# 23.4 Leaves

### Key Questions

- ***How is the structure of a leaf adapted to make photosynthesis more efficient?***
- ***What role do stomata play in maintaining homeostasis?***

### Vocabulary

blade • petiole • mesophyll • palisade mesophyll • spongy mesophyll • stoma • transpiration • guard cell

### Taking Notes

**Preview Visuals** Before you read the lesson, look at **Figure 23–15.** Locate the three main tissue systems and infer which tissue system makes up the leaf veins.

**THINK ABOUT IT** We hear a lot these days about "green industry," such as biofuels and material recycling, but did you know that the most important manufacturing sites on Earth are already green? They are the leaves of plants. In a sense, plant leaves are the world's most important manufacturers. Using the energy captured in their leaves, plants make the sugars, starches, and oils that feed virtually all land animals, including us.

## Leaf Structure and Function

***How is the structure of a leaf adapted to make photosynthesis more efficient?***

Recall from Chapter 8 that photosynthesis uses carbon dioxide and water to produce sugars and oxygen. Leaves, therefore, must have a way of obtaining carbon dioxide and water as well as distributing end products. **The structure of a leaf is optimized to absorb light and carry out photosynthesis.**

**Anatomy of a Leaf** To collect sunlight, most leaves have a thin, flattened part called a **blade.** The flat shape of a leaf blade maximizes the amount of light it can absorb. The blade is attached to the stem by a thin stalk called a **petiole** (PET ee ohl). Like roots and stems, leaves have an outer covering of dermal tissue and inner regions of ground and vascular tissues, as shown in **Figure 23–15.**

▶ ***Dermal Tissue*** Leaves are covered on their top and bottom surfaces by epidermis. Leaf epidermis is made of a layer of tough, irregularly shaped cells with thick outer walls that resist tearing. The epidermis of nearly all leaves is also covered by a waxy cuticle. The cuticle is a waterproof barrier that protects tissues and limits the loss of water through evaporation.

▶ ***Vascular Tissue*** The vascular tissues of leaves are connected directly to the vascular tissues of stems, making them part of the plant's fluid transport system. Xylem and phloem tissues are bundled in leaf veins that run from the stem throughout the leaf.

▶ ***Ground Tissue*** The area between leaf veins is filled with a specialized ground tissue known as **mesophyll** (MES uh fil), where photosynthesis occurs. The sugars produced in mesophyll move to leaf veins, where they enter phloem sieve tubes for transport to the rest of the plant.

