cell Division; which is made up of cells that are created in the apical meristem, the Zone of Cellular Elongation; where the newly created cells elongate due to water being moved into the vacuole, and the Zone of Cellular Maturation; where the cell differentiates. The elongation of the cell makes the root move through the soil. When the cell differentiates, root hairs develop to assist in absorbing water and xylem cells are created to transport water and nutrients (Plant Roots). Roots progressively mature as the apical meristem moves away from those cells. In crop plants a root will grow about 1 cm per day while in a natural ecosystem the plant will grow only 1 mm or less per day. The roots of annual plants like many crops and flowering plants have fine roots that last only weeks or months. The more coarse roots of trees and perennials have well built roots. The lifespan of a plant can be estimated by looking at the roots of a plant.



The root is made up of 3 different layers within it. The first of this is the epidermis which is the outermost layer of the root. It is the portion of the root that comes into contact with the soil as the root moves through and absorbs. Its only one cell thick but it acts as protection to the rest of the root. The second layer from the outside is the cortex which is used for storage of food and water. It is made up of storage tissues, air spaces, and the endodermis. The purpose of the endodermis is to prevent water from suddenly rushing into the root. It acts as a flood gate to slowly let water in. The inner most layer is what gives purpose to the root because it contains vascular tissue. The vascular tissue is the xylem and phloem. The xylem moves water and nutrients up and down the plant. The phloem moves food down from the leaves. The xylem effectively absorbs water and moves it up into the plant while the phloem moves food down to the roots to be stored (root). There is a distinct difference between the setup of the monocot root and the dicot root. In the monocot root there is a center of pith surrounded by the xylem tubes as seen above. The xylem and phloem in the monocot are organized in a circular fashion about the center of pith. In the dicot root the xylem and phloem are organized in a cross in the middle of the pericycle. It can sometimes be found that the xylem and phloem are on organized and are randomly placed in the pericycle. Dicots lack the pith that monocots have as seen above.

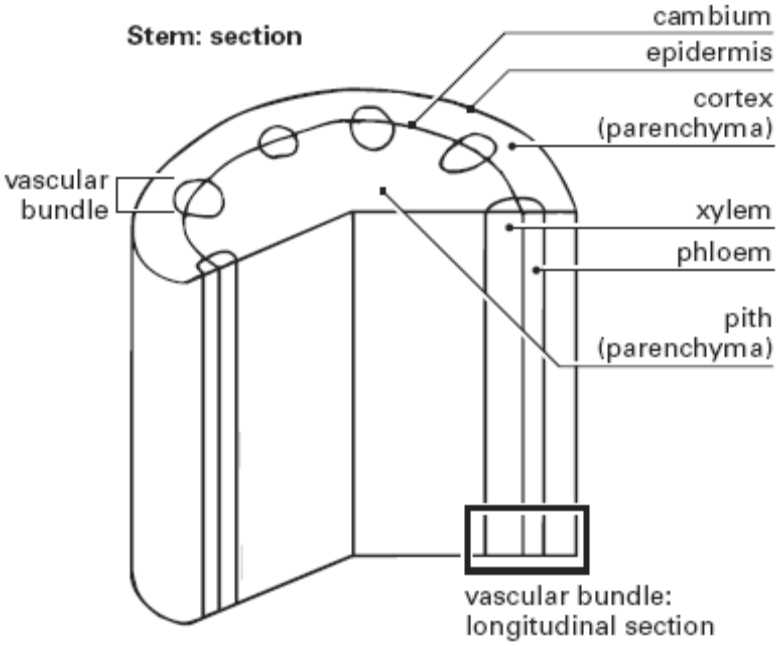
Stems

The plant stem is the second organ of the plant. It is also the second part of the plant when moving upwards from the roots. The stem has 3 primary functions: to support the plant, to transport materials between the upper levels of the plant and the roots, to grow in height and in width. The stem must grow in height so that it can lift the leaves in the direction of the sun so that photosynthesis can occur. The second most important part is for it to transport materials between roots and the growths above. Without the stem water and nutrients from the roots would not be able to get to the leaves for photosynthesis and photosynthetic food would not be able to get to the roots. To support all the needs of plant there are complex systems within that need to work in perfect synergy.



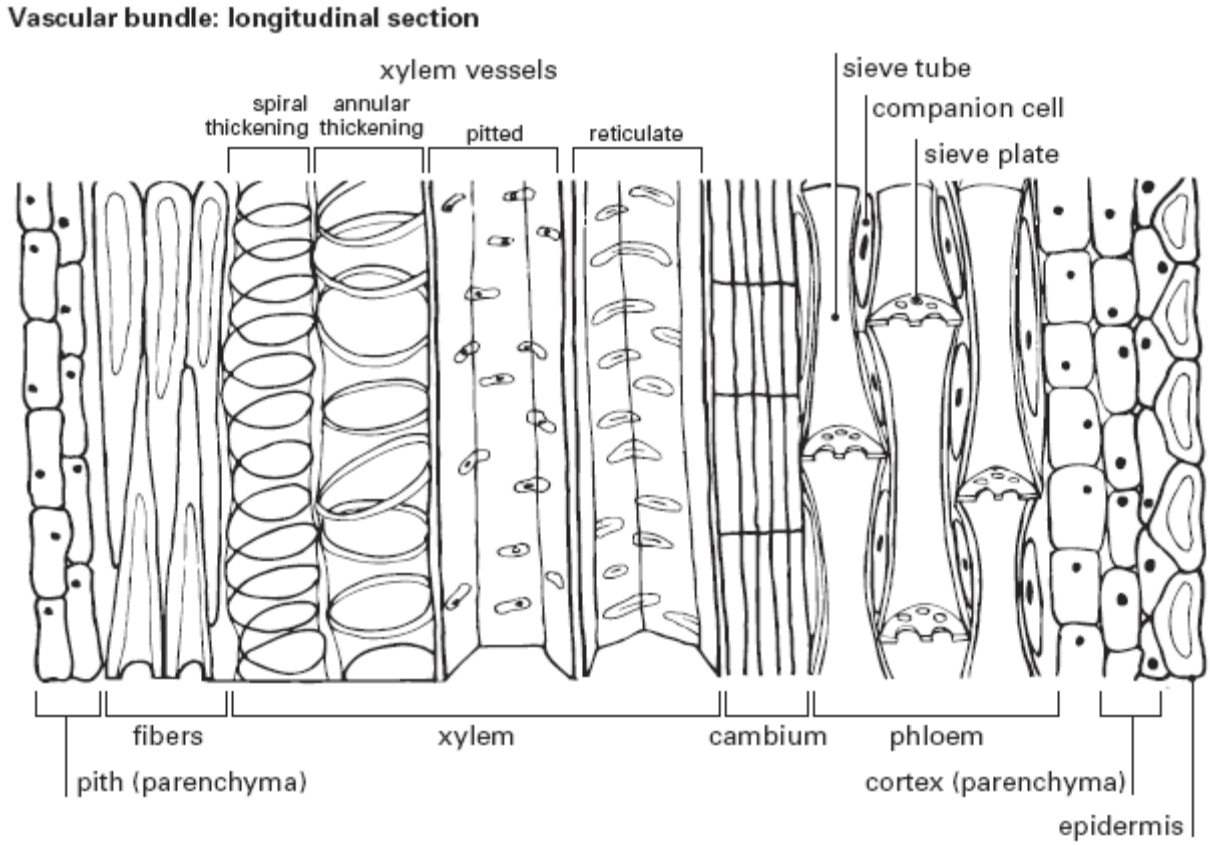
Stems are only found in the vascular plants, which are the conifers and pterophytes, gymnosperms, and angiosperms. They are not found in bryophytes. There are three major types of stems that can be found. They are quite different from each other due to the requirements of the growth that they must do. Some are meant to support and grow larger while others are not so. Some have grown differently and do not even grow above the surface of the earth. They can be mistaken for roots to uneducated eye.

The first is the woody stems which are typically found in the form of trees, bushes, shrubs, and other large growing plants. The woody stem is differentiated by the fact that it is more firm than the herbaceous stem which is found on annual plants. The woody stem is more solid because it survives multiple years and over time it develops a tough body. The stem becomes woody because it experiences secondary growth after the initial



growth every year after the first growth it grows a little bit larger. This can be measured by counting the rings within a tree. The rings in a tree show the number of years old that it is and it also shows how the environment was. A large growing season can be seen by looking at a ring larger than the rest because nutrition was better or there was more moisture. A tree can also tell about if the environment was poor and the tree was in recession. The woody stem survives for much longer than the herbaceous because the plant must survive for longer.

