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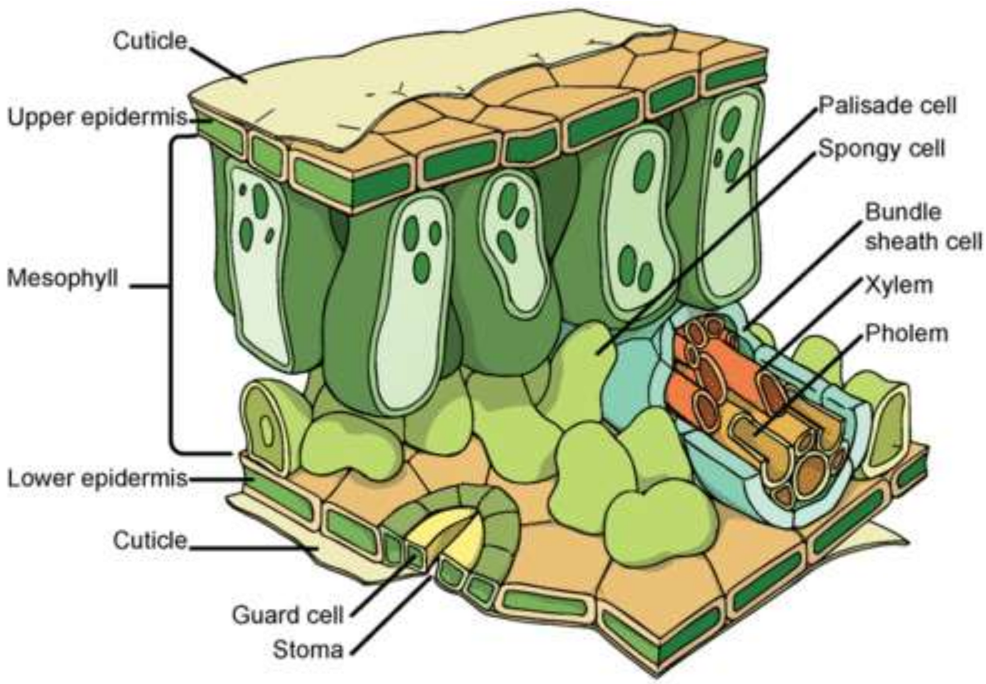
Leaf Structure + Function

DIRECTIONS: Read the article to fill out the Leaf Cross Section Flipchart.
https://www.ck12.org/biology/leaf-structure-and-function/lesson/Leaf-Structure-and-Function-Advanced-BIO-ADV/
https://www.nature.com/scitable/topicpage/photosynthetic-cells-14025371

Factories for Photosynthesis

A leaf is a highly organized factory – an organ constructed of several kinds of specialized tissues, each of which has its own duties. The product of the factory is no less than the food which supports nearly all life on Earth (although we must not forget that roughly half of Earth's photosynthetic productivity is the province of algae and bluegreen bacteria, both evolutionary ancestors of plants.) In this section, we will explore how each tissue's structure contributes to the production of food.



A cross section of a leaf shows that it is a complex organ built of several different kinds of specialized tissues. The tissues, in turn, are built of specialized cells, and the cells, of organelles.[Figure1]

The outer surface of the leaf has a thin waxy covering called the **cuticle**, this layer's primary function is to prevent water loss within the leaf. (Plants that live entirely within water do not have a cuticle).

Directly underneath the cuticle is a layer of cells called the **epidermis**. **Epidermis** covers the upper and lower surfaces of the leaf. Usually a single layer of tightly-packed cells, the epidermis mediates exchanges between the plant and its environment, limiting water loss, controlling gas exchange, transmitting sunlight for photosynthesis, and discouraging herbivores.

The epidermis secretes a waxy **cuticle** of suberin, which restricts evaporation of water from the leaf tissue. This layer may be thicker in the upper epidermis compared to the lower, and in dry climates compared to wet ones. Epidermal hairs can discourage herbivores, limit the effects of wind, and trap a layer of moisture to reduce water loss.

Mesophyll ("middle leaf" – refer again to **Figure 1**) includes the tissues which build most of the interior of the leaf. These tissues conduct most of the photosynthesis for most plants. In flowering plants and ferns, two different layers make up the mesophyll - Palisade cells are more column-like, and lie just under the epidermis, the spongy cells are more loosely packed and lie between the palisade layer and the lower epidermis.

- The upper, **palisade layer** captures most of the sunlight and carries out most of the photosynthesis. The columnar cells of the palisade layer contain many chloroplasts. Slight but precise separations between the cells maximize availability of the raw materials for photosynthesis by allowing diffusion of CO_2 and capillary movement of H_2O. Leaves exposed to high levels of sunlight contain as many as five layers of palisade cells, while shade leaves may contain only one.

