Undergraduate Level Course of ZHIYUAN College

Life—The Science of Biology

Plant Body, Transportation, and Nutrition

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Shanghai Jiao Tong University
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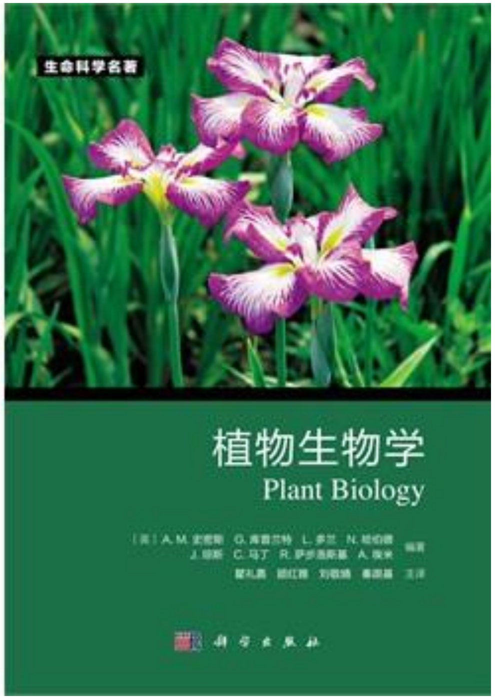
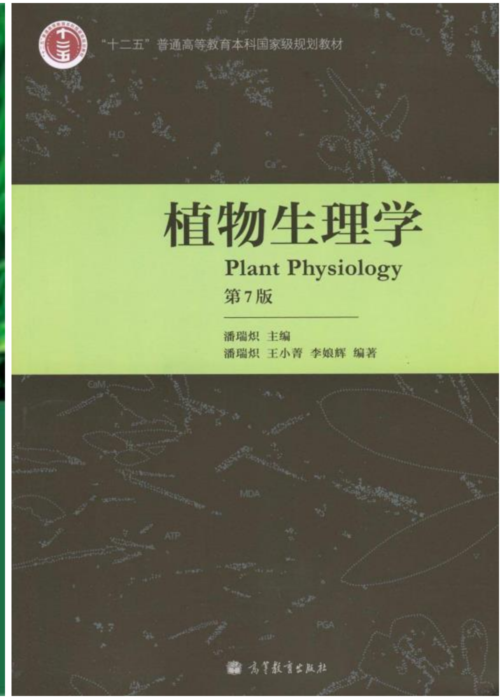
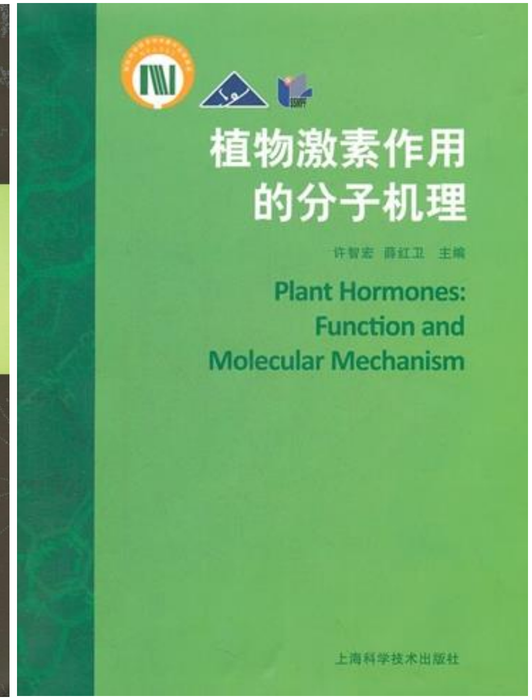
Reference Books



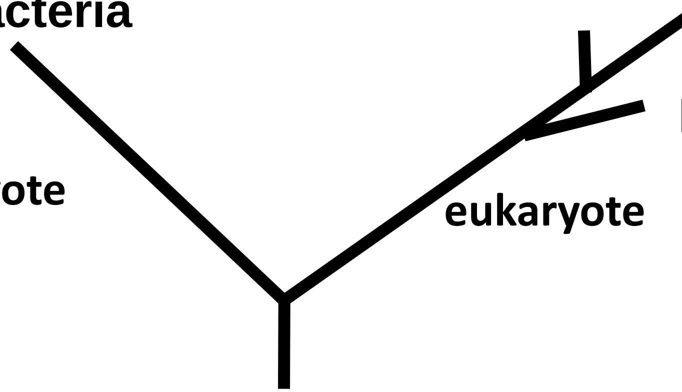




- 植物生物学 瞿礼嘉 顾红雅 刘敬婧 秦跟基 主译 科学出版社
- 植物激素作用的分子机理 许智宏 薛红卫 主编 上海科学技术出版社
- 植物生理学 潘瑞炽 主编 高等教育出版社

What is plant?

Plant, like most animal, is multicellular eukaryote（真核生物）



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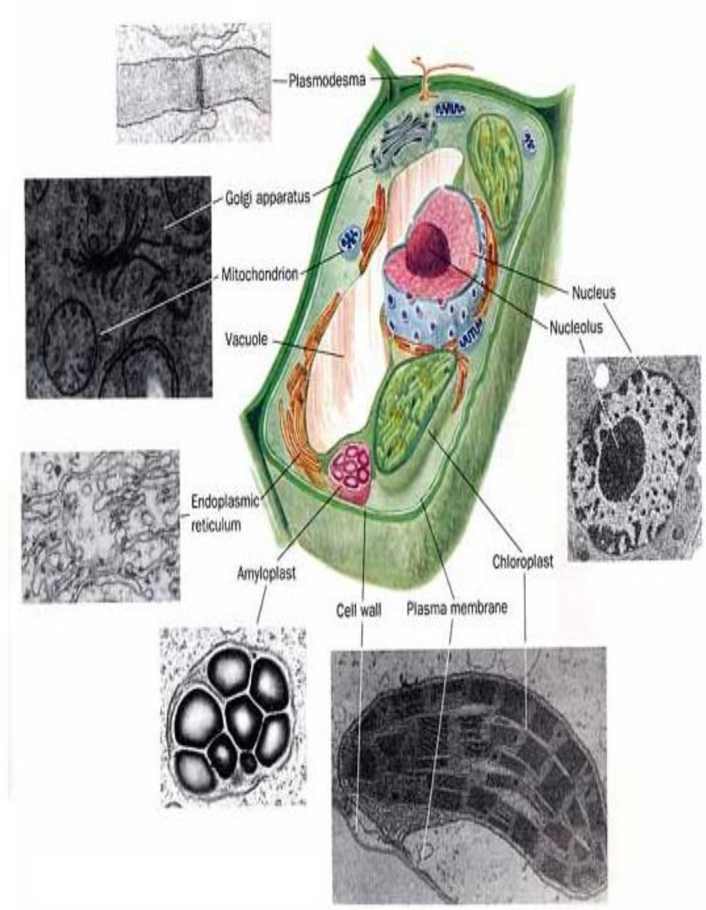
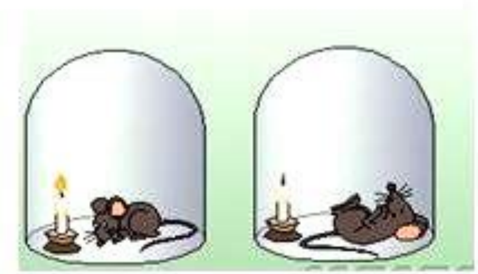
What are differences between plant and animal?

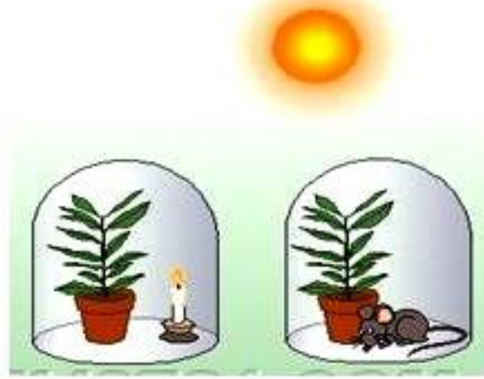
- Anatomical difference: cell wall
- Mobility difference: cell, body
- Continuous development difference: determinate & indeterminate growth
- Plastic（可塑性）, totipotency (全能性) and regenerate（可再生）difference
- Acclimatization（适应性）difference
- ……



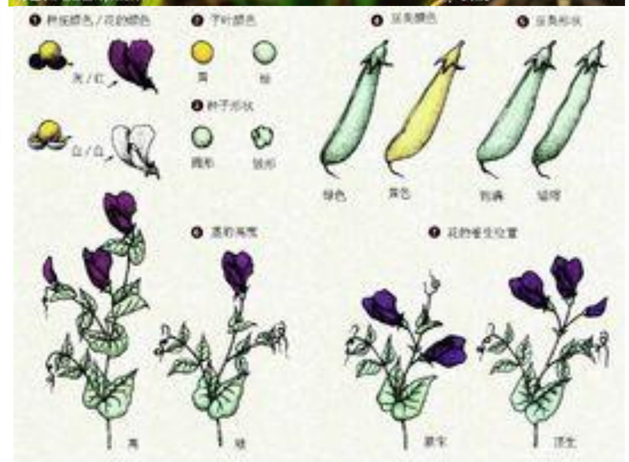
How important is plant?

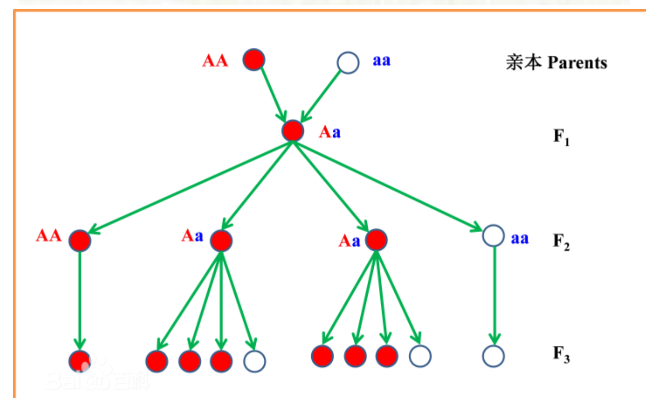


实验一



实验二





Plant Body

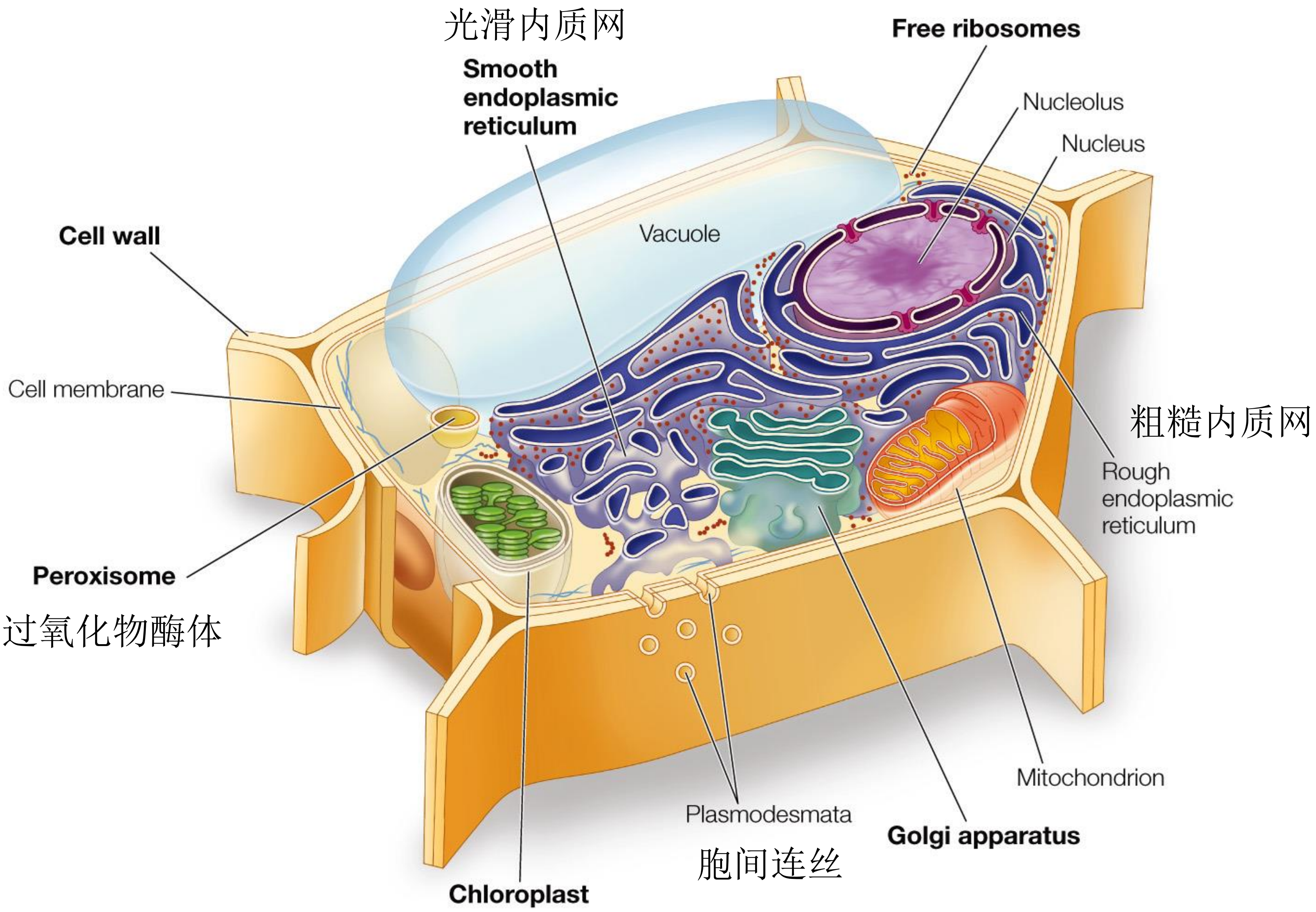
33.1 The Plant Body Is Organized in a Distinctive Way