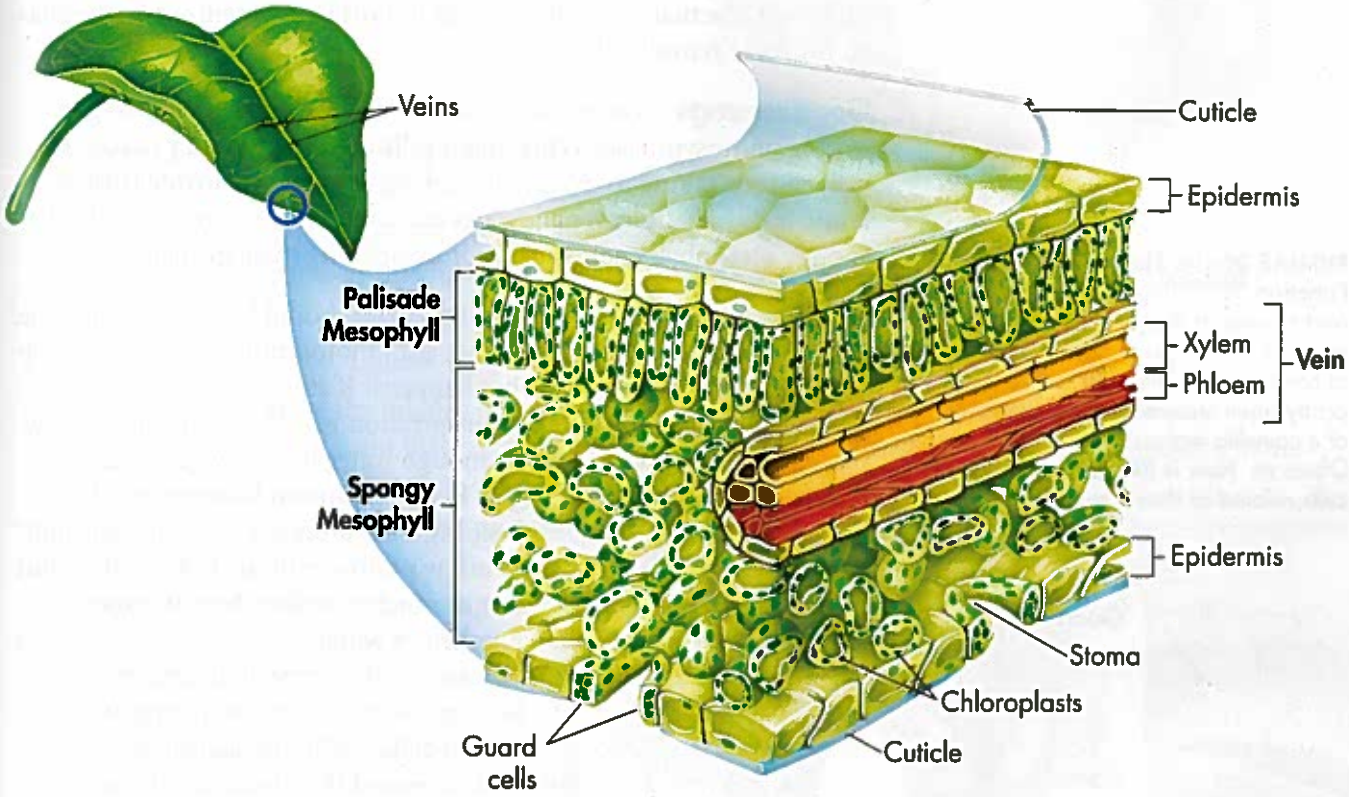
**MYSTERY CLUE**

**The mature fig's stems and leaves block sunlight from the host. How might this affect photosynthesis in the host?**

## ZOOMING IN

### ANATOMY OF A LEAF

**FIGURE 23–15** Leaves absorb light and carry out most of the photosynthesis in a plant.
**Compare and Contrast** ***Compare the structure of the two types of mesophyll cells in a leaf.***




**Photosynthesis** The mesophyll tissue in most leaves is highly specialized for photosynthesis. Beneath the upper epidermis is a layer of cells called the **palisade mesophyll,** containing closely packed cells that absorb light that enters the leaf. Beneath the palisade layer is a loose tissue called the **spongy mesophyll,** which has many air spaces between its cells. These air spaces connect with the exterior through **stomata** (singular: stoma). Stomata are small openings in the epidermis that allow carbon dioxide, water, and oxygen to diffuse into and out of the leaf.

**Transpiration** The walls of mesophyll cells are kept moist so that gases can enter and leave the cells easily. The trade-off to this feature is that water evaporates from these surfaces and is lost to the atmosphere. **Transpiration** is the loss of water through leaves. This lost water may be replaced by water drawn into the leaf through xylem vessels in the vascular tissue. Transpiration helps to cool leaves on hot days, but it may also threaten the leaf's survival if water is scarce.

**In Your Notebook** *Make a two-column table in which you list structures found in a leaf cross section and describe their functions.*

**BUILD Vocabulary**

**WORD ORIGINS** **Mesophyll** comes from two Greek words: *meso,* meaning "middle," and *phyllon,* meaning "leaf." **Stomata** comes from the Greek word meaning "mouths."

# Gas Exchange and Homeostasis

***What role do stomata play in maintaining homeostasis?***

You might not think of plants as "breathing" the same way that animals do, but plants need to exchange gases with the atmosphere, too. Plants, in fact, can even be suffocated by lack of oxygen, something that often happens during extensive flooding. A plant's control of gas exchange is actually one of the most important elements of homeostasis for these remarkable organisms.

**Gas Exchange** Leaves take in carbon dioxide and give off oxygen during photosynthesis. When plant cells use the food they make, the cells respire, taking in oxygen and giving off carbon dioxide (just as animals do). Plant leaves allow gas exchange between air spaces in the spongy mesophyll and the exterior by opening their stomata.