- The lower **spongy layer** contains more rounded cells with fewer chloroplasts. The cells are loosely packed, separated by larger, airy spaces. This lower layer of cells is closely associated with the stomata, and the airy spaces allow diffusion of oxygen, water vapor, and carbon dioxide through the stomata when they are open.

A layer or region of compactly arranged cells surrounding a vascular bundle in a plant. The **bundle sheath cells** regulate the movement of substances between the vascular tissue and the parenchyma and, in leaves, protect the vascular tissue from exposure to air.

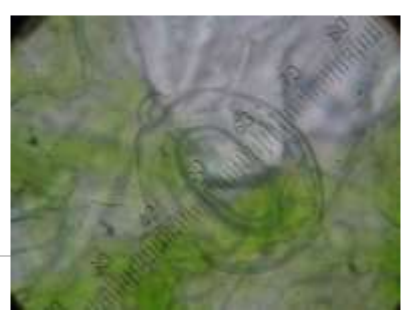
The vascular tissue, xylem and phloem are found within the veins of the leaf. Veins are actually extensions that run from to tips of the roots all the way up to the edges of the leaves. The outer layer of the vein is made of cells called **bundle sheath cells**, and they create a circle around the xylem and the phloem. On the picture, **xylem** is the upper layer of cells… while the lower half of the cells in the vein are the **phloem**.

An upper layer of **xylem** transports water and minerals from the roots and stem into and throughout the leaves. Xylem is made of dead cells, with heavily thickened but pitted cell walls. The cells are arranged end-to-end, straw-like, allowing hydrogen bonds between water molecules (cohesion) to pull each other (and hitch-hiking mineral ions) through the xylem columns when stomatal evaporation begins the transpirational pull.

Living cells of the lower layer of **phloem**, also arranged in bundles of straw-like columns but connected by sieve plates (and plasmodesmata), transport sugars made in the leaves ("sugar sources") to parts of the plants which need these fuels ("sugar sinks").
Like guard cells, vascular tissue harnesses the power of osmosis to accomplish movement without muscles. This feat is especially impressive because osmosis itself is a passive, entirely physical process.

Epidermis also lines the lower area of the leaf (as does the cuticle). The leaf also has tiny holes within the epidermis called stomata. Specialized cells, called **guard cells** surround the stomata (or "stoma" for a single pore) and are shaped like two cupped hands. Changes within water pressure cause the stoma (singular of stomata) to open or close. If the guard cells are full of water, they swell up and bend away from each other which opens the stoma. During dry times, the guard cells close to prevent water loss.

The presence of the cuticle limits water loss, but also inhibits absorption of carbon dioxide and excretion of oxygen. These functions are served by **stomata** (singular, **stoma**), "little mouths" which regulate water loss, O_2 release, and CO_2 intake. In most leaves, stomata are more abundant in the lower epidermis, limiting water loss due to direct sunlight. More movement without muscles! How do they work?



An microphotograph of a stoma shows the two guard cells which regulate its opening and closure to limit water loss, excrete oxygen, and absorb carbon dioxide. [Figure2]

The openings or pores in stomata are formed by two specialized sclerenchymal cells, the **guard cells** (**Figure** above). In guard cells, the thickenings spiral around the cell, preventing them from increasing in diameter. Epidermal cells stitch the guard cells firmly together so that they can expand only by bowing apart, forming the opening, or pore. But what makes them expand? Although the mechanism is not completely understood, it is known to harness the power of osmosis. In daylight or high humidity, when CO_2 is needed for photosynthesis and water loss can be minimized, the guard cells open (by using active transport to alter the concentration of hydrogen and potassium ions so that water flows into the cells; pressure builds up, and expands the cells to open the pores).

Closing the stomata is controlled by signals from roots when they sense water shortage. Under these conditions, the roots release a hormone, **abscisic acid (ABA)**, which binds to receptors in the guard cell membranes and alters ion uptake and concentrations. Consequent reduction in cytoplasm ion concentrations leads to the loss of water by osmosis, the guard cells "relax", and the pores close.

What Cells and Organelles Are Involved in Photosynthesis?