33.2 Plant Organs Are Made Up of Three Tissue Systems

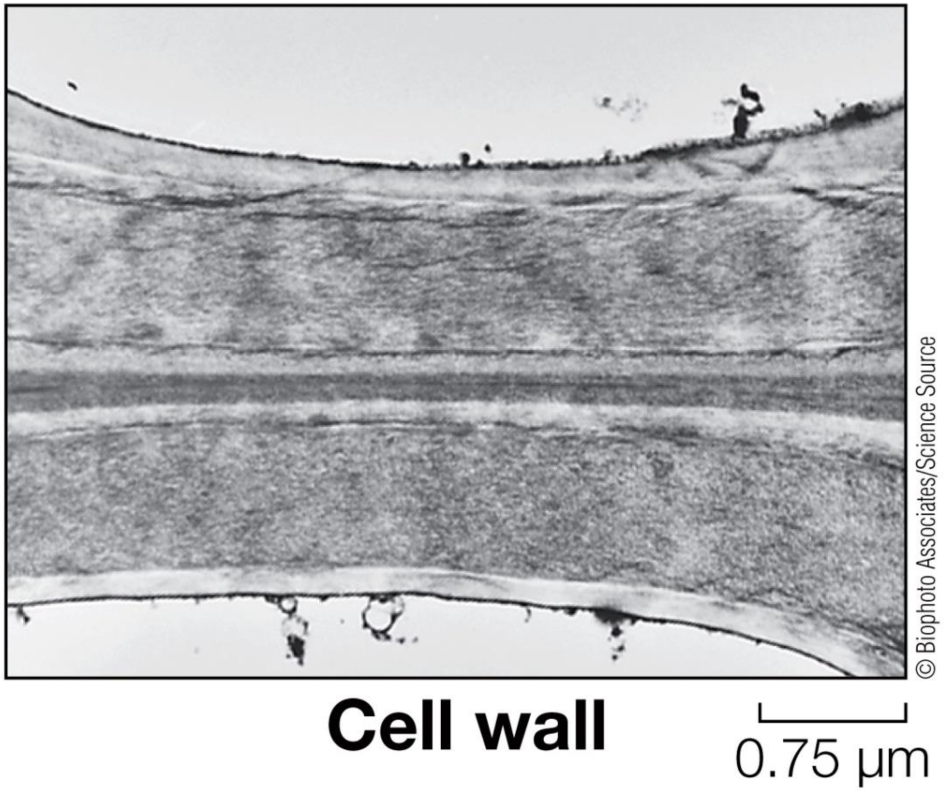
33.3 Meristems Build a Continuously Growing Plant

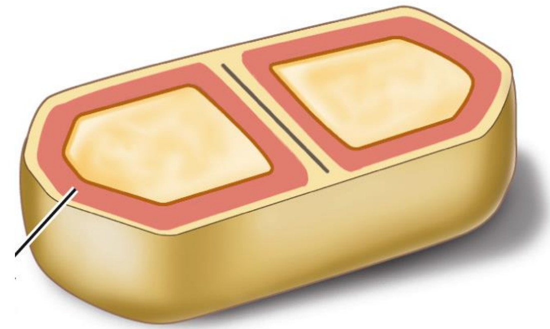
33.4 Domestication (驯化) Has Altered Plant Form

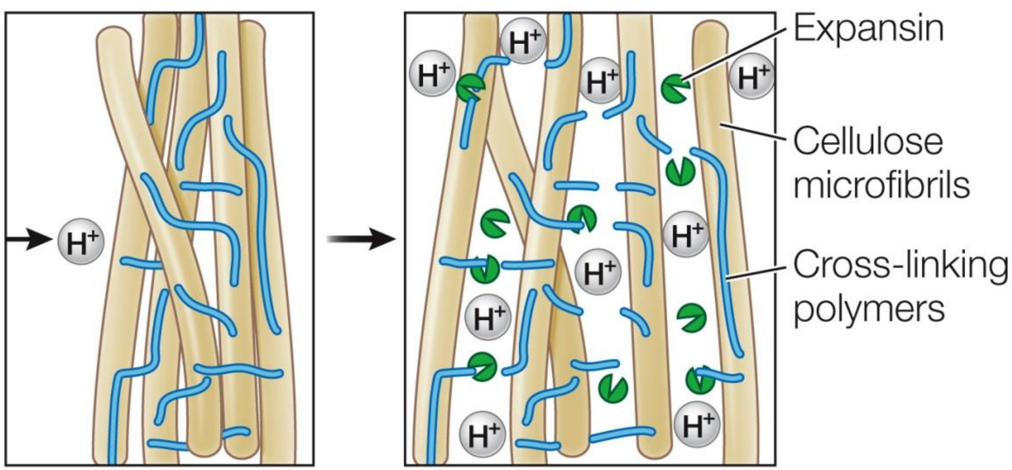
Plant cell



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.7 (Part 8)

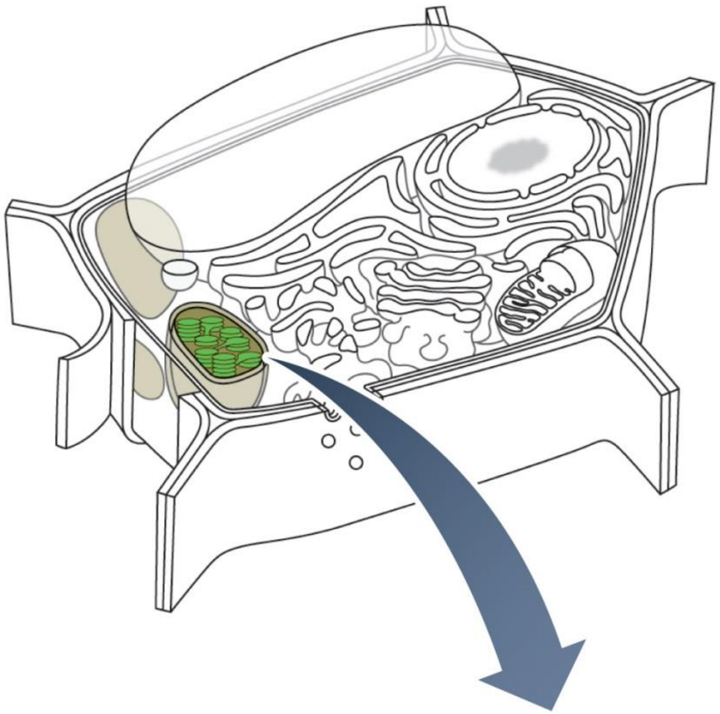




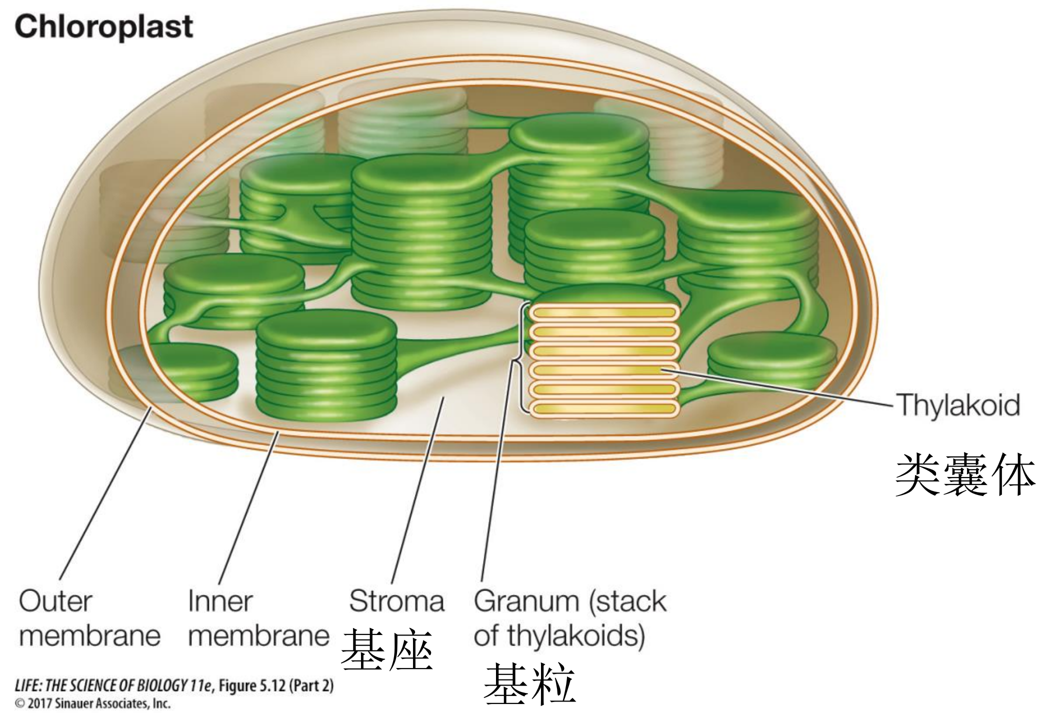


Acid growth hypothesis: Protons are pumped from cytoplasm into the cell wall, lowering the pH of the wall and activating enzymes (expansins) that catalyze changes in the cell wall structure. Expansion of plant cells is driven primarily by water uptake. For the cell to expand, the wall structure must loosen.

Chloroplasts Feed the World

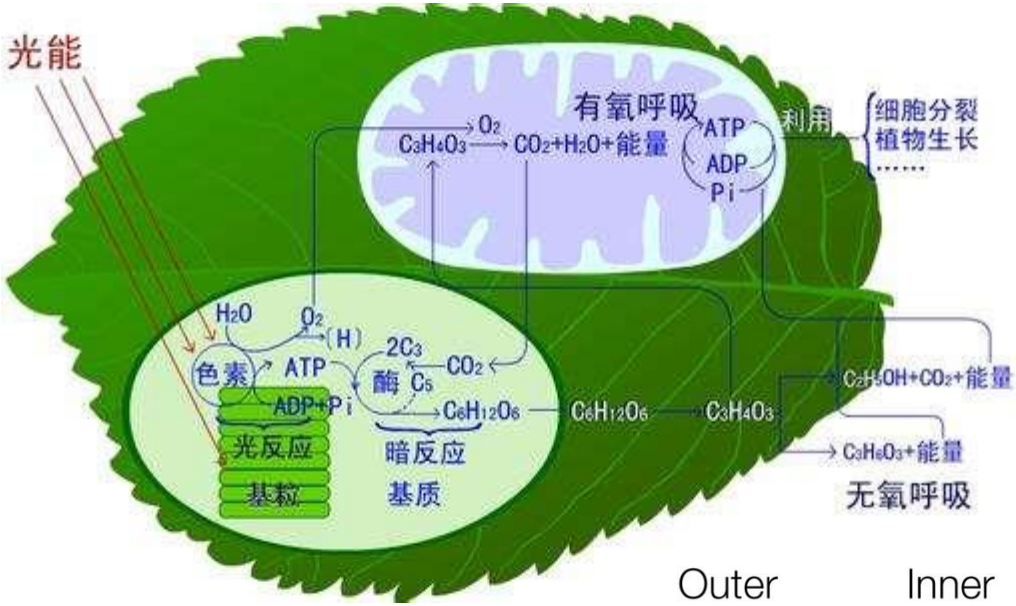


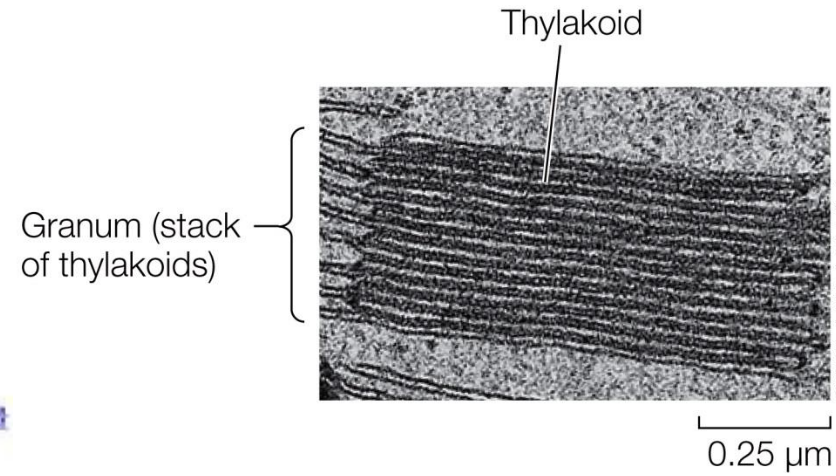
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.12 (Part 1)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.12 (Part 2)

The electron micrographs show chloroplasts from a leaf of corn. Chloroplasts are large compared with mitochondria and contain extensive networks of thylakoid membranes. These membranes contain the green pigment chlorophyll, and are the sites where light energy is converted into chemical energy for the synthesis of carbohydrates from CO_2 and H_2O.