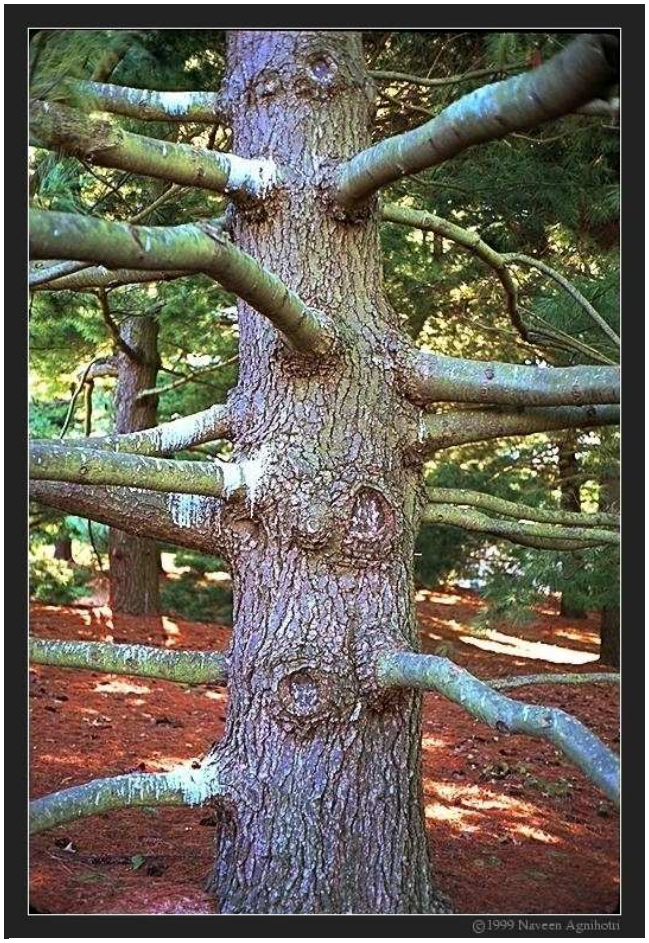
The structure of the woody stem can be seen in three steps. The first step of a woody stem is its initial growing period when the plant is first growing. It begins on the outside with the epidermis which protects the plant from harm. Below the surface of the epidermis is a layer called the cortex which stores food that is created in the leaves of the plant. The phloem cells which are hollow cells that food travels through to get to the roots of the plant from the leaves are surrounded on one side by the cortex. After the phloem cells there is a layer of cells called the vascular cambium. The vascular cambium is where the stem grows out from. These cells experience rapid mitosis to make the tree expand laterally. On the other side of the vascular cambium are the primary xylem cells which act like the phloem. There are key differences between the phloem and the xylem. The xylem is not capable of transporting water and nutrients in both directions through the plant. It is also made of different kinds of cells. The cells that it is made out of are called vessel elements and tracheids. The phloem cells are made up of sieve tube elements and companion cells surround them. The vessel elements are long and hollow and the tracheids help to move water and nutrients between the xylem cells. The sieve tube elements that make up the phloem have small holes in them that allow substances to move in and out. The companion cells help the phloem to move substances in and out of the phloem. The xylem and phloem make up vascular bundles. Within the dicot stem the bundles are organized in a circular pattern about the center. In the monocots they are randomly placed. On the other side of the xylem is what is called pith. The pith is found only in dicot plants and is made up of parenchyma cells.



Together all these parts make up the first year of growth for a plant. In the second growth cycle a layer of cork replaces the epidermis. The cork is produced in the cork cambium. A secondary layer of phloem grows between the phloem and the vascular cambium. It grows in a ring around the vascular cambium. On the side of the xylem a secondary layer of xylem grows and expands the trees diameter. These layers together are the layers that occur before the plant becomes fully mature. At maturity the stem will continue adding to the first and secondary growth layers. It will keep doing this and continue to get larger and larger. In a tree the pith will become what is known as the heartwood and the xylem layers become sapwood. The phloem layers and the cork will become the bark of the tree.

The xylem's movement of water is also called transpiration. This means that the movement of water goes from the roots to the leaves and then out the stoma. The stomata control this operation by opening and closing. The water moves from low concentration in the roots to high concentration in to leaves and so it moves up the plant using cohesion to move through the stem to the leaves.

Above: This is an herbaceous stem with a green outside a flexible stem.



Above: This is a woody stem with dark bark on the outside.

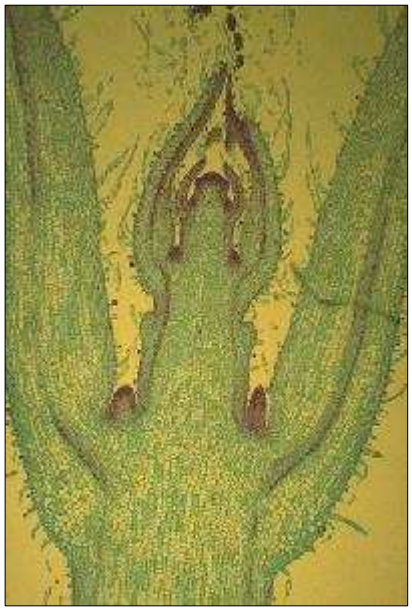
The woody stem contains all of the layers needed to make it function as a stem effectively; it is not however the only kind of stem in existence. The other very common stem is the herbaceous stem. The herbaceous stem can be found on angiosperms, gymnosperms, conifers, and pterophytes. It is not found on bryophytes. The herbaceous stem is different from the woody stem because they develop little if any woody tissue within themselves. They do not gain the firmness and inflexibility that woody tissue. They are also easily identified by the fact that they are often only around for one year before dying and then returning the following year if at all.

The last kind of stem that is not as often seen as the herbaceous or the woody stem is the modified stem. The modified stem is unlike the other two because it doesn't have the same form or function. Some of the modified stems grow underground in the form of tubers, bulbs, or corms. There are also tendrils and vines that grow along the ground and up other surfaces to gain height.

The layers of a plant create the lateral growth of the tree and the method to move nutrients, food, and water through the plant. The last purpose of the stem is to grow in the vertical direction. This occurs at the apical meristem. This point is

found at the point of junction between the roots and the stem and also again at the split of the stem into branches. At these points cells split through mitosis to make many new cells that make the tree grow in height.

The two different growths that come off of a stem are the lateral and terminal buds. The terminal bud is a bud that is at the tip of a stem. A terminal bud may turn into a flower or may be the highest point on a plant (Ashworth). A lateral bud is a bud that is produced on the side of a stem rather than the tip. This bud may turn into leaves, a lateral growth like a branch, or flowers.

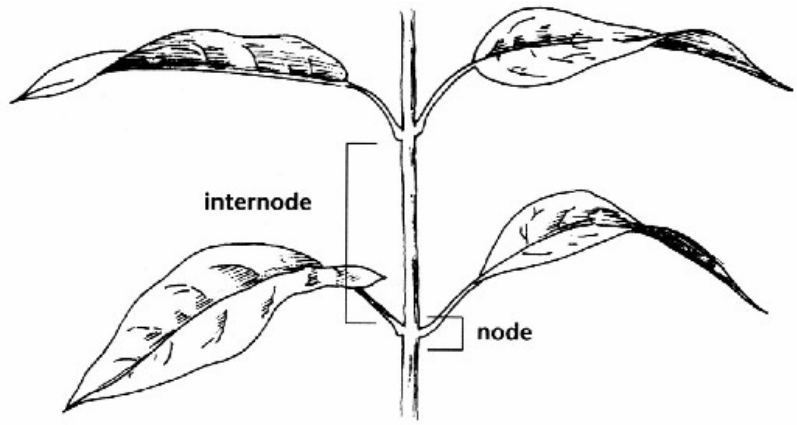


The growth of a plant is governed by hormones as it is in human cells also. It is controlled by a hormone called indole acetic acid or auxin. This hormone sponsors the growing of the apical meristem to make the stem longer and supports the vascular cambium to make the stem larger laterally. It also helps in lateral budding which creates lateral growths. Often times off of these lateral growths will come leaves, flowers, and further branching (auxin). Another hormone is cytokinins which is a hormone that controls cell division. In the root cytokinins stimulate cell division to make the roots larger or longer and it also stimulates lateral bud growth. It is believed by scientists that auxin and cytokinin together cause tissue differentiation in plants (cytokinins). A further hormone is gibberellin which is exclusively used to control shoot extension from the vertical stem. They are used to create large internode periods between lateral growths in plants with long growing days such as lettuce. These hormones control lateral, vertical growth, and root growth of plants.