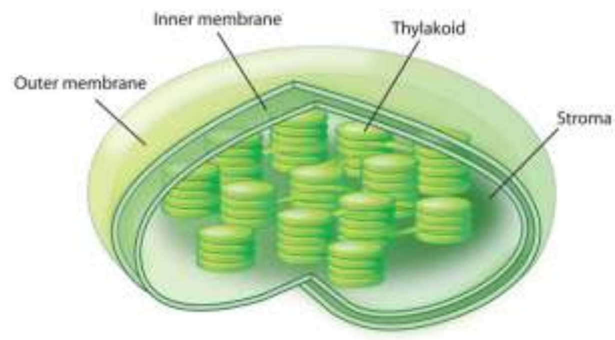


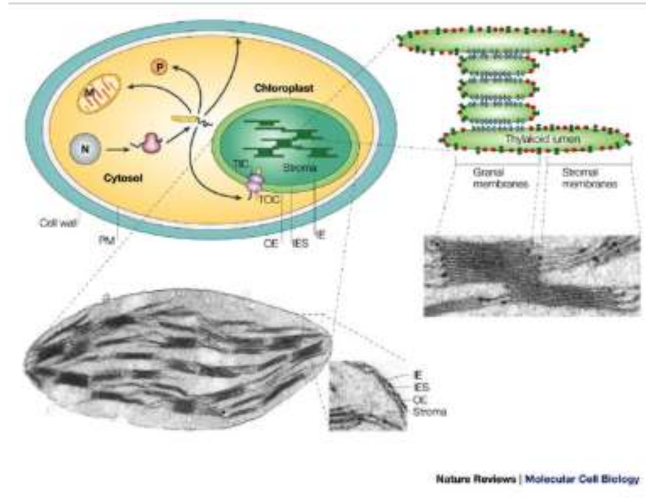
Figure 3: Structure of a chloroplast

Photosynthetic cells contain special pigments that absorb light energy. Different pigments respond to different wavelengths of visible light. Chlorophyll, the primary pigment used in photosynthesis, reflects green light and absorbs red and blue light most strongly. In plants, photosynthesis takes place in chloroplasts, which contain the chlorophyll. Chloroplasts are surrounded by a double membrane and contain a third inner membrane, called the thylakoid membrane, that forms long folds within the organelle. In electron micrographs, thylakoid membranes look like stacks of coins, although the compartments they form are connected like a maze of chambers. The green pigment chlorophyll is located within the thylakoid membrane, and the space between the thylakoid and the chloroplast membranes is called the stroma (Figure 3, Figure 4).

Chlorophyll A is the major pigment used in photosynthesis, but there are several types of chlorophyll and numerous other pigments that respond to light, including red, brown, and blue pigments. These other pigments may help channel light energy to chlorophyll A or protect the cell from photo-damage. For example, the photosynthetic protists called dinoflagellates, which are responsible for the "red tides" that often prompt warnings against eating shellfish, contain a variety of light-sensitive pigments, including both chlorophyll and the red pigments responsible for their dramatic coloration.

Figure 4: Diagram of a chloroplast inside a cell, showing thylakoid stacks. Shown here is a chloroplast inside a cell, with the outer membrane (OE) and inner membrane (IE) labeled. Other features of the cell include the nucleus (N),

mitochondrion (M), and plasma membrane (PM). At right and below are microscopic images of thylakoid stacks called grana. Note the relationship between the granal and stromal membranes.



What Are the Steps of Photosynthesis?

Photosynthesis consists of both light-dependent reactions and light-independent reactions. In plants, the so-called "light" reactions occur within the chloroplast thylakoids, where the aforementioned chlorophyll pigments reside. When light energy reaches the pigment molecules, it energizes the electrons within them, and these electrons are shunted to an electron transport chain in the thylakoid membrane. Every step in the electron transport chain then brings each electron to a lower energy state and harnesses its energy by producing ATP and NADPH. Meanwhile, each chlorophyll molecule replaces its lost electron with an electron from water; this process essentially splits water molecules to produce oxygen (Figure 5).