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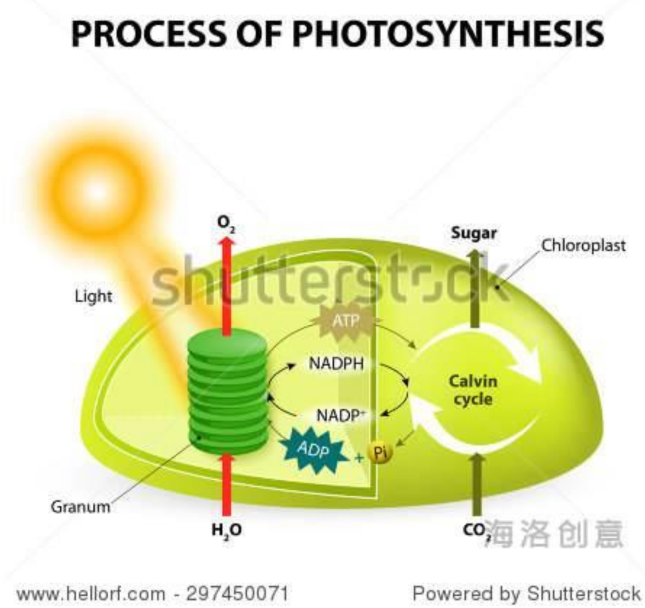
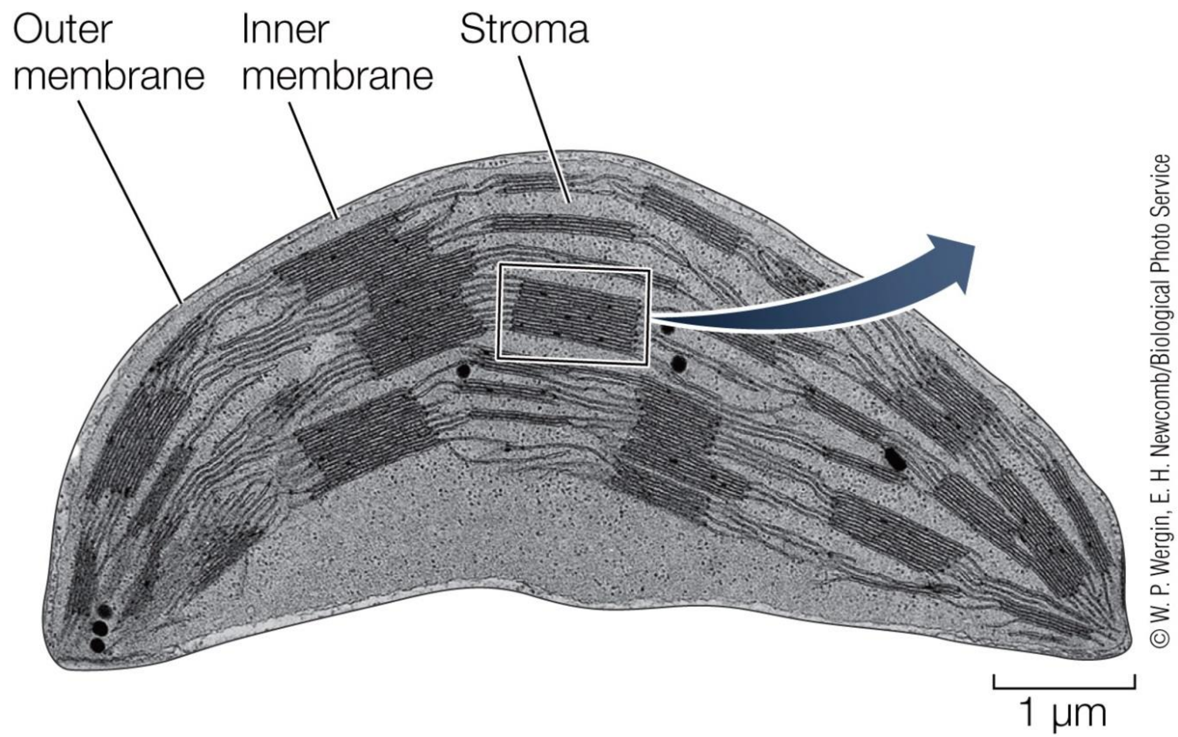
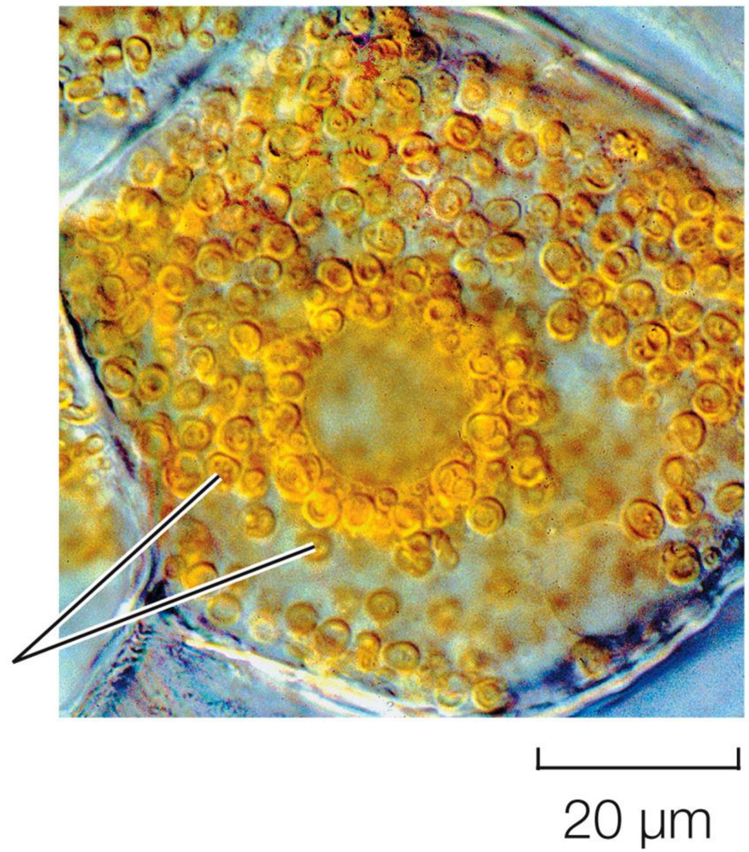




LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.12 (Part 3)

Chromoplasts (成色素细胞) contain red, orange, and yellow pigments—give color to flowers.

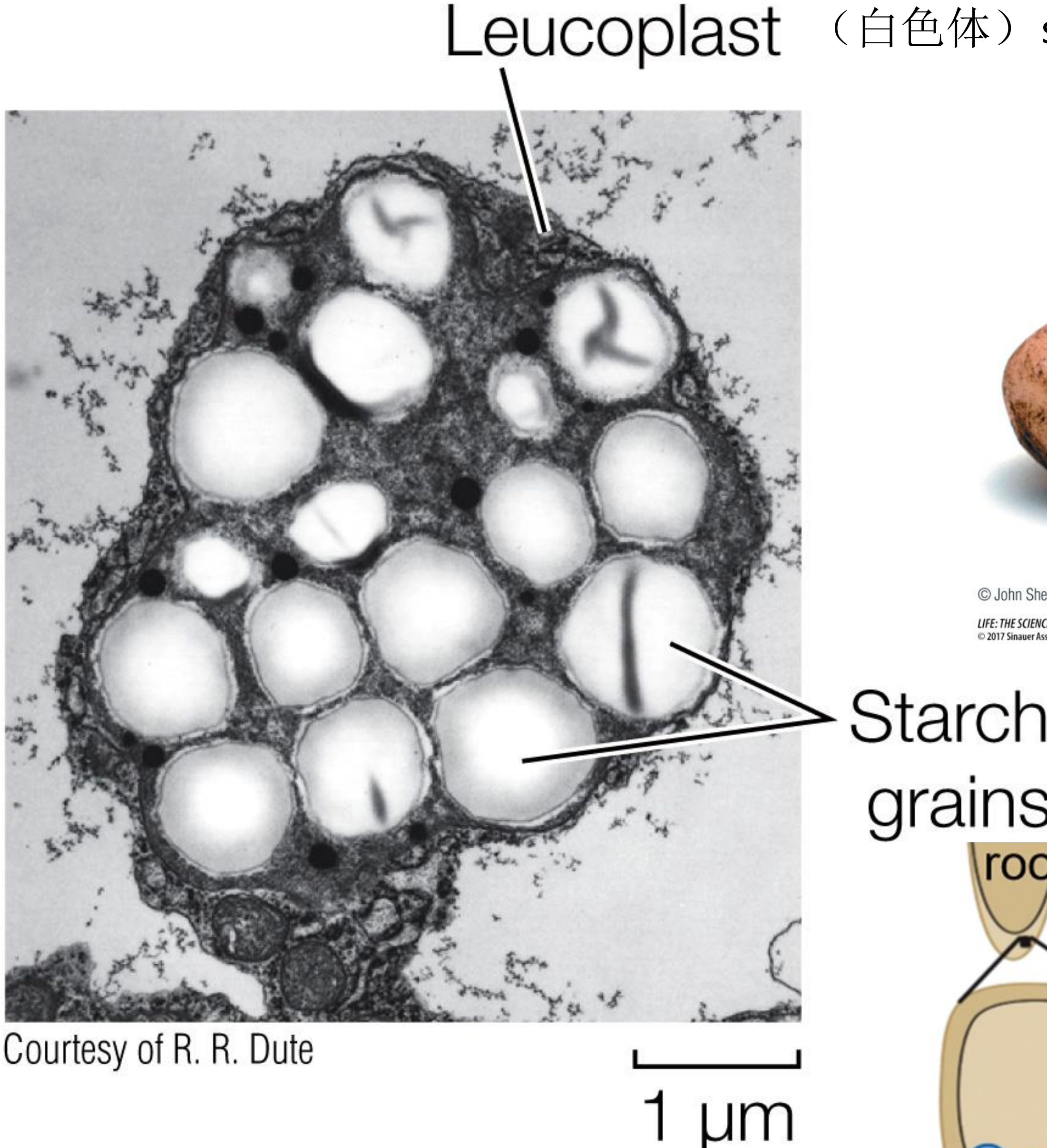
LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 5, p. 96 (1) (Part 1)



From Gunning, B. E. S. *Plant Cell Biology on DVD: Information for students and a resource for teachers.* Springer, 2009 (www.springer.com/life+sciences/plant+sciences/book/978-3-642-03690-3)

LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 5, p. 96 (1) (Part 2)

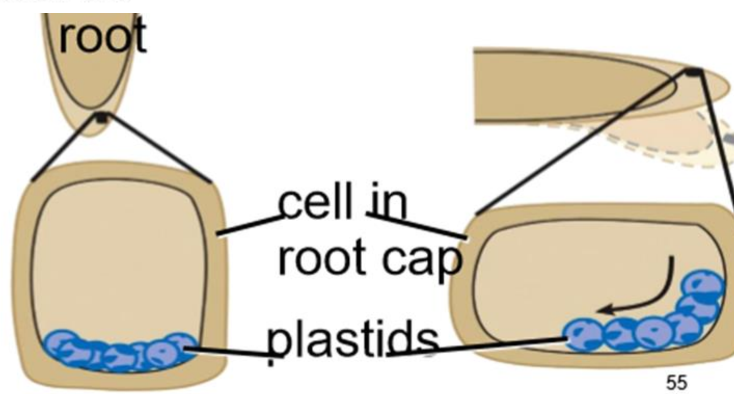
Leucoplast （白色体）store starches and fats



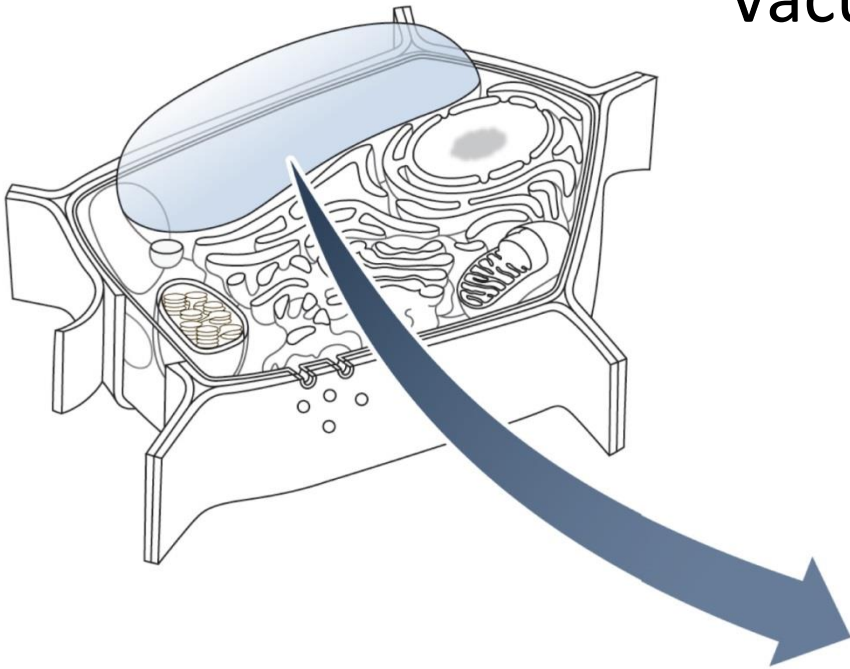
Courtesy of R. R. Dute

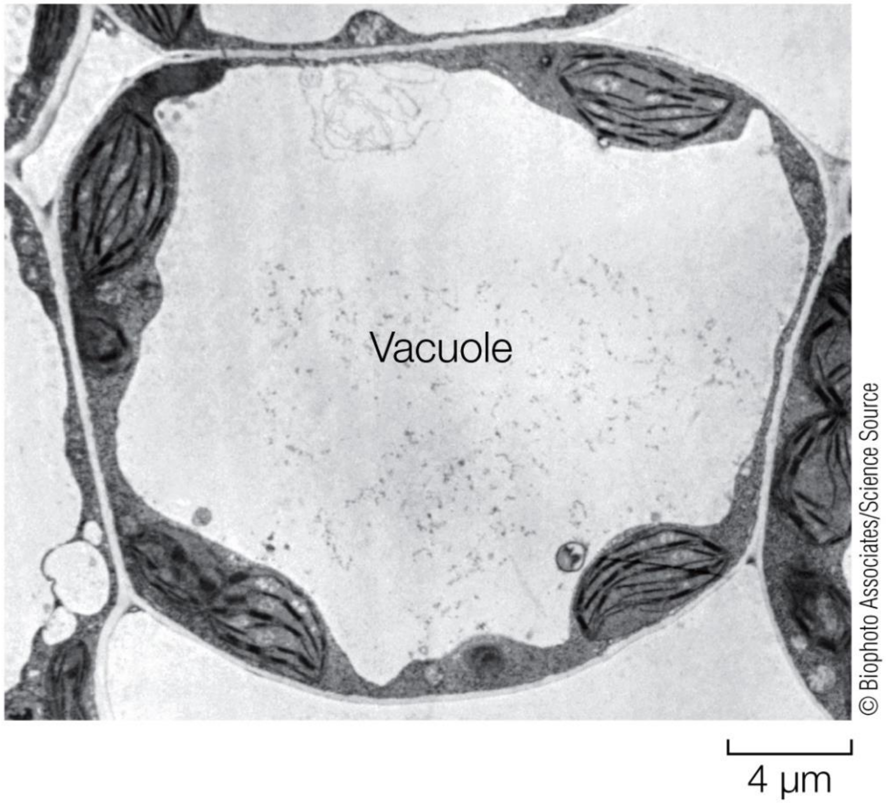
LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 5, p. 96 (2) (Part 2)

LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 5, p. 96 (2) (Part 1)



Vacuoles



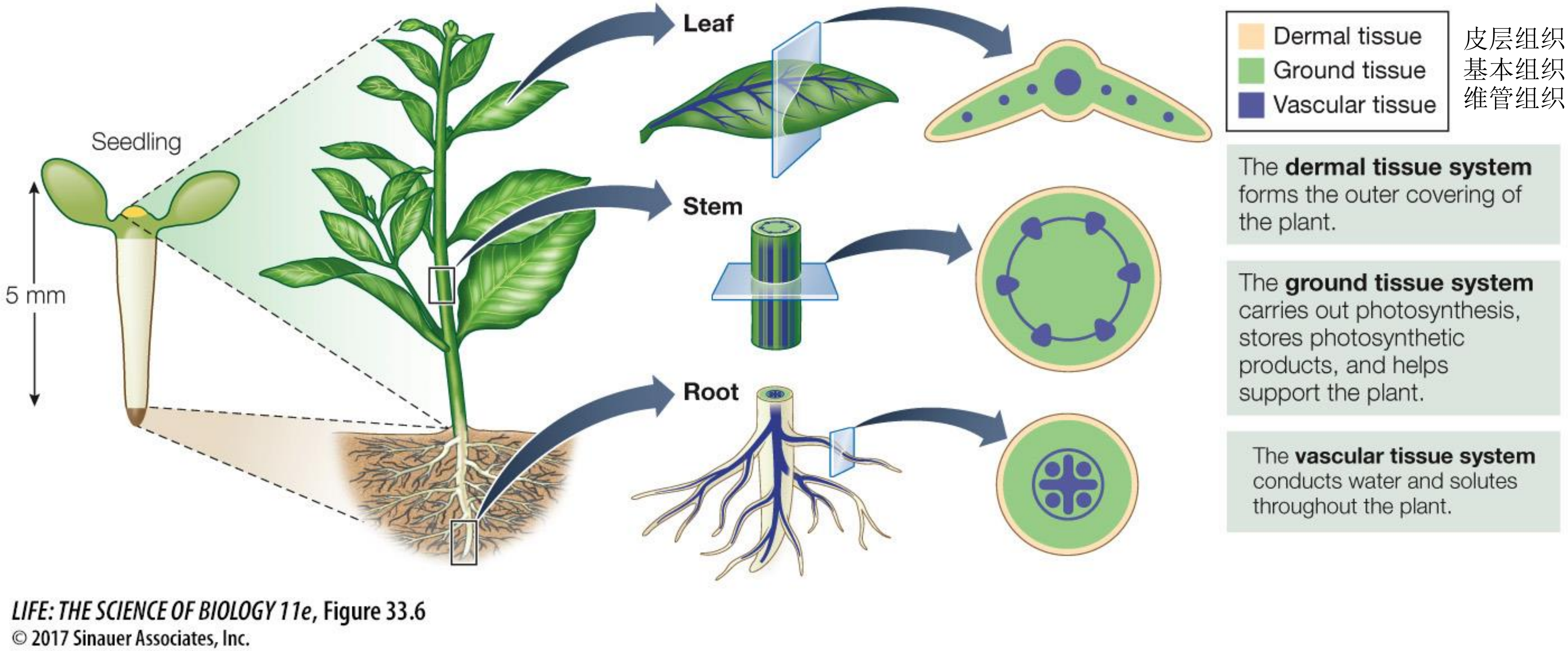


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.13 (Part 2)

Plant and protist cells have **vacuoles.** The large central vacuole in this cell is typical of mature plant cells.

- Store waste products and toxic compounds; some may deter herbivores.
- Provide structure for plant cells—water enters the vacuole by osmosis, creating turgor pressure
- Store anthocyanins (花青素， pink and blue pigments) in flowers and fruits; the colors attract pollinators.
- Vacuoles in seeds have digestive enzymes to hydrolyze stored food for early growth.

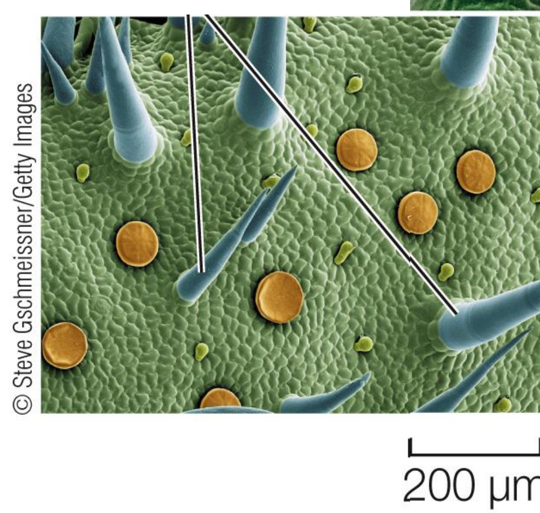
Plant Tissues

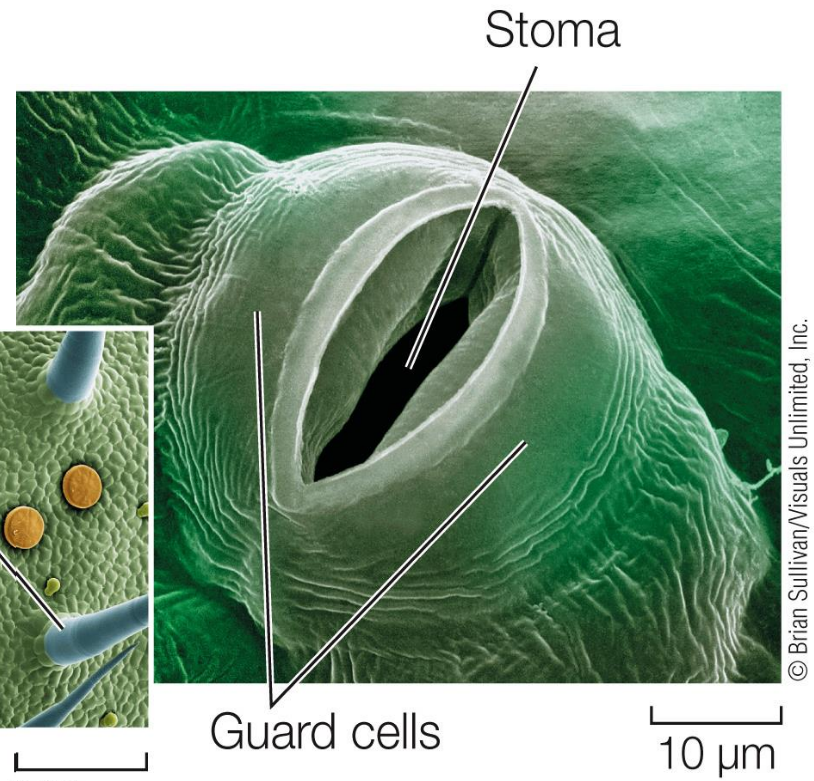


Plant tissues are grouped into 3 **tissue systems**: dermal, ground, and vascular. These ultimately extend throughout the plant body in a concentric arrangement. Ground tissue forms most of the plant body and includes parenchyma, collenchyma, and sclerenchyma. The dermal and vascular systems have parenchyma and sclerenchyma. Vascular tissue consists of xylem and phloem, which are the plant’s transport system.

Dermal tissue
- **Epidermis表皮（Cuticle角质）**
  - **Stomatal guard cells**
  - **Trichomes (leaf hairs)**
  - **Root hairs**
- **Periderm周皮**

Made up of cutin, a complex mixture of waxes and cell wall polysaccharides. It limits water loss, protects against damaging solar radiation, and is a barrier to pathogens.

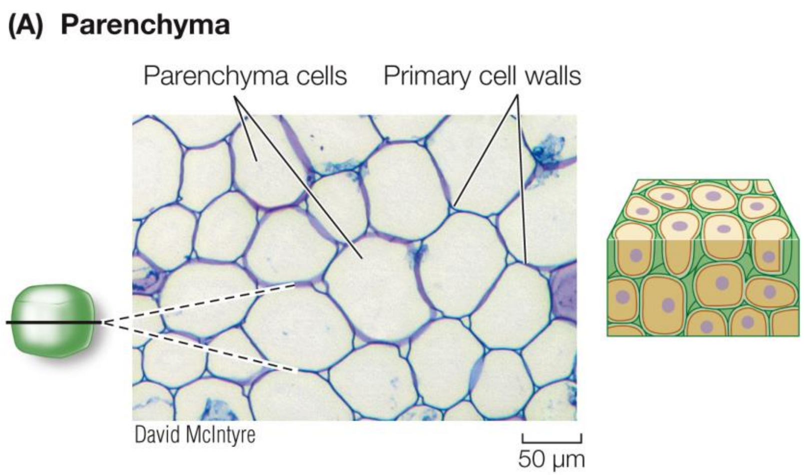




LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.16 (Part 3)

Stomatal guard cells—form stomata (pores) for gas exchange
Trichomes (leaf hairs)—protection against insects and damaging solar radiation
Root hairs—increase root surface area for uptake of water and mineral nutrients

Ground tissue
- **Collenchyma cell厚角细胞**
- **Parenchyma cell薄壁细胞** → Makes up most of the plant body. Functions in storage, support, and photosynthesis
- **Schlerenchyma cell厚壁细胞**



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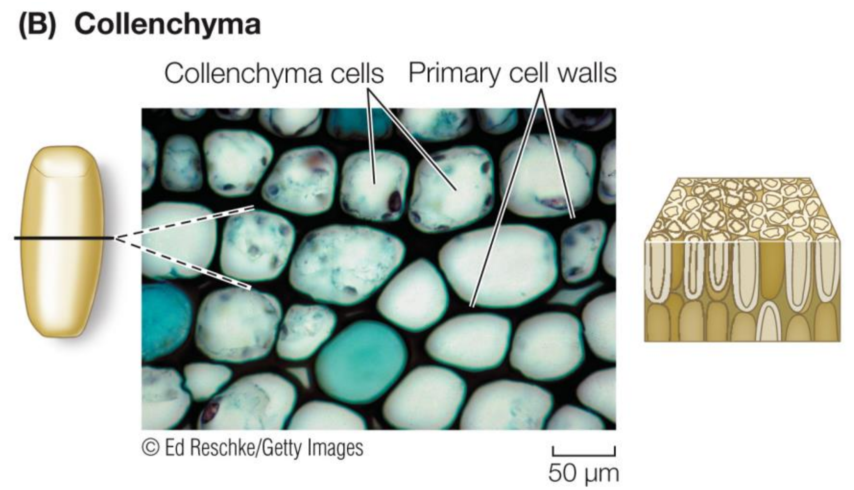
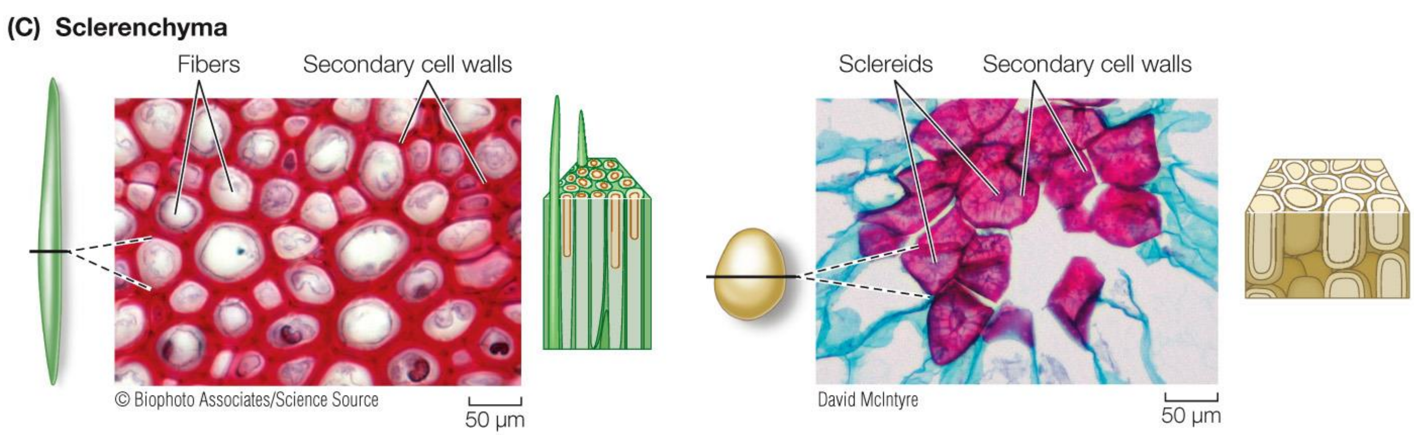