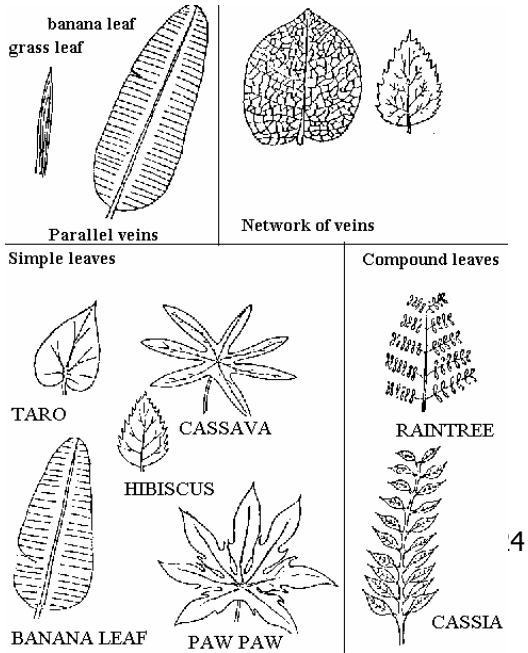
Chapter 4: Leaves

Leaves are one of the most commonly seen organs of a plant because it is seen during all seasons. Leaves on trees are seen on seasonal plants in the spring and summer and on the ground in fall. On ever greens and in warmer climates the leaves are left on all year round. The primary purpose of the leaf is to create food for the plant through the process of photosynthesis. The other purpose of the leaf is to get rid of excess moisture through the pores in the leaves (Leaves). In some plants the leaves are capable of trapping insects in their leaves so that they may be used as food (Moore). The leaf is the last organ of the leaf as you move from the ground up. It is one of the most fascinating parts.

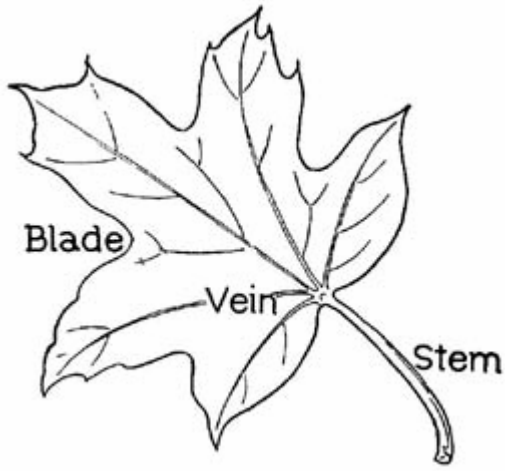
Leaves grow from joints or nodes of stems. There is an upward angle between the leaf and the stem and that is called the axil. The leaves are called opposite if they grow on the opposite side of a node. On the sugar maple leaves grow in the opposite fashion. If the leaves of the plant grow from the nodes on the stem and nowhere else they are called alternate or spiraled. The American elm is an example of this growing feature. There is a third growing type called whorled which is a more rare kind and can be seen on the catalpa. These three make up the leaf growing arrangements from the stem. In the case of trees the leaves don't necessarily come off of the vertical stem but instead come off of the lateral stems called branches. The area between each node is called the internode which is another name for the space between the two. This is seen often in trees.



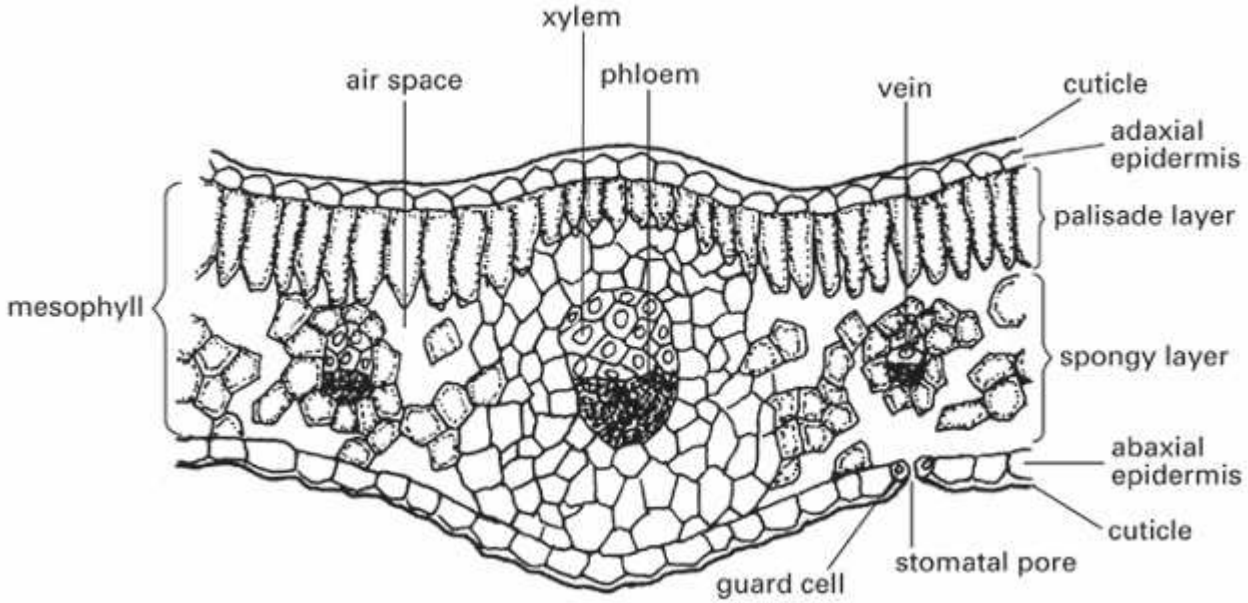
There are several different parts of the leaf and each has its own unique part in the growth of the tree. The first part of the leaf is the leafstalk or petiole which connects the blade to the stem. On some plants stipules grow from the petiole. Sometimes the stipules act like only shreds of a plant and in others they act like full leaves. The petiole acts to bring nutrients to the leaf and take away the photosynthetic food. The petiole also turns the blade towards the light to capture more sunlight. The blade is the second



part of the leaf structure and it is generally thin and flat with a wide area. In some cases it is not so and is thin and has little width like in pine needles or onion grass. Some plants have leaves that store water and they develop in thickness. Within the blade the tubes that move through the petiole spread out into veins to transport nutrients in and out as well as food. The veins can be set up into two formats: parallel or netted. The parallel veins are found commonly in monocots and the veins run side by side through the entire blade. The netted veins are found commonly in dicots and the veins spread out from a central vein. The veins do not run parallel but meander through the entire blade of the leaf. These parts together make up the leaf.



In addition to the parts of the leaf there are the different kinds of leaves: simple and compound. A simple leaf is the leaflet of a compound leaf and can be lance-shaped, oval, elliptical, or many other shaped. The side of the leaf could be smooth, serrated, waved, or have a deep indentation called a lobe. The compound leaf is made up of leaflets or simple leaves that grow off a lateral branch. In a pinnately compound leaf the leaves grow off of one side of petiole while on a palmately compound leaf they grow off of the tip of the petiole. There is another kind of compound leaf called a double compound leaf where leaflets grow off of leaflets. The more complex nature of the leaf is the structure of the individual leaf. The structure of the leaf is what makes it capable of being photosynthetic. The uppermost layer is the waxy cuticle layer. It is designed to prevent water loss from the plant. It is made of cutin. The next layer is the epidermis which is made to protect the leaf. It also contains pores called stomata or if in the singular called stoma. They are used to exchange gases with the atmosphere. Among these gases are oxygen, carbon dioxide, and water vapor. The stomata are open and closed by the guard cells. These open and close by having water pumped in and out which opens and closes them. These cells prevent the stomata from remaining open and losing too much water. The next layer in the structure is the palisade layer. The palisade layer is a layer of cells that have chloroplasts in them. The chlorophyll is responsible for photosynthesis within the leaf and creates food. The next layer which also has photosynthesis is the spongy layer. The