**Homeostasis** It might seem that stomata should be open all the time, allowing gas exchange to take place and photosynthesis to occur at top speed. However, this is not what happens! If stomata were kept open all the time, water loss due to transpiration would be so great that few plants would be able to take in enough water to survive. So, plants maintain a kind of balance. **Plants maintain homeostasis by keeping their stomata open just enough to allow photosynthesis to take place but not so much that they lose an excessive amount of water.**

Guard cells in the epidermis of each leaf are the key to this balancing act. **Guard cells** are highly specialized cells that surround the stomata and control their opening and closing. Guard cells regulate the movement of gases, especially water vapor and carbon dioxide, into and out of leaf tissues.

The stomata open and close in response to changes in water pressure within the guard cells, as shown in **Figure 23–16.** When water is abundant, it flows into the leaf, raising water pressure in the guard cells, which then open the stomata. The thin outer walls of the cells are forced into a curved shape, which pulls the thick inner walls of the guard cells away from one another, opening the stoma. Carbon dioxide can then enter through the stoma, and water is lost by transpiration.

When water is scarce, the opposite occurs. Water pressure within the guard cells decreases, the inner walls pull together, and the stoma closes. This reduces further water loss by limiting transpiration.

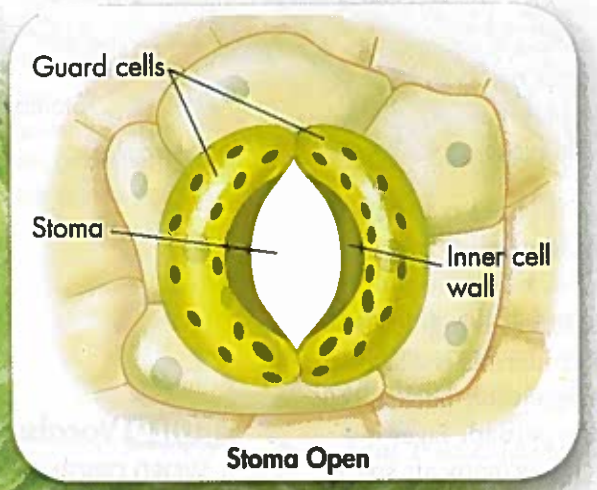



**FIGURE 23–16 How Guard Cells Function** Plants regulate the opening and closing of their stomata to balance water loss with rates of photosynthesis. The photo shows two partly open stomata on the underside of a camellia leaf (SEM 1500×).
**Observe** ***How is the structure of guard cells related to their function?***

## Quick Lab
GUIDED INQUIRY

### Examining Stomata

1. Obtain different kinds of leaves from your teacher.
2. Spread a thick coating of clear nail polish on the underside of each leaf.
3. Wait about 10 minutes for the polish to dry completely.
4. Attach a strip of clear tape to the polish and gently peel off the tape, lifting the dried polish.
5. Tape the polish to a clean microscope slide and examine under a 400× lens.
6. For each leaf, move the microscope stage so you can count stomata from three distinct fields of view.

**Analyze and Conclude**

**1. Calculate** What is the average number of stomata per square cm for each leaf? MATH

**2. Graph** Make a graph that compares these averages.

**3. Form a Hypothesis** What could account for differences in stoma density among plants? Write a hypothesis.

In general, stomata are open during the daytime, when photosynthesis is active, and closed at night, when open stomata would only lead to water loss. However, stomata may be closed even in bright sunlight under hot, dry conditions in which water conservation is a matter of life and death. Guard cells respond to conditions in the environment, such as wind and temperature, helping to maintain homeostasis within a leaf.

**Transpiration and Wilting** Osmotic pressure keeps a plant's leaves and stems rigid, or stiff. High transpiration rates can lead to wilting. Wilting results from the loss of water—and therefore pressure—in a plant's cells. Without this internal pressure to support them, the plant's cell walls bend inward, and the plant's leaves and stems wilt. When a leaf wilts, its stomata close. As a result, transpiration slows down significantly. Thus, wilting helps a plant to conserve water.

**FIGURE 23–17 Wilting** A plant may wilt when water is scarce.

**In Your Notebook** *Make a list of molecules that are exchanged through the stomata. Which ones primarily enter the leaf? Which ones primarily exit the leaf?*

## Adaptations of Leaves

**FIGURE 23–18** The plants shown here grow in different biomes. The leaves of these plants have adaptations to the dry or low-nutrient conditions in which they live.