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.7 (Part 2)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.7 (Part 3)

Parenchyma cells:

- Thin primary walls, large central vacuoles
- **Middle lamella**—layer of pectin that cements adjacent cells together
- Sites of photosynthesis and storage (e.g., starch in roots)
- Many can divide and can give rise to new cells (e.g., to heal a wound)

Collenchyma cells:

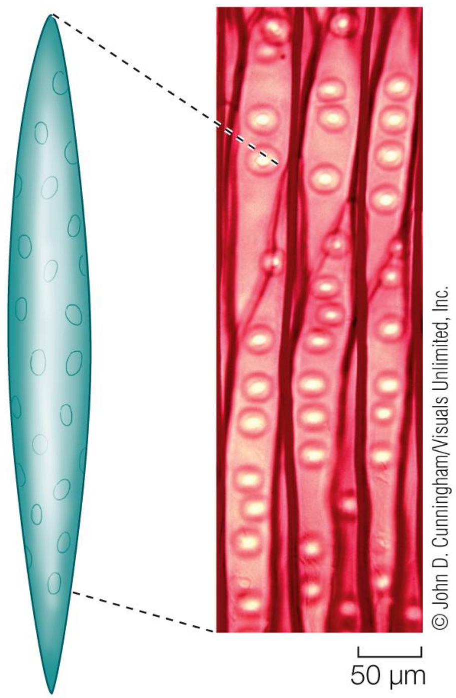
- Primary walls thickened by pectins; usually elongate
- Provide support in leaf petioles, nonwoody stems, and growing organs
- Tissue is flexible; can bend without snapping
- Celery “strings” are collenchyma cells

Sclerenchyma cells:

- Thickened secondary walls; many undergo apoptosis after secondary wall is laid down.
- **Fibers**: Elongated cells provide rigid support; often in bundles.
- **Sclereids** may be densely packed as in nut shells, or in clumps as in stone cells in pears.

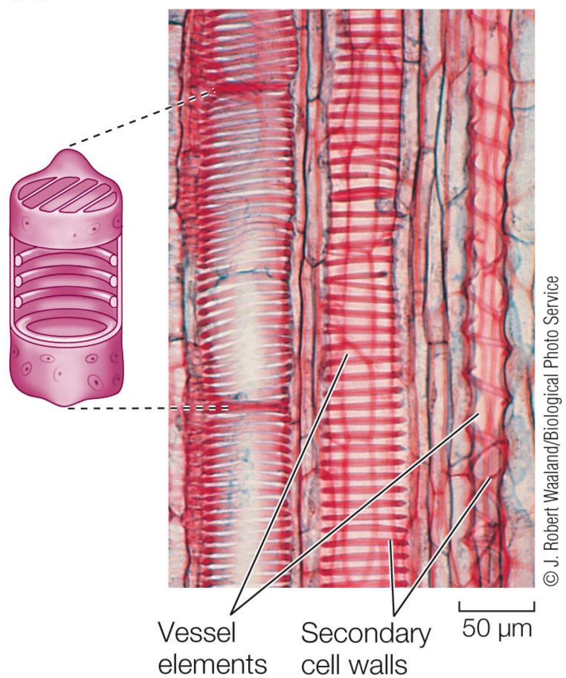
Vascular tissue
- **Xylem导管** **（tracheary elements管状分子）**
  - **Tracheids管胞**
    gymnosperm裸子植物
  - **vessel element管状分子**
    angiosperm被子植物
- **Phloem筛管** **（Sieve tube elements筛管分子）**
  （companion cells伴胞）

(A) Tracheids



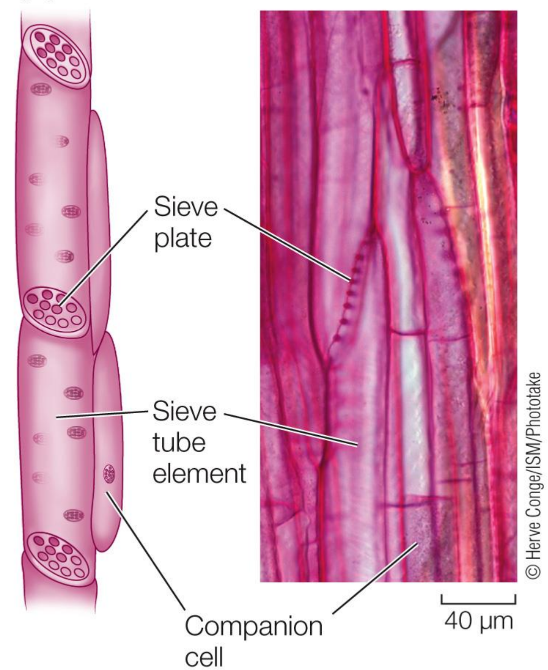
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.8 (Part 1)

(B) Vessel elements



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.8 (Part 2)

(C) Sieve tube elements



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.8 (Part 3)

Vascular tissue system:

Xylem distributes water and minerals taken up by roots to all parts of the plant.

Phloem transports carbohydrates from site of production (**sources**) to sites of utilization or storage (**sinks**).

Xylem: Mature cells are dead.

Two types of **tracheary elements**:

1. Gymnosperms have **tracheids** with pits in the secondary walls that allow materials to move freely; major cell type in gymnosperm wood.

2. Flowering plants have vessels made of **vessel element** cells end-to-end, also with pits.

    Pits larger diameter than tracheids.

    End walls break down before death, forming hollow tubes.

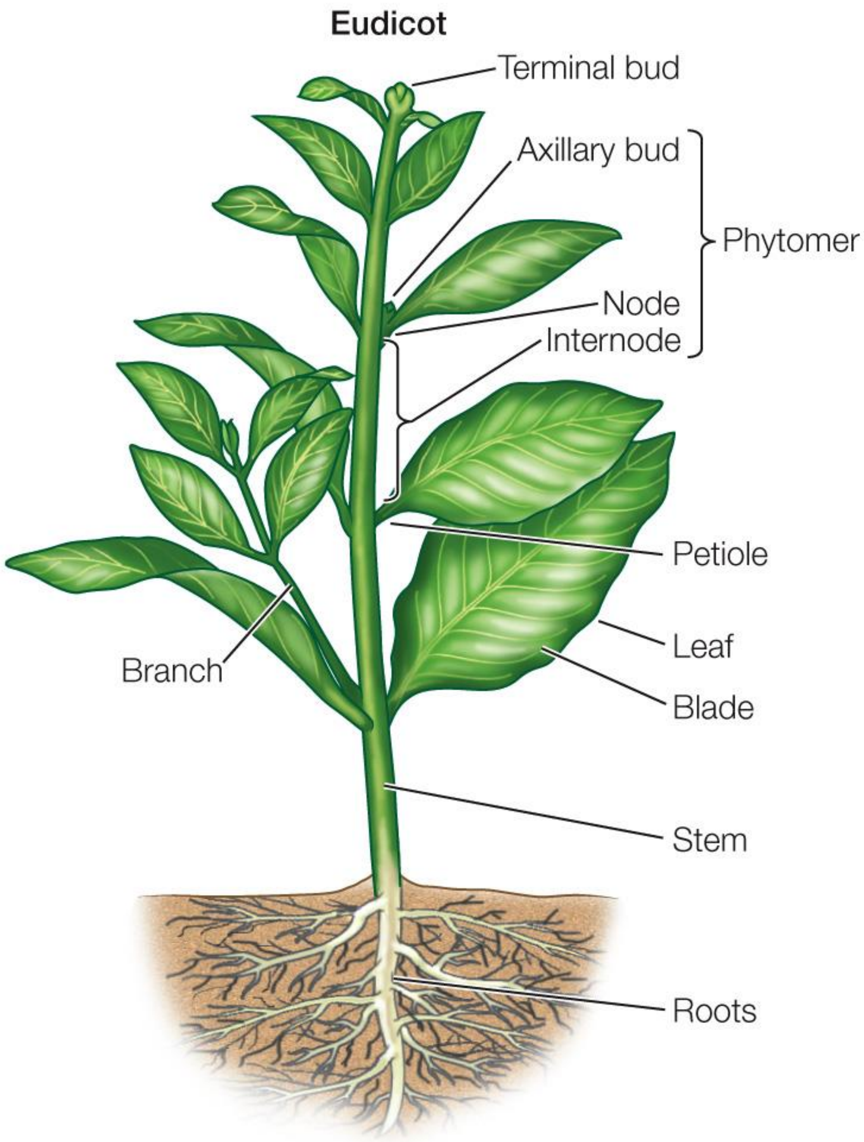
Xylem of many angiosperms also contains tracheids.

Phloem: Mature cells are living.

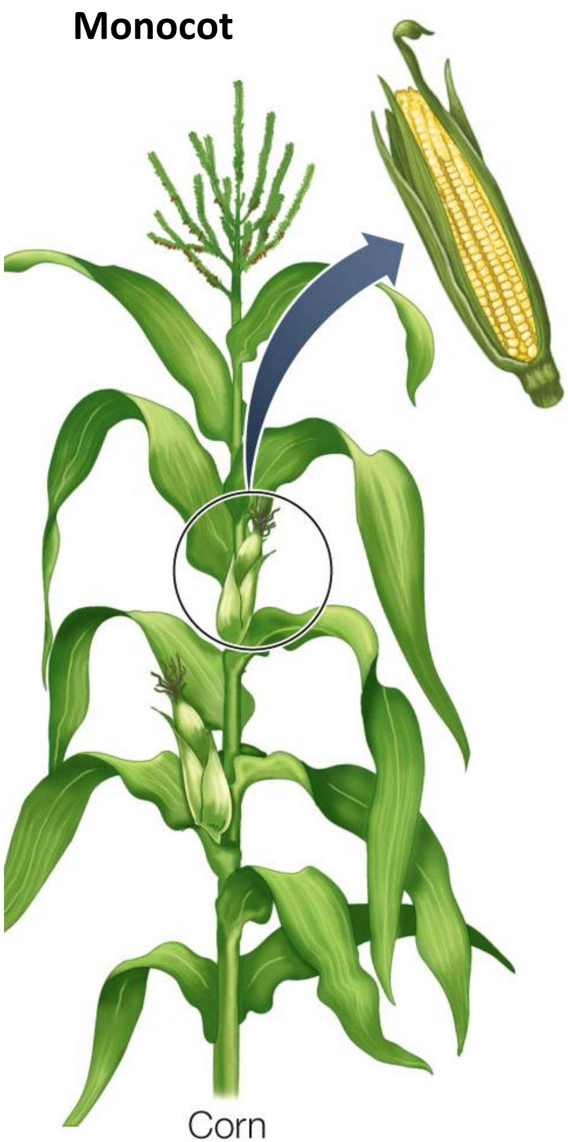
Sieve tube elements: Cells meet end-to-end; plasmodesmata in the end walls enlarge to form pores—the sieve plate.

Some cell components break down, but **companion cells** retain all organelles and act as “life support” for sieve tube elements.