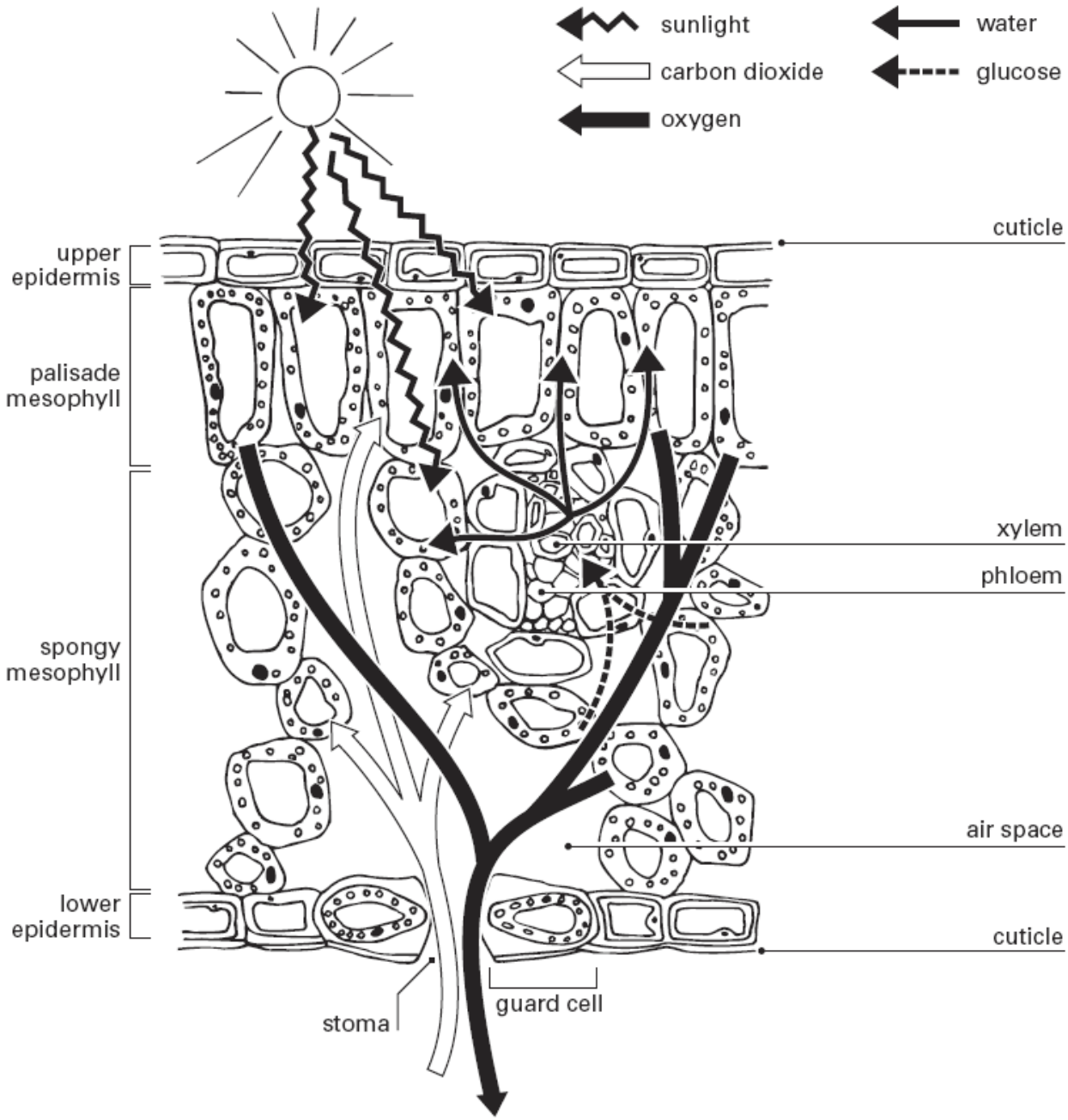
spongy layer also has chloroplasts to make photosynthetic food. The palisade and spongy layer make up the mesophyll where photosynthesis occurs. In order for the leaf to remain alive the layer of veins is required to supply the leaf with nutrients and transport food away. The veins are made up of xylem and phloem. In addition to transport the veins give structure to the leaf. The last layer that protects the opposite side of the leaf is the lower epidermis which is covered by another layer of cuticle and has stomata in it. It protects the bottom side of the leaf and lets gases in and out. These layers together make up the leaf.

Photosynthesis is the most important process in plants because it is what allows them to exist and survive. Photosynthesis is also what makes plants so interesting to humans. Photosynthesis is defined as the conversion of light energy to

chemical energy. This process occurs commonly in green plants and algae which are protists. These two groups use chlorophyll to absorb photons of energy and it is stored in the form of ATP or in enzymes (generally NADPH). Plants and protists are both capable of producing everything they need like carbohydrates, proteins, or other materials. To produce carbohydrates the plant uses the ATP and NADPH as needed in the reaction:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Leaf section showing movement of materials required for or produced by photosynthesis



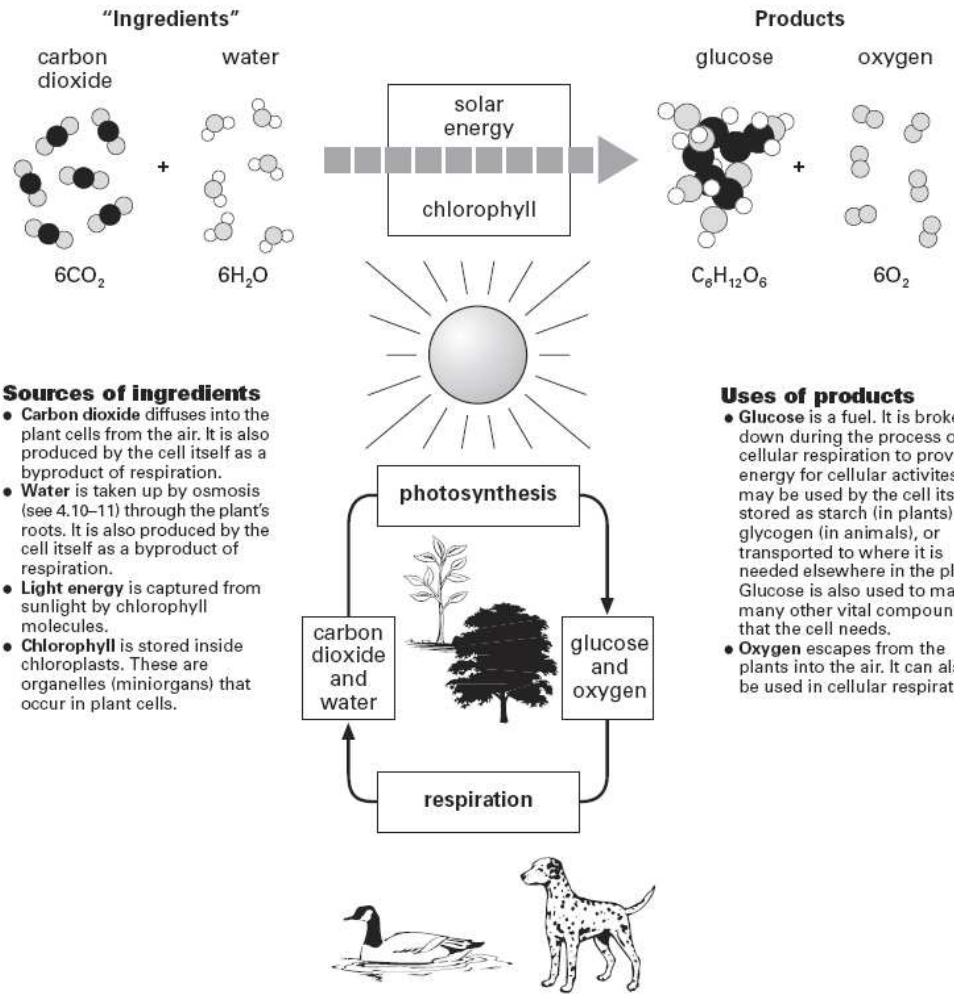
The point of reaction uses the energy from the ATP to make an endothermic reaction and convert the CO2+4H2O into food (Hine).

Photosynthesis 1: overview

Photosynthesis is how plants – and some algae and bacteria – make their own food. Described here is the process as carried out by plants. Bacteria perform a slightly different, simpler version of these events and some can use infrared (invisible) light.

Summary

- Plants use the energy of sunlight and the green pigment chlorophyll to convert the gas carbon dioxide and water into the sugar glucose. This glucose is effectively a plant's food.
- It takes six molecules each of carbon dioxide and water to produce one glucose molecule.
- A byproduct of this process is oxygen.