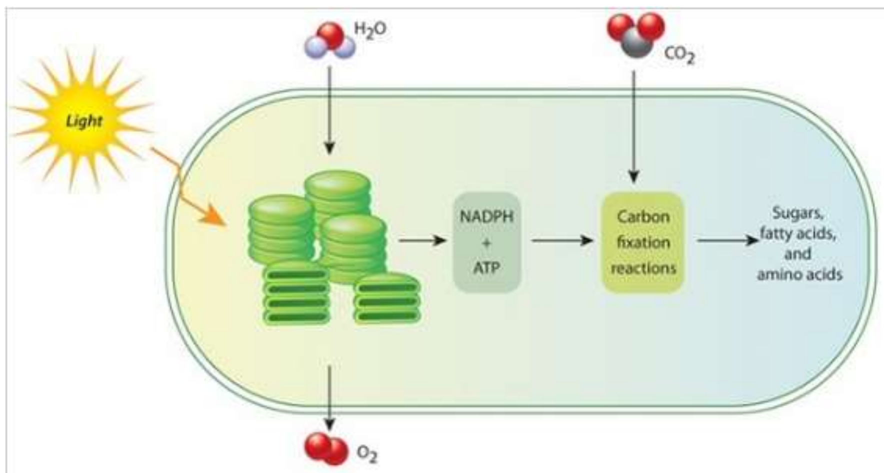


Figure 5: The light and dark reactions in the chloroplast

The chloroplast is involved in both stages of photosynthesis. The light reactions take place in the thylakoid. There, water (H_2O) is oxidized, and oxygen (O_2) is released. The electrons that freed from the water are transferred to ATP and NADPH. The dark reactions then occur outside the thylakoid. In these reactions, the energy from ATP and NADPH is used to fix carbon dioxide (CO_2). The products of this reaction are sugar molecules and various other organic molecules necessary for cell function and metabolism. Note that the dark reaction takes place in the stroma (the aqueous fluid surrounding the stacks of thylakoids) and in the cytoplasm.

Once the light reactions have occurred, the light-independent or "dark" reactions take place in the chloroplast stroma. During this process, also known as carbon fixation, energy from the ATP and NADPH molecules generated by the light reactions drives a chemical pathway that uses the carbon in carbon dioxide (from the atmosphere) to build a three-carbon sugar called glyceraldehyde-3-phosphate (G3P). Cells then use G3P to build a wide variety of other sugars (such as glucose) and organic molecules. Many of these interconversions occur outside the chloroplast, following the transport of G3P from the stroma. The products of these reactions are then transported to other parts of the cell, including the mitochondria, where they are broken down to make more energy carrier molecules to satisfy the metabolic demands of the cell. In plants, some sugar molecules are stored as sucrose or starch.

TEACHER SUMMARY TABLE:

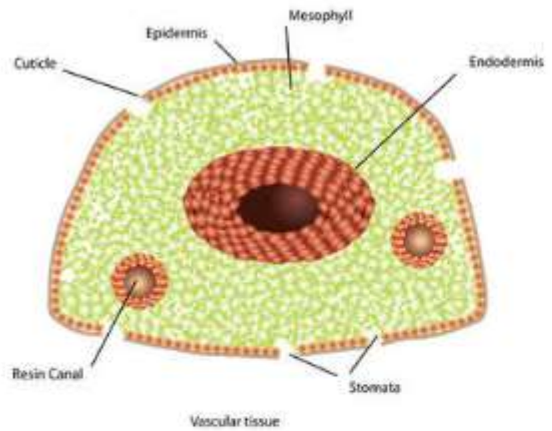
Structure-Function Relationship: Leaves

The **Table** below summarizes the structures which build leaves. Note once again how the structure's form suits its function.

Name of Structure	Structure	Function
ABA	Hormone molecule which binds to guard cell membrane receptors	Regulates closure of guard cells
Chloroplasts	Green organelles with stacked membranes	**Photosynthesis**
Cuticle	Layer of suberin	Limiting water loss
Epidermis	Single layer of thin, closely packed cells	Transmit light, limit water loss and control gas exchange
Guard cells	Spiral walls, bound at ends	Open and close to control gas exchange
Palisade cells	Tall, many chloroplasts, precisely spaced	Photosynthesis
Phloem	Elongated cells, living but without nucleus or ER, connected end to end by sieve plates and plasmodesmata	Transport of sugars in sap
Pith	Parenchyma with vacuoles and plastids	Storage, support
Plasmodesmata	Openings between sieve tubes connecting cytoplasm	Transport of sap
Spongy cells	Rounded, widely spaced, near stomata	Allow gas exchange
Suberin	Waxy molecule	Waterproofing
Vascular cambium	Undifferentiated, rapidly dividing cells between the xylem and phloem	Growth in diameter
Xylem	Elongated cells with thickened, pitted walls, connected end to end	Absorbing and transporting water and ions

TEACHER ADDITIONAL INFO:

Food production, habitat design, and regulation of Earth's atmosphere, temperature and water and carbon cycles make leaves our "green inheritance…without [which] we will surely perish.