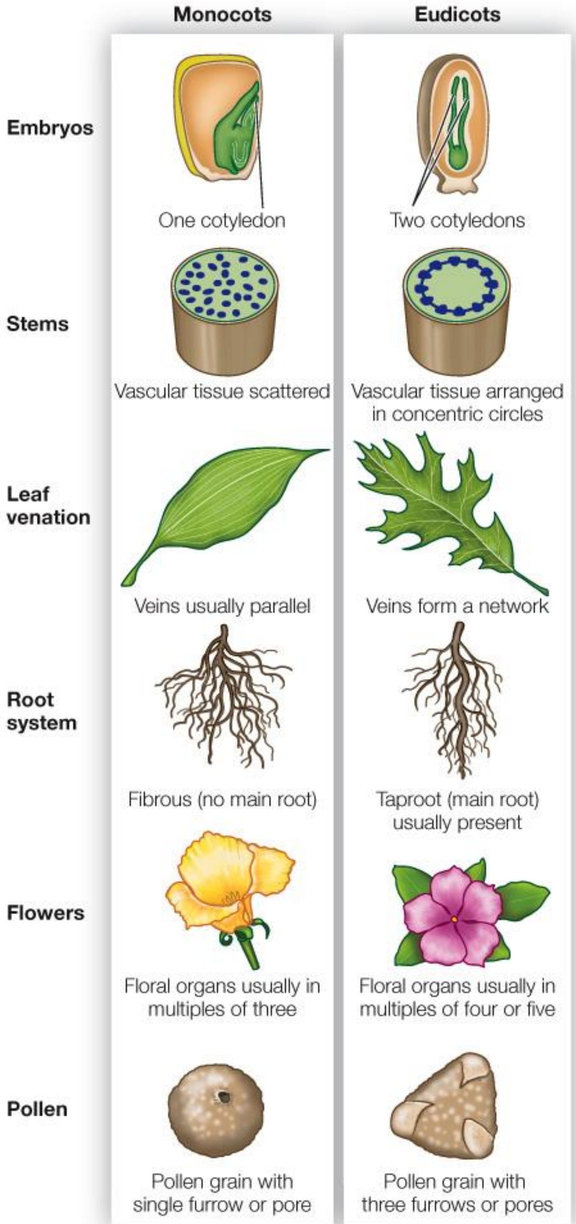
Plant organ and body—the basic structure of the angiosperms



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.1



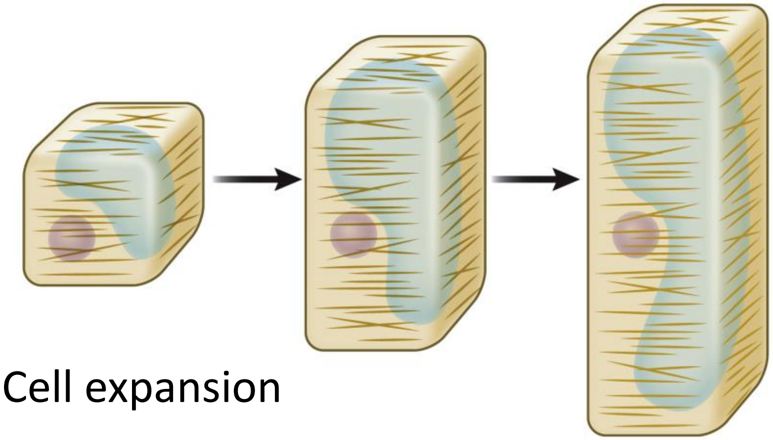
The difference of Monocot and eudicot



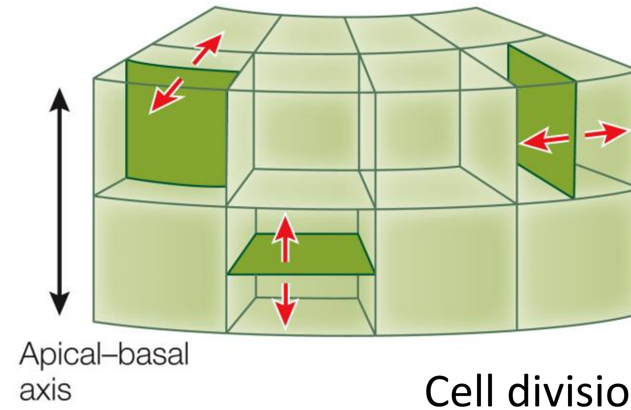
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.2

Model Plant of eudicot and monocot: Arabidopsis and rice

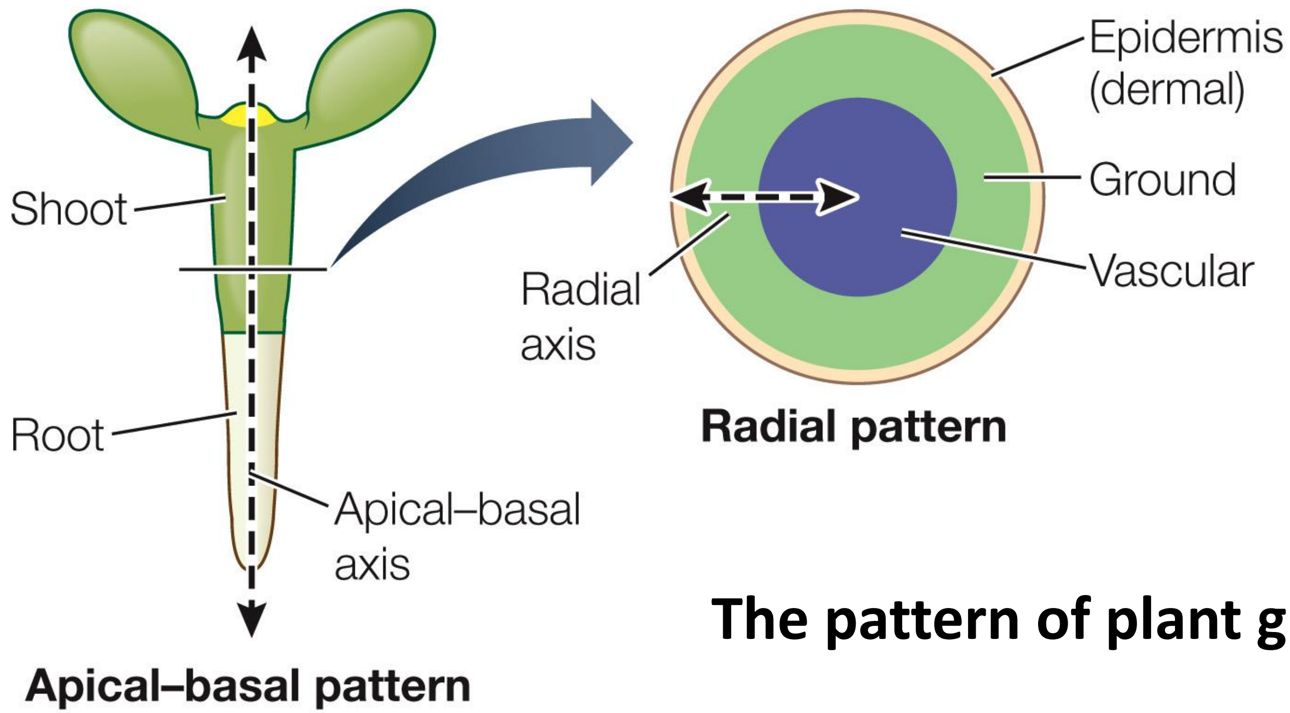
- Fast life cycle
- Small genome
- Small size
- Diploid（二倍体）
- Self-fertile (in-breeding)
- Availability of numerous mutations
- Fully sequencing and annotation



Cell expansion



Cell division



The pattern of plant growth

Processes of plant development:

Determination—commitment of cells to their ultimate fates

Differentiation—cell specialization

Morphogenesis—organization of cells into tissues and organs

Growth—increase in body size

Development is influenced by 4 features:

1. Meristems—regions of undifferentiated cells where cell division occurs.
   Apical meristems occur at tips of shoots and roots; allow plants to grow throughout their lives.
2. Totipotency: **Totipotent**: cells can differentiate into any type of cell in the body.
   Some differentiated plant cells can dedifferentiate and become totipotent.
   A plant can repair damage caused by the environment or herbivores.
3. Vacuoles
   Mature plant cells usually have a **central vacuole** containing a high concentration of solutes.
   The solutes are pumped into the vacuole by transporter proteins in the **tonoplast**, the vacuolar membrane.
4. Cell walls
   Each plant cell is surrounded by a rigid cell wall.
   Morphogenesis is controlled by the plans of cell division, which determine the direction in which a piece of tissue will grow.

Plants grow by cell expansion.

Proteins called expansins in the cell wall help loosen it by disrupting noncovalent bonds between cellulose microfibrils and other polysaccharides.

This is followed by assembly of new polysaccharides and microfibrils, allowing the cell wall to grow.

Primary cell wall—wall of a growing cell.

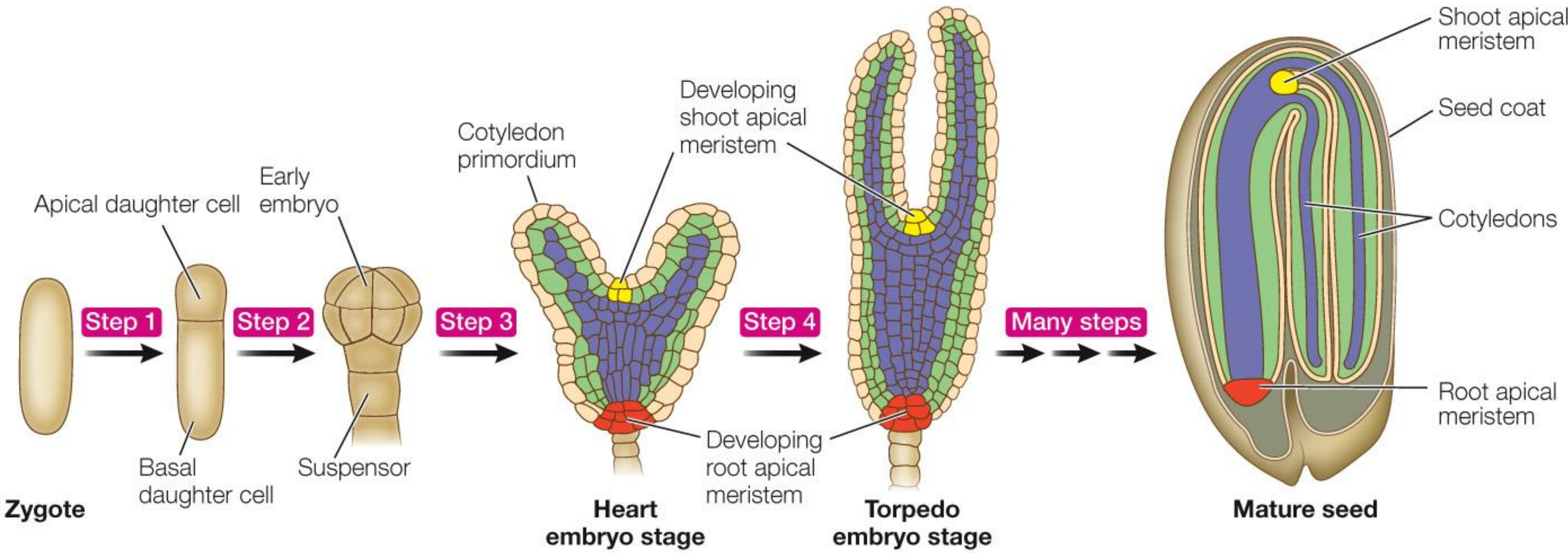
When cell expansion stops, some plants deposit more cellulose layers to form a rigid **secondary cell wall**.

Secondary walls cannot expand. They contain **lignin**, a complex polymer that is a major component of wood.

Two basic patterns are established in the plant embryo:

- *Apical–basal axis*: Arrangement of cells and tissues along the main axis from root to shoot.
- *Radial axis*: Concentric arrangement of the tissue systems.

The Plant Body Is Organized in a Distinctive Way



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.5

The first division of a zygote results in uneven distribution of the cytoplasm, which establishes polarity. One cell produces the embryo, the other produces a supporting structure, the **suspensor**. In eudicots, the cotyledons begin to develop in the heart stage. Elongation results in the torpedo stage. The **shoot apical meristem** develops between the cotyledons. At the other end of the axis, the **root apical meristem** forms. By the end of embryogenesis, radial symmetry has been established; the 3 tissue systems are arranged concentrically.

Meristems: Localized regions of undifferentiated cells; source of all new growth in adult plants.

Cells that perpetuate the meristem are called **initials** (comparable to animal stem cells).

When initials divide, some daughter cells become specialized, others develop into new initials.

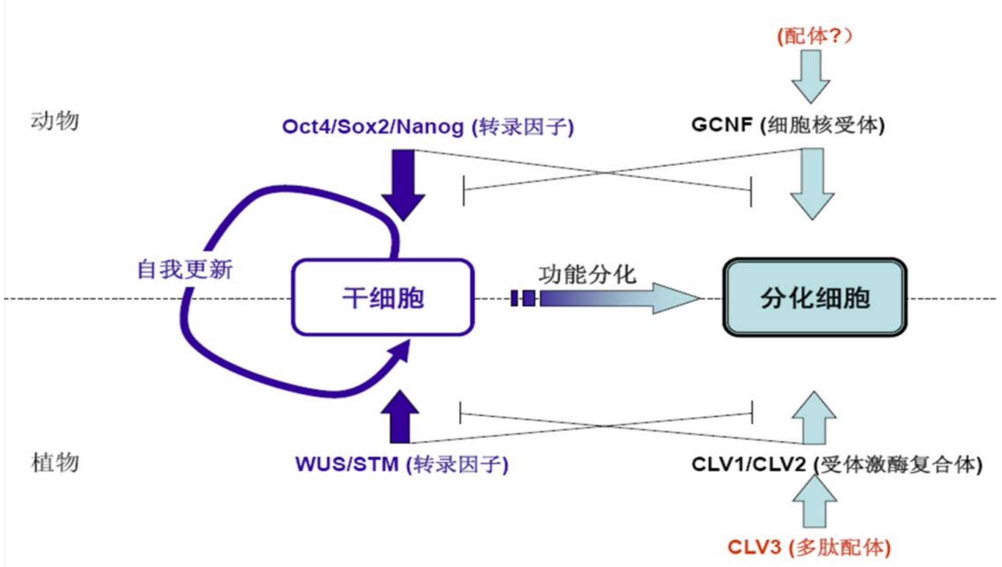
Apical meristems result in primary growth; give rise to every cell in the primary body.

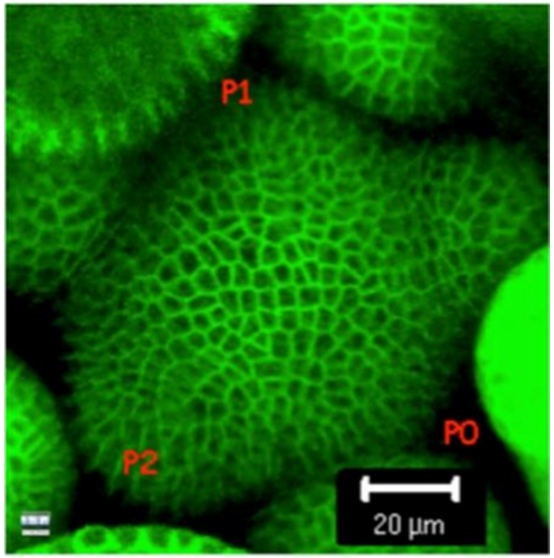
Types of meristems:

Primary meristems develop from initials; give rise to the 3 tissue systems.