Sources of ingredients

- **Carbon dioxide** diffuses into the plant cells from the air. It is also produced by the cell itself as a byproduct of respiration.
- **Water** is taken up by osmosis (see 4.10–11) through the plant's roots. It is also produced by the cell itself as a byproduct of respiration.
- **Light energy** is captured from sunlight by chlorophyll molecules.
- **Chlorophyll** is stored inside chloroplasts. These are organelles (miniorgans) that occur in plant cells.

Uses of products

- **Glucose** is a fuel. It is broken down during the process of cellular respiration to provide energy for cellular activites. It may be used by the cell itself, stored as starch (in plants) or glycogen (in animals), or transported to where it is needed elsewhere in the plant. Glucose is also used to make many other vital compounds that the cell needs.
- **Oxygen** escapes from the plants into the air. It can also be used in cellular respiration.

Photosynthesis is vital to life on Earth. Animals are not able to create their own food from inorganic compounds. They need to consume plants – or other animals that have consumed plants – in order to obtain products such as glucose. This, in turn, is used by cells to carry out celluar respiration (the breakdown of glucose to provide energy), which all living cells need to perform. Respiration produces carbon dioxide and water, which can be used for photosynthesis.

Beyond the realm of autotrophic plants there are the carnivorous plants that are both heterotrophs and autotrophs. These plants are often found in areas where there is not a plentiful amount of the resources needed. These resources are expressed in the N-P-K concept. The N-P-K concept refers to an idea where a plant needs nitrogen, phosphorus, and potassium to run complex chemical reactions like the production of proteins. In an area where these elements cannot be gotten easily by the plant the plant turns to another method . The method found is that of catching insects and using enzyme the plant digests the insect still alive. This occurs with the Venus Fly Trap found exclusively in North and South Carolina in bogs. There are several other species of plants found in other regions of the world that are capable of catching insects. In these insectivorous plants the leaves are sticky, cone shaped with smooth sides, or fast acting by covering the insect and killing it. All of these methods rely on special abilities by the plant to catch the insect and then use complex enzymes to take apart the bug and obtain the nutrients it needs.

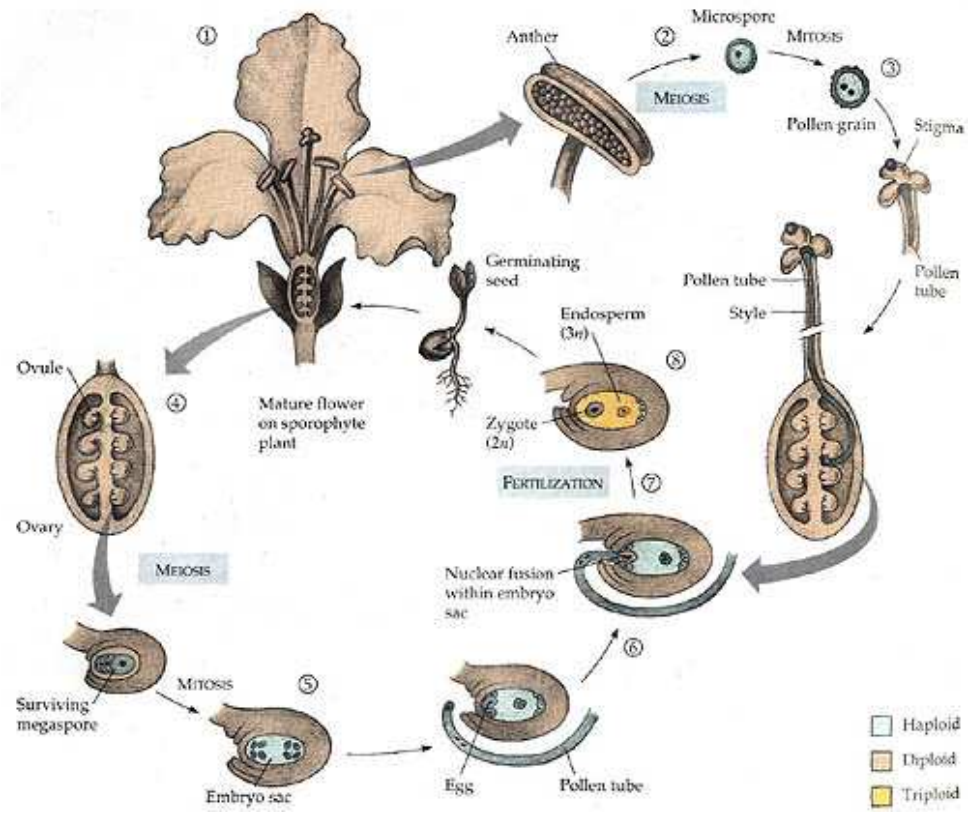
Every fall the autumn solstice comes and around this time the trees begin to lose their leaves. This is caused by two different chemicals; the first being abscisic acid which is a hormone and ethylene. They show up in increasing amounts during the cooler seasons and its arrival causes transpiration to stop and the water falls back into the roots. The plant cuts off the flow of water to the leaves and as a result the stem to the leaf dries out. Once the stem is dried out weather conditions such as wind, rain, snow, or others are able to knock the leaves off. A plant that loses it's leaves every year is a deciduous. One that doesn't is an evergreen and has needles instead.

Another phenomenon is the color changing of leaves. In most plants the leaves of a plant are made green by the chlorophyll in the leaves which is used in the creation of food. As the leaf begins to die due to hormones being introduced to it the chlorophyll begins to die as well. The result of the chlorophylls disappearance is that the other pigments that exist in the leaf come out. Most leaves change yellow, brown, orange, gold, red, or purple when they die. The pigments

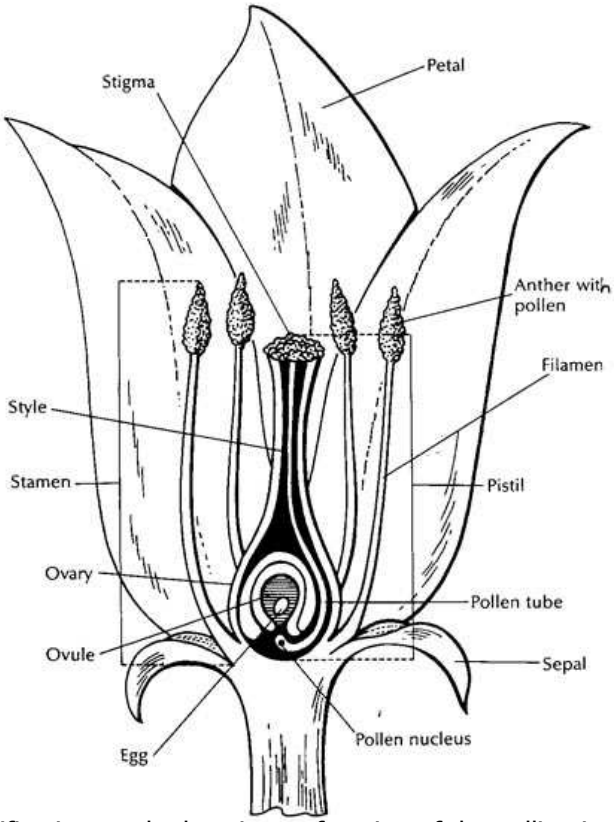
that make these colors are: xanthophylls (yellow), tannins (brown) and carotenes (yellowish orange to light red). The deep reds, purples, and blues of the leaves are created by a reaction of sunlight and sugars in leaves. This is quite common in the sugar maple which has a high quantity of sugar in its leaves.

Chapter Five: From Fruit to Flower

The **angiosperms**, flowering plants, are the most numerous and widespread of all plants. Possibly the reason for this is their unique adaptations for reproduction. The life cycle of the angiosperm is similar to the life cycle of the gymnosperm save for several distinct differences. The sporophyte generation is still dominant in the angiosperm, but the gametophyte is smaller even than in the gymnosperms. The microgametophyte, located in the pollen grain, consists of only three cells, while the megagametophyte in the ovule is made up of seven cells and eight nuclei, the extra being used for double fertilization. Also, angiosperms lack the archegonia present in the gymnosperms. The life cycles of both have been covered at length earlier in this book, and so the focus of this chapter will fall on the structures and other adaptations responsible for pollination.