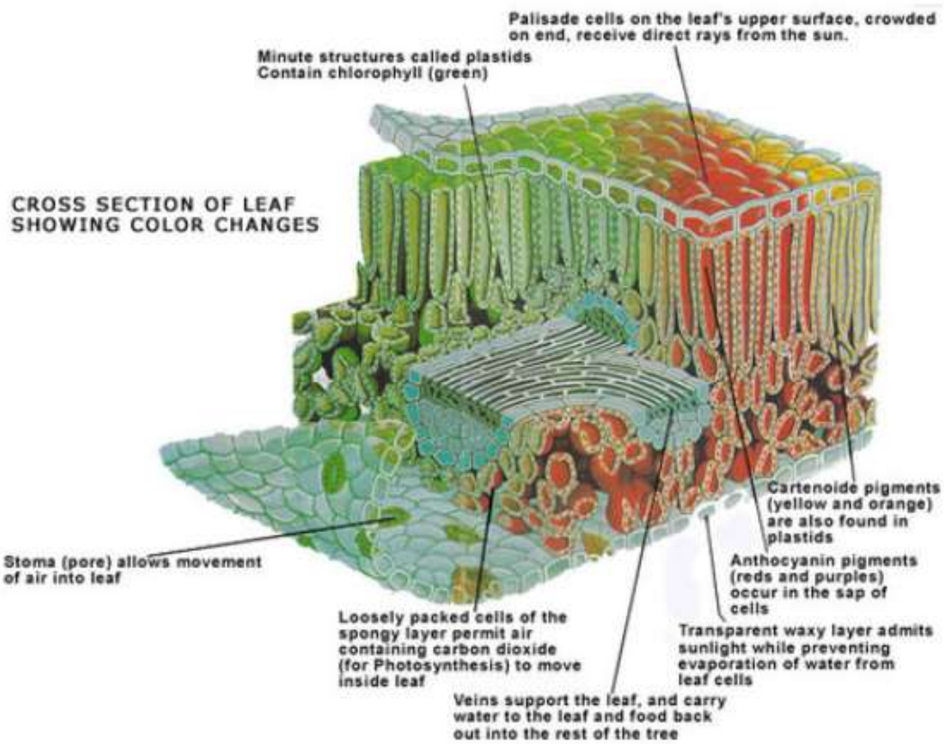
A cross-section of the needle-like leaf of a pine shows tissues similar to those of a flowering plant: protective epidermis with stomata, photosynthetic mesophyll, and vascular xylem and phloem. Differences include not only the water-conserving shape, but also a thicker, two-layered epidermis, a thicker cuticle, a single central "vein" of vascular tissue, and resin ducts which secrete resin in response to injury.[Figure3]

The needle-like leaves of conifers (**Figure 3**) have similar tissues and several additional adaptations. A single, central core of vascular tissue consists of xylem surrounded by phloem. Photosynthetic mesophyll surrounds the vascular tissue; some conifers (pines) lack a palisade layer, while others have both palisade and spongy layers (balsam fir, for example). Stomata open to allow entry of carbon dioxide, but the double-layered epidermis and waxy cuticle are often thicker and tougher than in dicot leaves. Many conifer leaves secrete **resin** through resin ducts in response to injury in order to discourage herbivores.

Additional Leaf Functions

As indicated above, many plants lose their leaves seasonally; though this occurs most often in temperate zones before the cold, dry season of winter, some plants lose their leaves in advance of hot, dry seasons. **Deciduous leaves** have a region of cells at the base of the petiole specialized for this purpose. Weak-walled cells make up its top layer, and expansion of a bottom layer of cells in the fall (or other appropriate season) breaks the upper cells' walls to release the leaf. **Evergreen** plants also lose leaves by this mechanism, but their loss occurs randomly throughout the year. Hormones including ethylene and auxins help to control the timing of leaf loss; although abscisic acid (ABA) was named after the process (**abscission**), it was later discovered to be of minor importance to leaf loss. Plant hormonoes will be discussed in the following chapter.

Closely related to loss of leaves is their change in color – not a function in itself, but a beautiful side effect of seasonal loss of function. Plants respond to seasonal decreases in levels of light and lower temperatures by reducing their production of the green pigment, chlorophyll. The loss of chlorophyll reveals accessory pigments such as yellow xanthophylls and orange carotenoids, which function to absorb other colors of light for photosynthesis. The red pigments (anthocyanins) are now thought to be added during the transition, protecting leaves' nitrogen supplies from potentially harmful exposure to sunlight as they are salvaged from leaf tissue to be stored elsewhere for later use. **Figure** below shows the presence of these leaf pigments and reviews flowering plant leaf tissues structures and functions.



Fall color change results from a decrease in the production of chlorophyll, which reveals accessory pigments such as xanthophylls and carotenoids. The leaves synthesize anthocyanins during the time of transition to protect supplies of nutrientssuch as nitrogen from sunlight damage as they are relocated to other parts of the plant before the leaf is lost. This diagram also reviews the structures and functions of leaf tissues; use it to check your understanding![Figure5]