◀ **Pitcher Plant** The leaf of a pitcher plant is modified to attract and then digest insects and other small prey. Such plants typically live in nutrient-poor soils and rely on animal prey as their source of nitrogen.

▼ **Rock Plant** The two leaves of a rock plant are adapted for hot, dry conditions. They are rounded, which minimizes the exposure of their surface to the air. They also have very few stomata.

**Spruce** The narrow leaves of a spruce tree contain a waxy epidermis as well as stomata that are sunken below the surface of the leaf. These adaptations reduce water loss from the leaves. ▶

**Cactus** Cactus leaves are actually nonphotosynthetic thorns that protect against herbivores. Most of the plant's photosynthesis is carried out in its stems. ▼

# 23.4 Assessment

## Review Key Concepts

1. **a. Review** Describe how the structure of a leaf is adapted to make photosynthesis more efficient.
   **b. Explain** What is the role of the palisade mesophyll in a leaf?
   **c. Form a Hypothesis** The leaves of desert plants often have two or more layers of palisade mesophyll, rather than the single layer that is characteristic of most leaves. How might this modified structure be advantageous to a desert plant?
2. **a. Review** How do stomata help plants maintain homeostasis?
   **b. Predict** Are stomata more likely to be open or closed on a hot day? Explain your answer.

## BUILD VOCABULARY

3. The terms *spongy* and *palisade* are adjectives that describe two specific kinds of mesophyll. Look up these words in a dictionary to discover other contexts in which they are used. Then, explain why they are appropriate words for the types of mesophyll they describe.

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# 23.5 Transport in Plants

**THINK ABOUT IT** Look at a tall tree. Maybe there's one outside your school that's 15 meters high or even taller. Think about how much work it would be to haul water up to the top of that tree. Now think of a giant redwood, a hundred meters high. How does water get to the top?

## Water Transport

***What are the major forces that transport water in a plant?***

Recall that active transport and root pressure cause water to move from soil into plant roots. The pressure created by water entering the tissues of a root can push water upward in a plant stem. However, this pressure does not exert nearly enough force to lift water up into trees. Other forces are much more important.

**Transpiration** The major force in water transport is provided by the evaporation of water from leaves during transpiration. As water evaporates through open stomata, the cell walls within the leaf begin to dry out. Cell walls contain cellulose, the same material used in paper. As you know, dry paper towels strongly attract water. Similarly, the dry cell walls draw water from cells deeper inside the leaf. The pull extends into vascular tissue so that water is pulled up through xylem.

How important is transpirational pull? On a hot day, even a small tree may lose as much as 100 liters of water to transpiration. The hotter and drier the air, and the windier the day, the greater the amount of water lost. As a result of this water loss, the plant draws up even more water from the roots. **Figure 23–19** shows an analogy for transpirational pull.

### Key Questions

***What are the major forces that transport water in a plant?***

***What drives the movement of fluid through phloem tissue in a plant?***

### Vocabulary

adhesion • capillary action • pressure-flow hypothesis

### Taking Notes

**Compare/Contrast Table** As you read, create a table in which to compare and contrast the functions of xylem and phloem.