Parts of a Flower

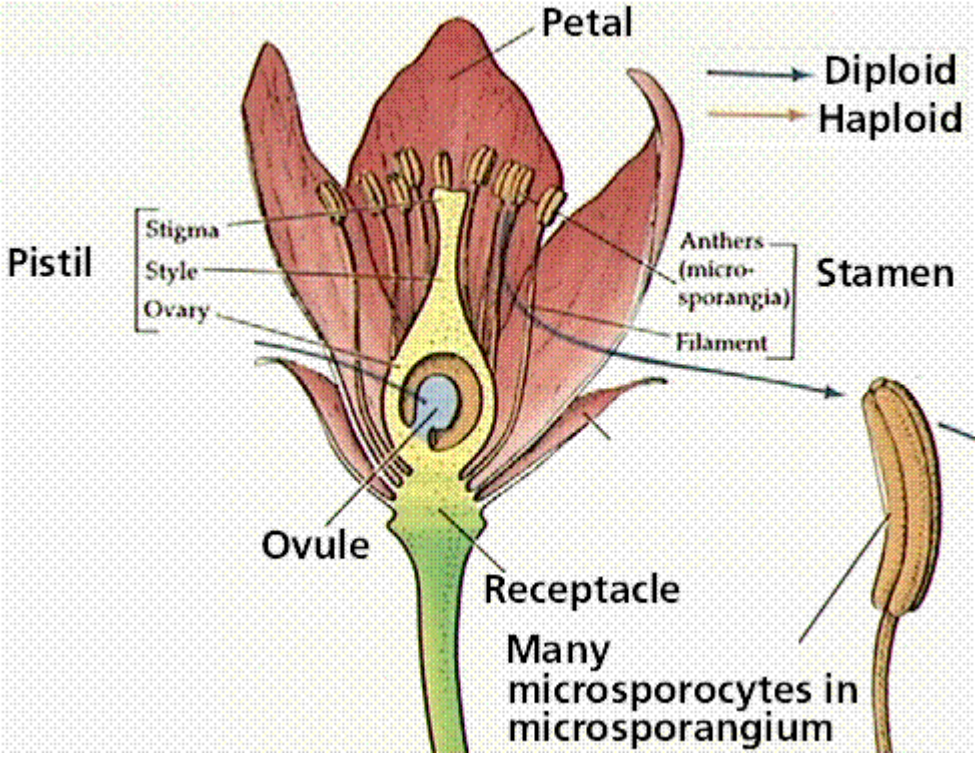


(Refer to the above diagrams for clarification on the location or function of the pollination structures being discussed.)

Like with all organisms that reproduce, angiosperms have distinct male and female parts. The female reproductive organ is the **pistil**, and the male reproductive organ is the **stamen**. Each of these organs consists of multiple pieces. The pistil is made up of a **carpel** or, in some cases, multiple carpels. When there is one carpel per flower, it is termed monocarpous. When there are multiple carpels per flower, it is said to be apocarpous when the carpels are distinct and syncarpous when they are indistinct.

The carpel is, in turn made up of three distinct parts, the **stigma**, the **style**, and the **ovary**. The stigma is located at the top of the carpel and is where the pollen grain lands to produce a pollen tube. The style is the tube at the base of the stigma that leads to the ovary. The ovary holds the **ovules** and is located at the base of the carpel. The egg inside each of these ovules will be fertilized by a sperm cell from the pollen grain, and its development will be controlled by an **auxin**, indole-3-acetic acid.

The stamen is composed of the **anther** and the **filament**. The anther holds **pollen**, the male gametophyte. The filament merely serves to hold the anther.



(In the above diagram, the components of the pistil and the stamen are shown in great detail.)

For more information on the angiosperm life cycle and the actual mechanism of pollination, consult Chapter Two. What will be explained in more detail here are the numerous ways in which the angiosperms have adapted to transport pollen from one flower to another.

One of the most efficient ways that angiosperms have to pollinate is to use another organism to carry the pollen from one flower to another. Each flower has special adaptations fitting to its preferred pollinator. Bees are the most important pollinator for angiosperms. The pollen of many angiosperms is specially adapted to adhere to the bees when they come to drink nectar from the flower. Two of the most common of these adaptations are sticky pollen and pollen with spines that cling to the bee.

Bees, however, are not the only animals to pollinate angiosperms. For example, plants seeking to be pollinated by birds will often have a perch for the bird. Hummingbirds require no perch; instead plants trying to attract them will often be red or orange, to match the hummingbird's vision, be free-hanging, and have dilute nectar.

(Below, a hummingbird is seen drinking nectar from a red flower.)

Butterflies are another example. Plants that prefer to be pollinated by butterflies have narrow flower tubes that the proboscis of a butterfly can fit into but not other insects.

Aside from these specialized adaptations, there are many general things flowers can do to attract pollinators. These include but are not limited to nectar, perfume, solid food, and even pollen. Visual and olfactory attractions are also an important tool employed by the angiosperms. Many have nectar or honey guides, color patterns that lead potential pollinators to the flower. Others use olfactory honey guides and osmophores, specialized odor producers, to attract pollinators. Some even employ thermogenic respiration, a heat producing process that aids in the evaporation of odors.

The reason that a vast majority of flowering plants must achieve **cross-pollination** is because, while they have come up with adaptations to make pollination easier, flowering plants have also adopted conditions that make **self-pollination** unlikely or impossible. Dichogamous flowers have pistils and stamens that reach maturity at different times. Dioecious flowers either produce pollen or have pistils so that the two never occur on the same plant. Heterostyly prevents flowers from self-pollinating because the pistil and stamen are at different height. Pins have long pistils and short stamens, and thrums have short pistils and long stamens.

(The above picture shows a thrum flower (left) and a pin flower (right).)

These conditions are, in fact beneficial to the angiosperms because they ensure genetic diversity and are yet another example of the adaptations of flowering plants that has led to them outnumbering all other types of plants.

Glossary

Angiosperm: a class of flowering plants that encloses its seeds within an ovary

Auxin: plant hormones that control many aspects of the angiosperm life cycle, the most important being indole-3-acetic acid which controls embryonic development, leaf formation, and fruit development among other things

Cross-pollination: pollination of a plant by a another plant

Endosperm: formed by a sperm cell and two nuclei in the ovule during double fertilization, it acts as food for the embryo produced by the angiosperm

Megaspore: the larger type of spore, it eventually develops into the embryo sac, or female gametophyte, in angiosperms

Microspore: the smaller type of spore, it develops into the male gametophyte

Ovary: the portion of the carpel containing ovules

Ovule: contains an egg cell and several other cells involved in double fertilization

Pollen Tube: a long tube burrowed down the style by the tube nucleus when a pollen grain attaches to the stigma

Seed: the body of a new plant developed from a fertilized ovule

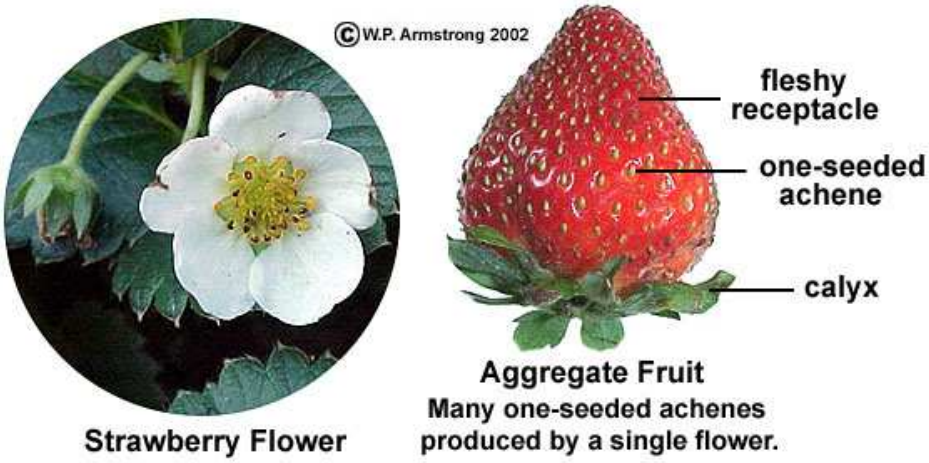
Self-pollination: pollination of a plant by that same plant