Lateral meristems orchestrate secondary growth.

Vascular cambium and cork cambium contribute to the secondary plant body.





Primary meristems
Lateral meristems

Meristems Build a Continuously Growing Plant

Primary growth
Secondary growth

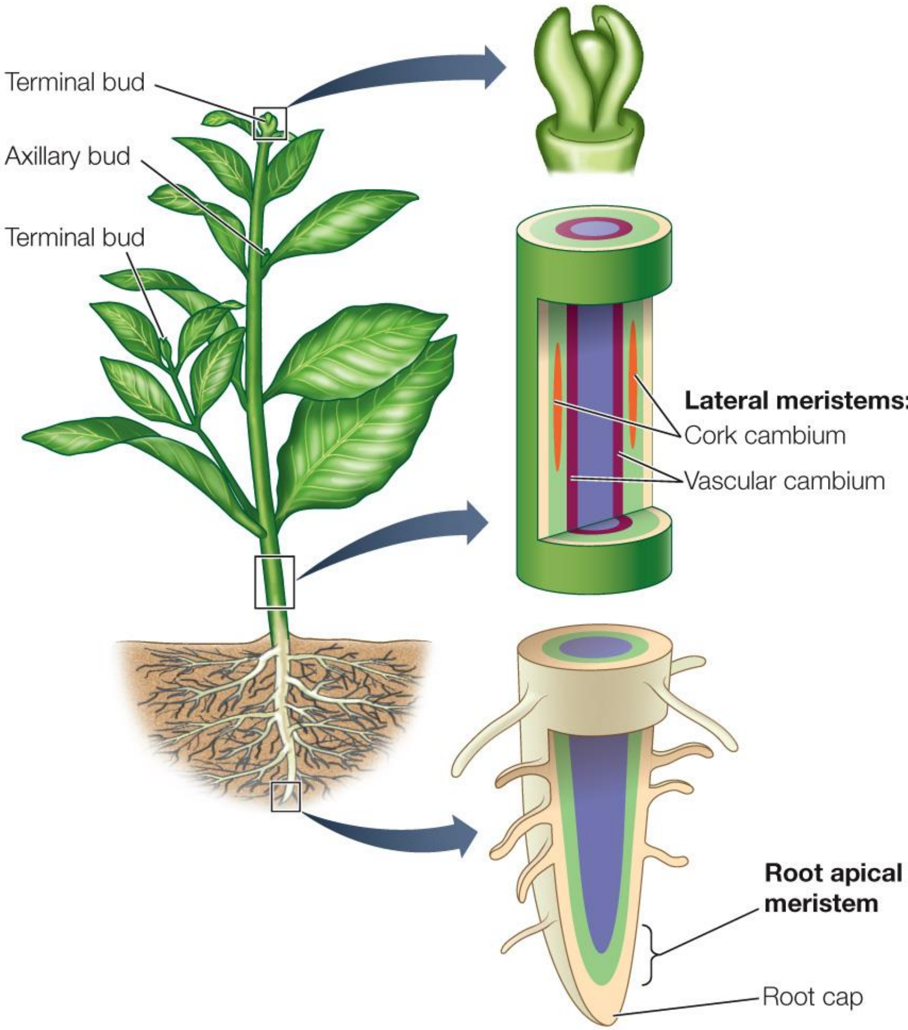
Apical meristems: Vegetative meristems—Inflorescence meristems—floral meristems

- Growth in plants can be either determinate or indeterminate.
- Growth in terms of cell numbers occurs at meristems.
- Different apical meristems are where growth in cell numbers occurs and gives rise to leaves, stems, flowers, and roots.

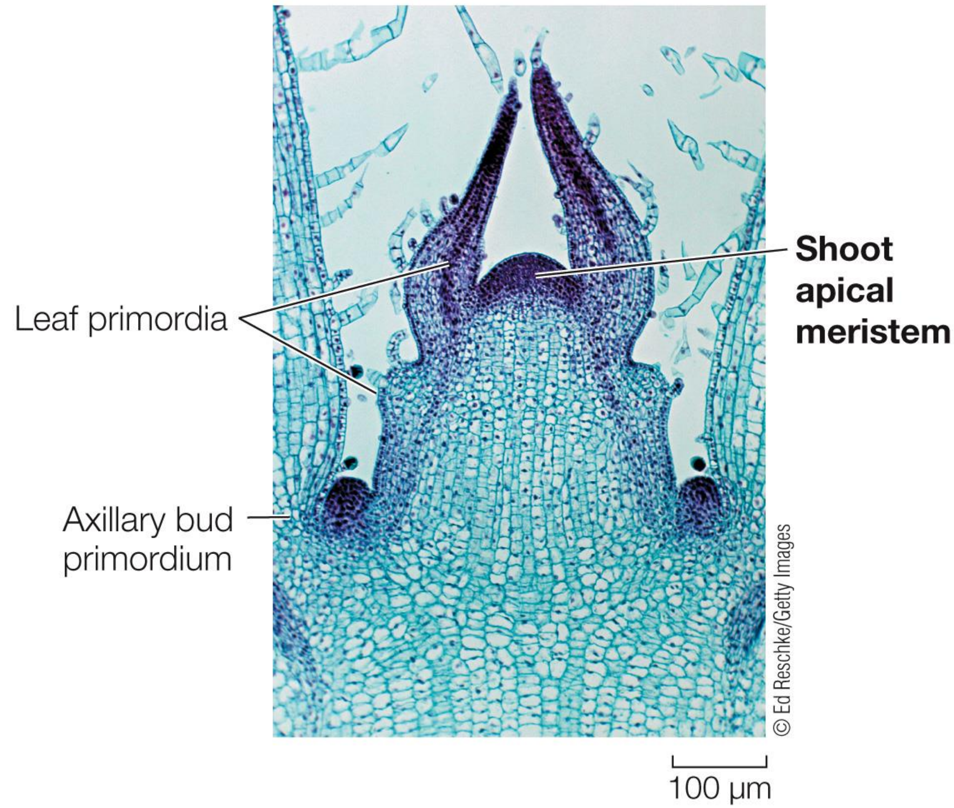
Primary growth: Cell division followed by cell enlargement; lengthens shoots and roots.
Results in the primary plant body: All non-woody parts of the plant.
Many herbaceous plants consist entirely of primary plant body.

Secondary growth: Increases plant thickness.

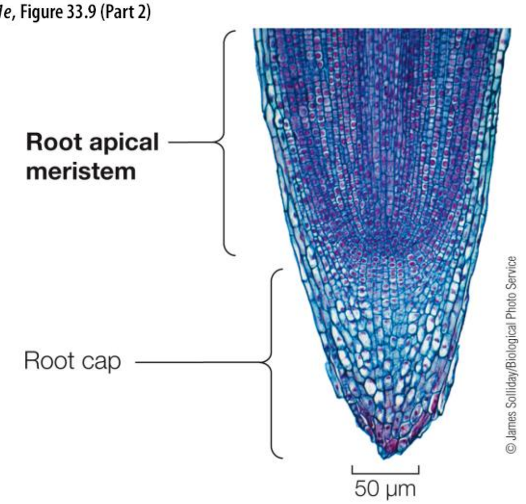
Trees and shrubs have a secondary plant body consisting of wood and bark.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.9 (Part 1)

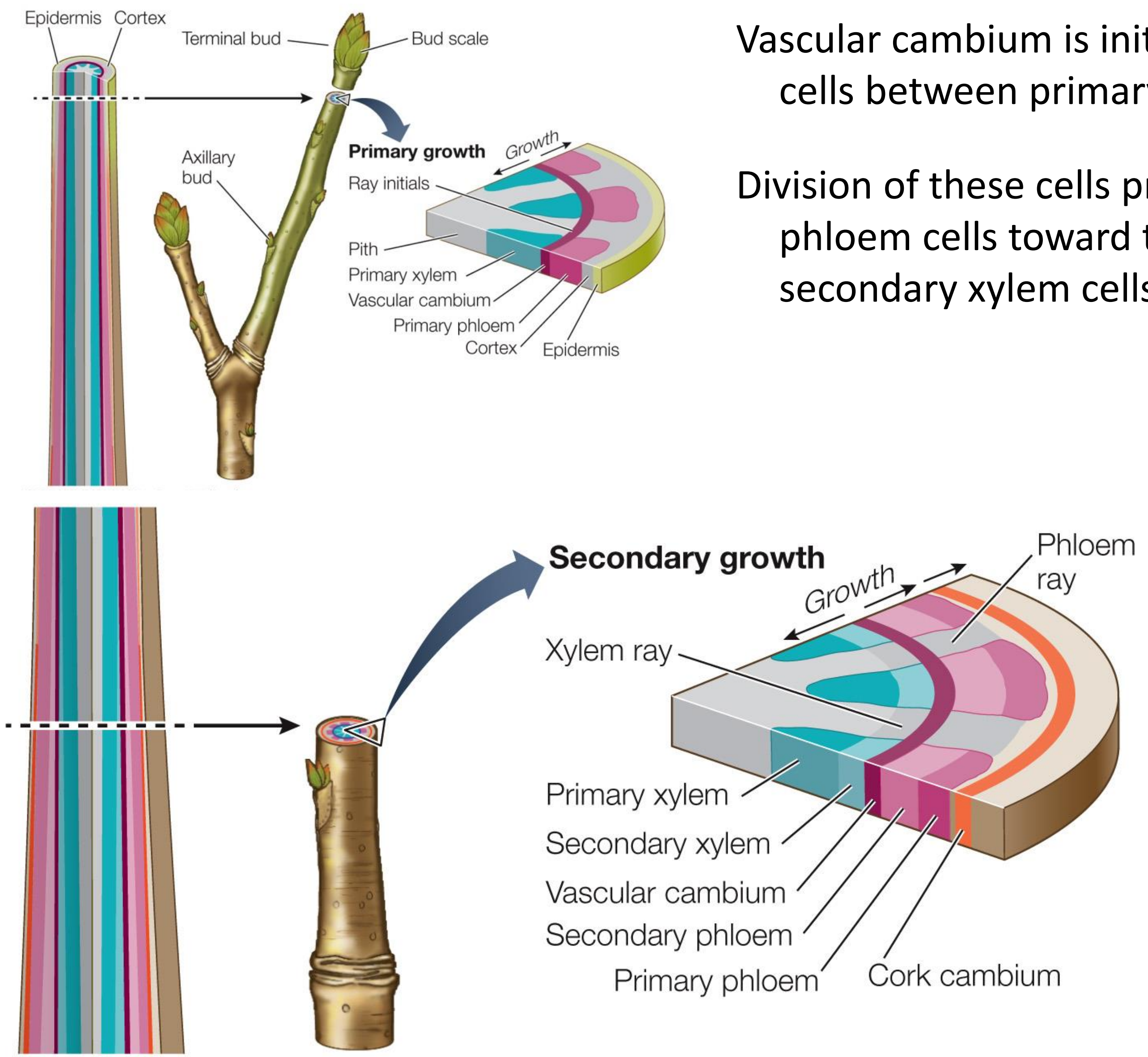


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.9 (Part 2)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.9 (Part 3)

Only the buds consist entirely of primary tissues.



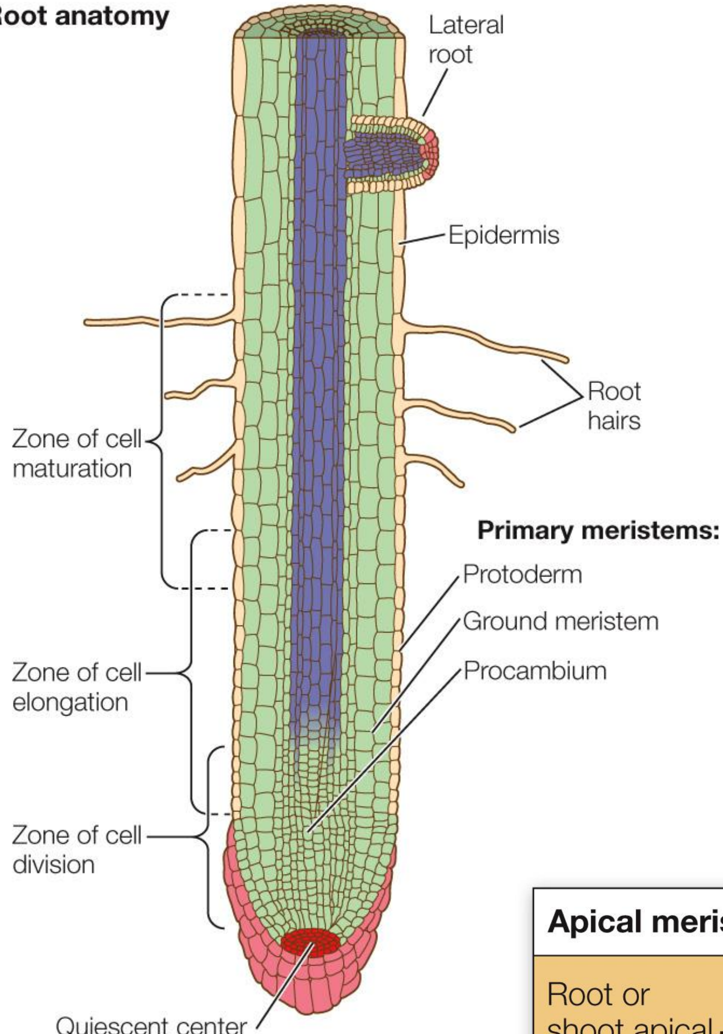
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.17 (Part 2)

Vascular cambium is initially a single layer of cells between primary xylem and phloem.