**VISUAL ANALOGY**

TRANSPIRATIONAL PULL

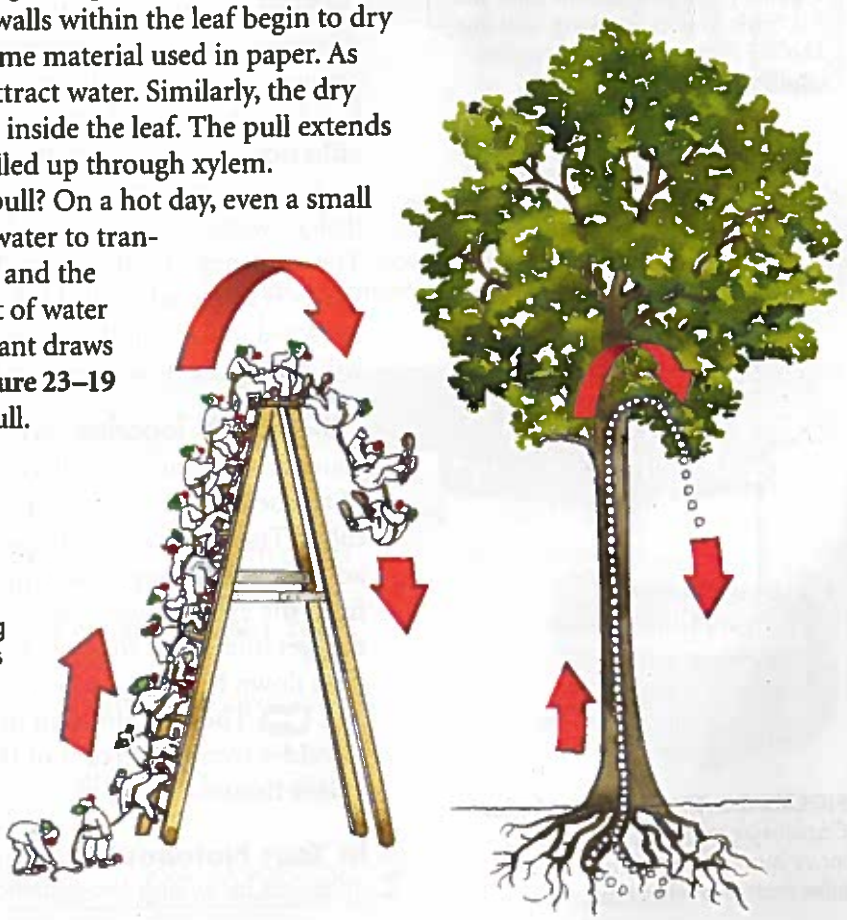

**FIGURE 23–19** Imagine a chain of circus clowns who are tied together and climbing a tall ladder. When the first clown reaches the top, he falls off, pulling the clowns behind him up and over the top. Similarly, the chain of water molecules in a plant extends from the leaves down to the roots. As molecules exit leaves through transpiration, they pull up the molecules behind them.

## Quick Lab
GUIDED INQUIRY

### What Is the Role of Leaves in Transpiration?

1. Use a scalpel to cut 1 cm off the bottoms of three celery stalks. **CAUTION:** *Use the scalpel with care.*
2. Remove the leaves from one stalk. Use a cotton swab to apply petroleum jelly to both sides of all the leaves on another stalk. Place all three stalks into a plastic container holding about 200 mL of water and several drops of food coloring.
3. Place the plastic container in a sunny location. Observe the celery at the end of the class and the next day. Record your observations each day.

**Analyze and Conclude**

1. **Observe** In which stalk did the colored water rise the most? The least?
2. **Infer** What effect did the petroleum jelly have on transpiration? What part of the leaf did the petroleum jelly affect?
3. **Draw Conclusions** How are leaves involved in transpiration?

**BUILD Vocabulary**

**WORD ORIGINS** The word *capillary* comes from the Latin word for "hair." Hairs are long and thin, like the narrow spaces in which **capillary action** takes place.

**FIGURE 23–20 Capillary Action** Capillary action causes water to move much higher in a narrow tube than in a wide tube.

**How Cell Walls Pull Water Upward** To pull water upward, plants take advantage of some of water's most interesting physical properties. Water molecules are attracted to one another by a force called cohesion. Recall from Chapter 2 that cohesion is the attraction of molecules of the same substance to each other. Water cohesion is especially strong because of the tendency of water molecules to form hydrogen bonds with each other. Water molecules can also form hydrogen bonds with other substances. This results from a force called **adhesion,** which is attraction between unlike molecules.

If you were to place empty glass tubes of various diameters into a dish of water, you would see both cohesion and adhesion at work. The tendency of water to rise in a thin tube is called **capillary action.** Water is attracted to the walls of the tube, and water molecules are attracted to one another. The thinner the tube, the higher the water will rise inside it, as shown in **Figure 23–20.**

**Putting It All Together** What does capillary action have to do with water movement through xylem? Recall that xylem tissue is composed of tracheids and vessel elements that form many hollow, connected tubes. These tubes are lined with cellulose cell walls, to which water adheres very strongly. So, when transpiration removes some water from the exposed walls, strong adhesion forces pull in water from the wet interior of the leaf. That pull is so powerful that it extends even down to the tips of roots and, through them, to the water in the soil. **The combination of transpiration and capillary action provides over 90 percent of the force that moves water through the xylem tissues of a plant.**

**In Your Notebook** *Distinguish between the terms* cohesion *and* adhesion *by writing two sentences that use the terms.*