Stigma: the tip of the carpel where pollen grains form a pollen tube

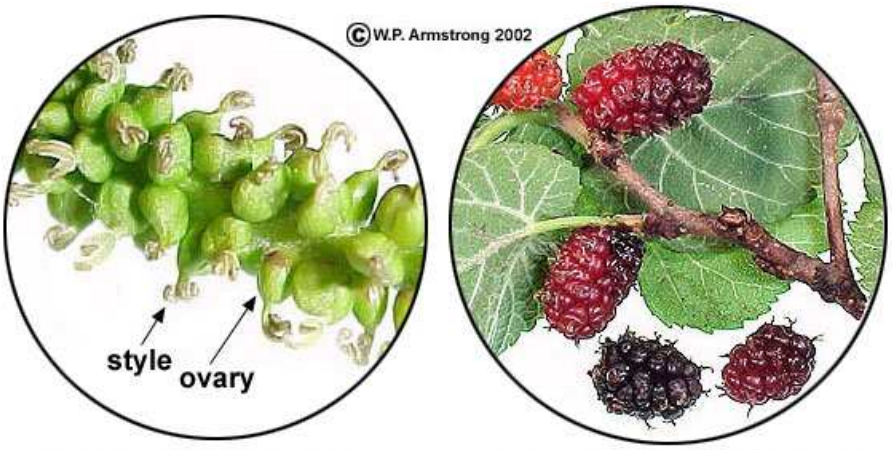
Style: The thin tube part of the carpel between the stigma and the ovary

Chapter 6: Fruit Classification and Ripening

There are numerous criteria by which fruits are classified. The broadest of these criteria deals with the number of ovaries and number of flowers the fruit developed from. At this broadest level of classification, there are three groups of fruit. **Simple fruits** are fruits developed form one ovary of one flower. **Aggregate fruits** are developed from multiple ovaries of a single flower. Some common examples are strawberries (shown below), blackberries, and raspberries. **Multiple fruits** comprise the third group at this level of classification. Multiple fruits develop from multiple ovaries of multiple flowers. Some of the more well-known varieties are mulberries (shown below) and pineapple.



Hybrid Strawberry (*Fragaria ananassa*)



Numerous Female Flowers: Each composed of an individual monocarpous pistil (gynoecium).

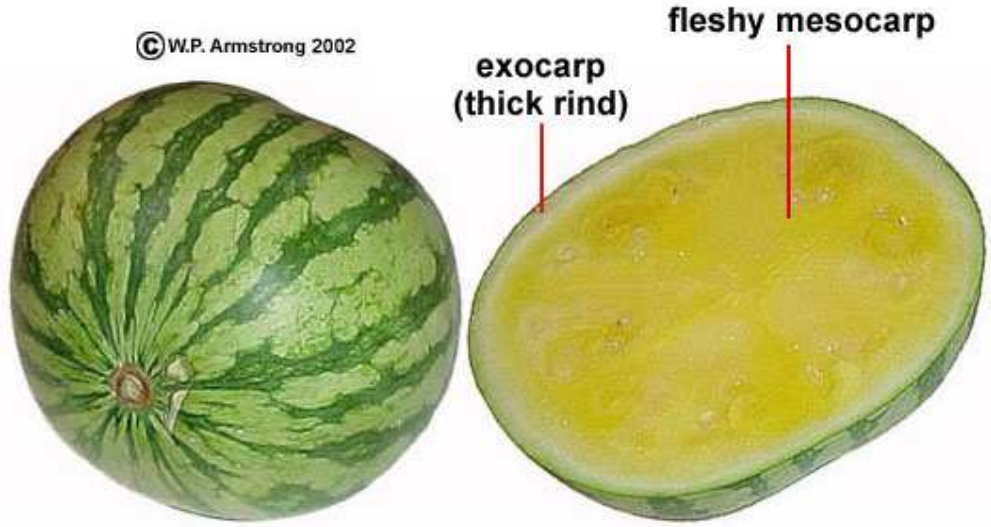
Multiple Fruit (Many Drupelets): Each seed-bearing drupelet from the ovary of one pistillate flower.

Multiple Fruit of the Black Mulberry (*Morus nigra*)

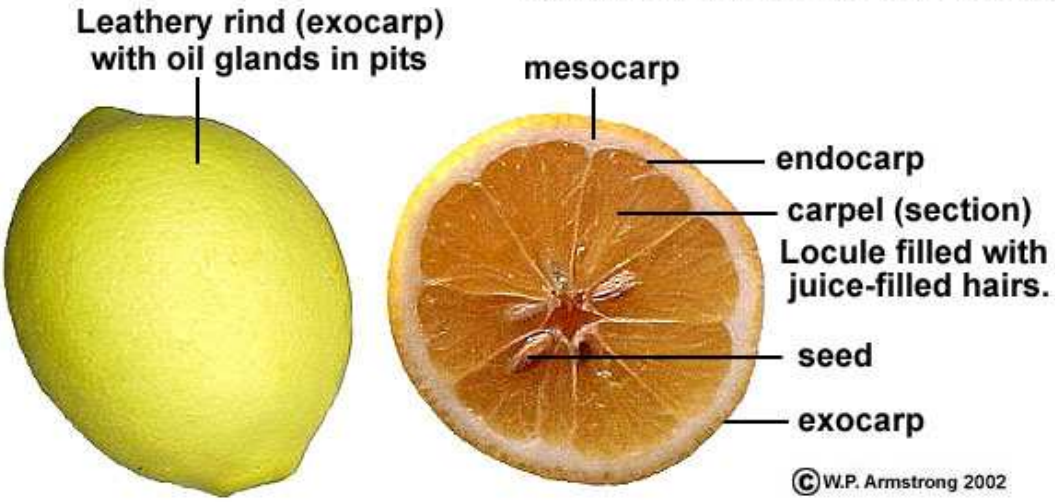
Another common way that fruits are classified is into two categories, **fleshy fruits** and **dry fruits**. Fleshy fruits have soft ovary walls when they are at maturity, and dry fruits have dry, rigid ovary walls when mature. Each of these categories is further subdivided.

Within the category of fleshy fruits there are five distinct subcategories. First, there are **berries**. In berries, the entire outer wall is fleshy. Another type of fleshy fruit is the **pepo**. A pepo is a type of berry that has a thick rind. Examples of pepo are gourds, a commonly known one being the watermelon. The third type of fleshy fruit is the **hesperidium**. A hesperidium has a leather-like rind and divisions in the fruit. Common examples are oranges and lemons. Fourth are **drupes**; a drupe has a hard inner layer enclosing the seed. Common drupes are peaches and plums. Lastly, there are **pome** fruits. This category, which includes the apple, is the most well-known. Pome fruits have an edible tissue surrounding the core.

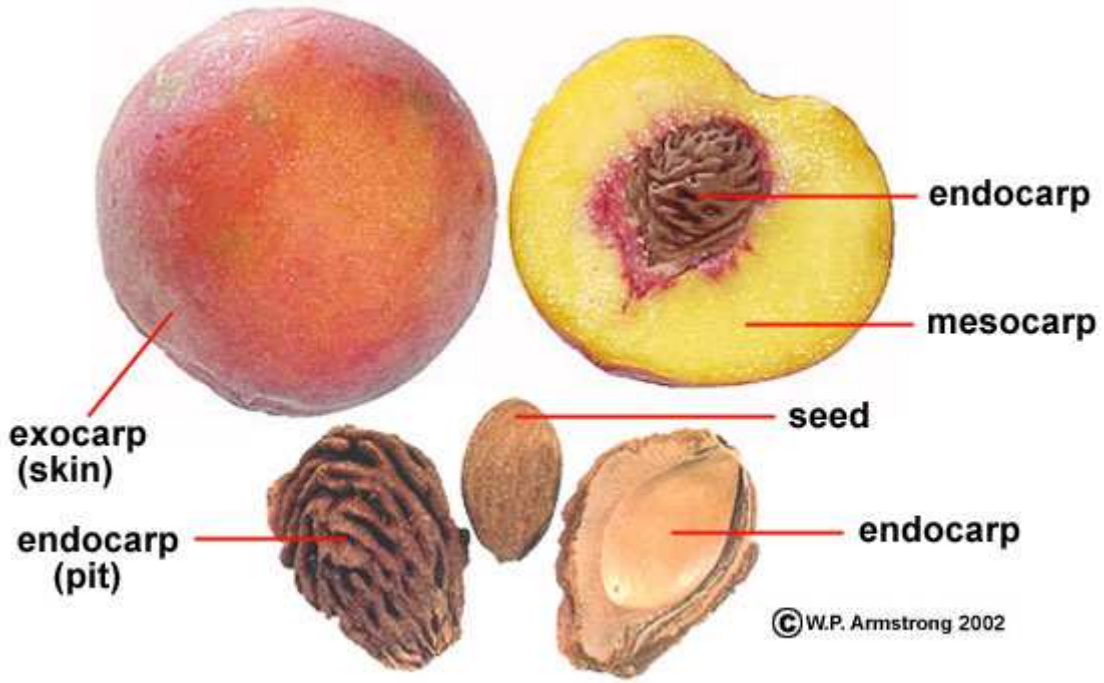
(Right, a cross-section shows the parts of a typical pepo.)



Pepo (a berry with a hard, thick rind)
e.g. watermelon (*Citrullus lanatus* var. *lanatus*)

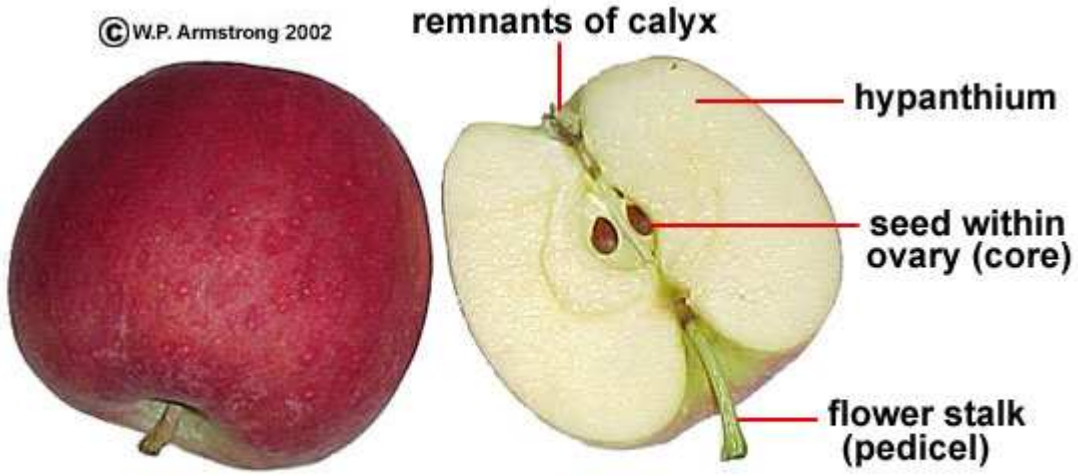


Hesperidium (berry with a leathery rind)
e.g. lemon (*Citrus lemon*)



Drupe (fleshy fruit with a stony endocarp)

(Shown above are cross sections of typical hesperidium and drupe fruits.)



Pome (ovary surrounded by fleshy hypanthium)
e.g. apple (*Malus domestica* cv. *'gala'*)

(Above, a cross-section of an apple shows the edible tissue around the core.)

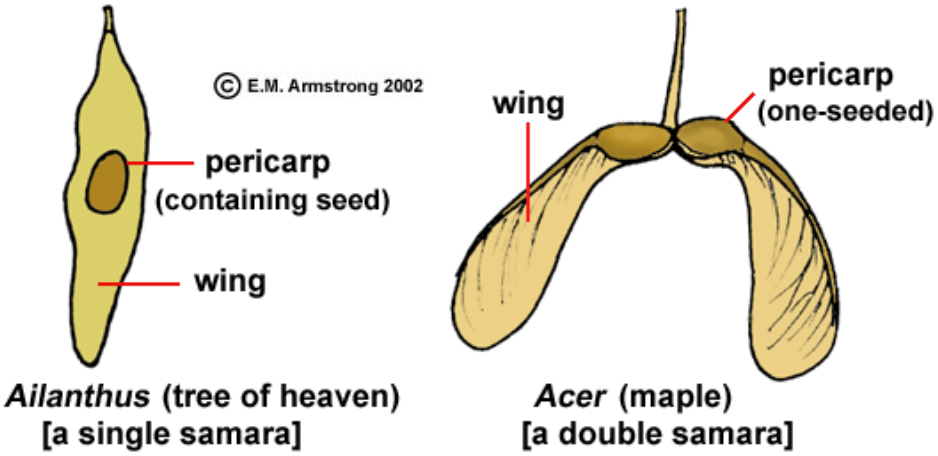
Dry fruit has two subcategories, **dehiscent** dry fruit and **indehiscent** dry fruit. Dehiscent fruit has an ovary wall with definite seams, and indehiscent fruit has no seams. Each of these categories is, again subdivided into many other categories.

The most important type of fruit in the dehiscent category is the family of fruits known as **legumes**. Legumes are the third most abundant family of plants. The legume **pod** has two distinct seams and resembles a folded leaf with seams at the edges.

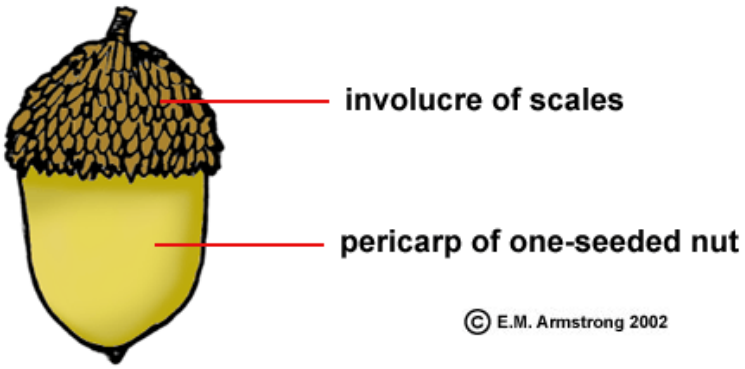
Peanut (*Arachis hypogea*): Pod (legume) & seeds.

(The peanut is a well-known legume as are peas, both of which can be identified as legumes because of their pods.)

Three of the types of fruit comprising the category of indehiscent dry fruit are commonly found, and, because of this, these are the most relevant. **Grain** is a one-seeded indehiscent fruit in which the seed coat is fused with the ovary wall. **Samaras**, or "helicopters," are a type of indehiscent fruit with a wing or wings. They are most often produced by trees, the maple being a common example. Lastly, **nuts** are, in fact a type of fruit. They are indehiscent and contain a single seed in a very hard ovary wall. They are often connected to a cuplike structure as is the case with the acorn.



Samara (a winged achene)



Oak (*Quercus* sp.): A true nut called an acorn.

(Above, the wings of a maple samara can be seen as can the cuplike structure attached to the hard ovary wall of the acorn.)

Even though the ways to classify fruits are so numerous, the development and ripening of each is controlled by the same two growth **hormones**, **auxin**, specifically indole-3-acetic acid, and **ethylene**. Auxin stimulates the development of the fruit, as was mentioned previously in Chapter 5. It is released when the seed starts to mature, and it directs the surrounding parts of the flower to develop into the fruit that surrounds the seed. When a fruit has reached its full size, it will begin to produce ethylene. Ethylene causes the ripening of the fruit, changing starches into sugars and releasing an aroma. This ripening makes the fruit more appealing to animals that disperse the seeds so that the seed plant life cycle can continue.

Glossary

Aggregate fruit: fruit developed from multiple ovaries of one flower

Berry: fleshy fruit with the entire outer wall being soft

Core: inedible center of a pome

Dehiscent: dry fruit with a seamed pericarp

Drupe: fleshy fruit with a hard inner layer enclosing the seed

Dry fruit: fruit with a hard, rigid ovary wall, or pericarp, at maturity

Ethylene: hormone responsible for fruit ripening

Fleshy fruit: fruit with a soft pericarp at maturity

Grain: indehiscent dry fruit with fused seed coat and ovary wall

Hesperidium: berry with a leather-like rind and partitions

Hormones: chemicals controlling development, see **Auxin**, Chapter 5 Vocabulary

Indehiscent: dry fruit with a seamless pericarp

Legume: a dehiscent pod plant, third most abundant family of plants

Multiple fruit: fruit developed from multiple ovaries of multiple flowers

Nut: indehiscent dry fruit with a very thick ovary wall

Pepo: berry with a thick rind

Pericarp: proper name for the ovary wall

Pit: hard inner layer of a drupe

Pod: outer, seamed casing of a legume

Pome: fleshy fruits with an edible layer surrounding the core

Samara: "helicopter," winged indehiscent dry fruit

Seed: body of a new plant, developed from fertilized ovule

Simple fruit: fruit developed from one ovary of one flower

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Role Sheet

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