Division of these cells produces secondary phloem cells toward the outside, and secondary xylem cells toward the inside.

Plant organ 1: root

(A) Root anatomy



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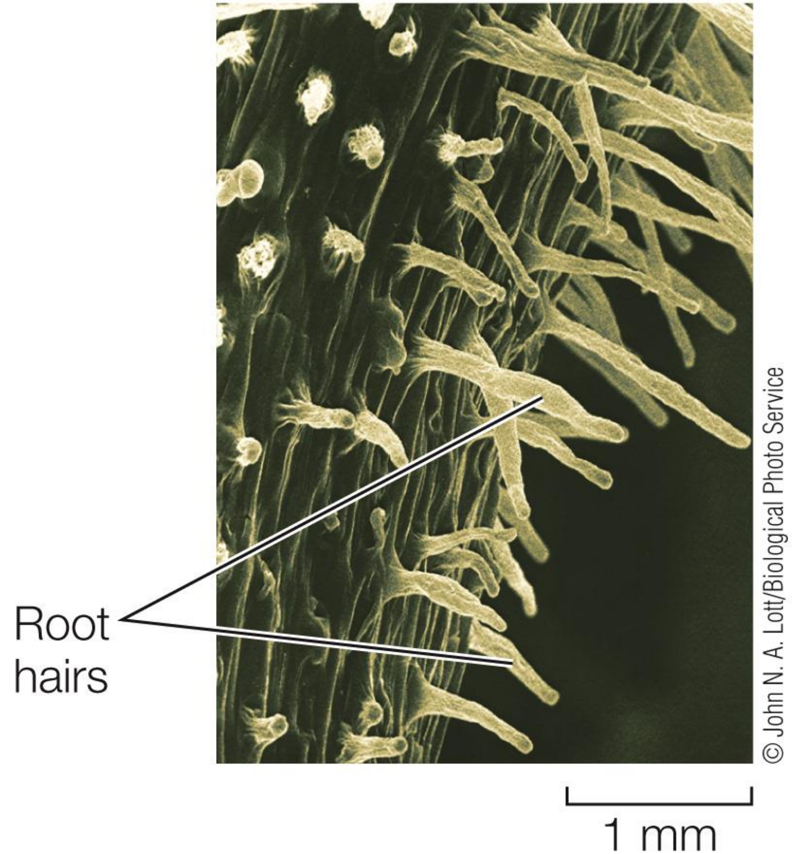
(B) Roots hairs (SEM)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.10 (Part 2)

Apical meristems →	Primary meristems →	Tissue systems	
Root or shoot apical meristem	Protoderm	Dermal tissue system	表皮原
	Ground meristem	Ground tissue system	基本分生组织
	Procambium	Vascular tissue system	原形成层

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Root apical meristem:

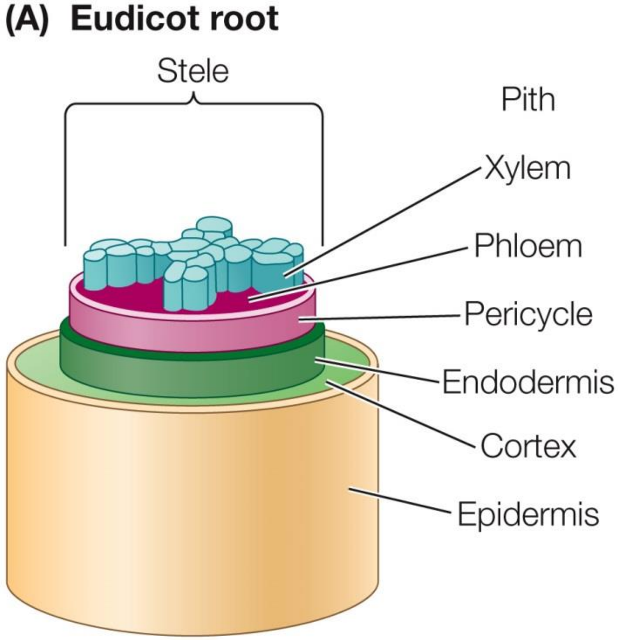
Some daughter cells become the **root cap**—protects root tip as it grows through the soil. The cap secretes a muco-polysaccharide (slime) as a lubricant. The root cap detects gravity and controls downward growth of roots.

Root tissues:

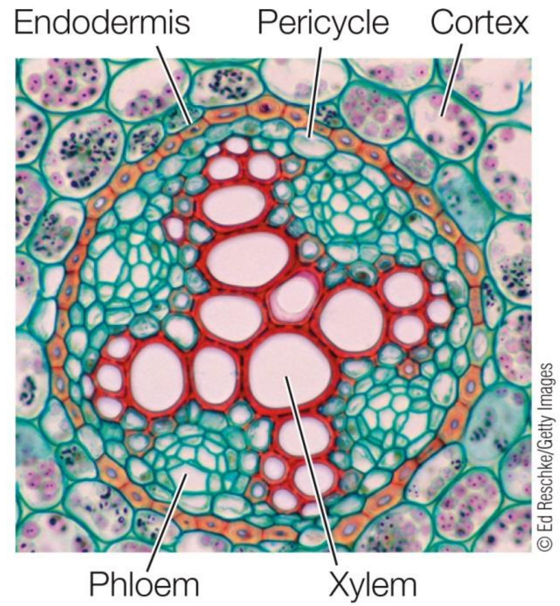
Arrangement of tissues is different in monocots and eudicots. Protoderm gives rise to the **epidermis—**protection and absorption. Many epidermal cells produce **root hairs**, which increase the root surface area.

Ground meristem gives rise to the **cortex** and **endodermis**. Endodermal cell walls have suberin (软木脂), a waterproof substance. Placement of suberin in certain parts of the cell wall allows control of water movement and mineral ions into the vascular tissue system. Procambium produces the vascular cylinder.

In eudicot roots, xylem is at the center, often in a star shape in cross section; between the points are bundles of phloem. Monocot roots have **pith** (parenchyma cells) at the center, which stores carbohydrates. Pith is also found in stems of both monocots and eudicots.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.11 (Part 1)



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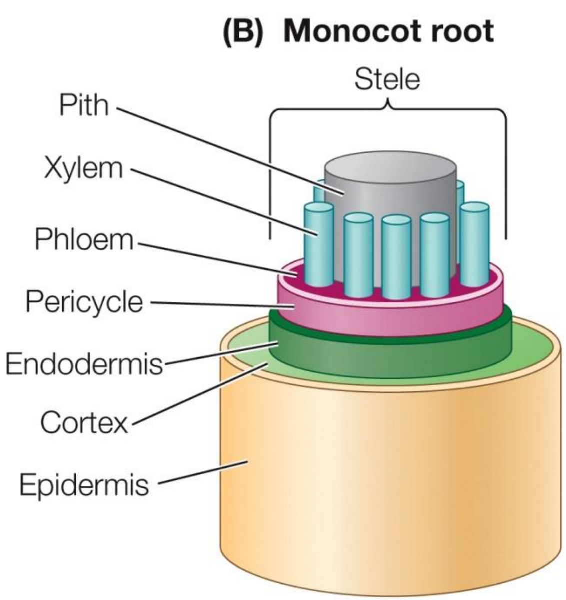

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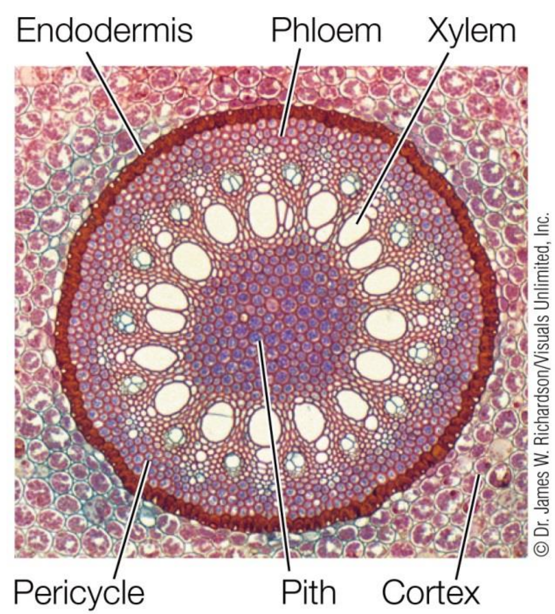


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.11 (Part 4)

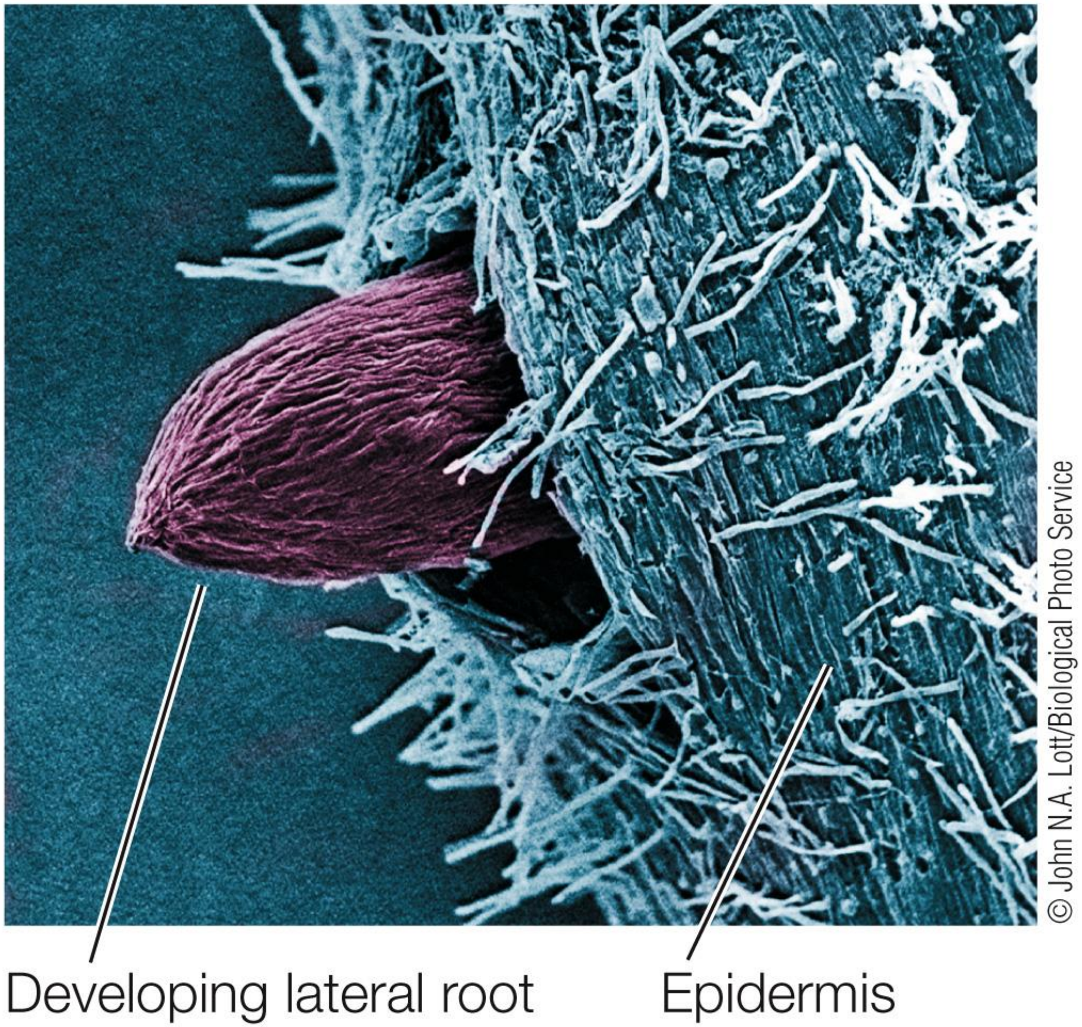
Protoderm gives rise to the **epidermis**

Ground meristem gives rise to the **cortex** and **endodermis**

Procambium produces the vascular cylinder or **stele**

Pericycle—undifferentiated cells:

- Gives rise to lateral roots
- Gives rise to lateral meristems that thicken the root
- Membrane transport proteins move nutrient ions into the xylem



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.12

Water and minerals enter through the root system in most plants. The root system is often larger than the shoot system.

The embryonic root is called the **radicle**.

In most eudicots the radicle develops into a primary root or **taproot** with outgrowth of **lateral roots**, forming a **taproot system**.

Taproots often function as food storage.

Typical monocot roots arise from the stem near ground level and are called **adventitious** roots. They form a **fibrous root system**: many thin roots of equal diameter originate from the stem at ground level or below.

Prop roots are adventitious roots that help support the stem in some plants (corn, banyan trees, some palms).

These species cannot support aboveground growth by the thickening of their stems.

(A) Taproots

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(B) Fibrous root system

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(C) Prop roots

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Plant organ 2: stem

Shoots are composed of repeating modules called phytomers (体节); shoots grow by adding new phytomers. New phytomers originate from cells in shoot apical meristems at stem tips and axillary buds (腋芽). Shoot apical meristem forms 3 primary meristems that give rise to the 3 tissue systems.

Leaf primordia develop on the sides of the shoot apical meristem at regular intervals—these sites become the nodes.

Bud primordia form at the bases of the leaf primordia. They can become apical meristems of new shoots.

Flower primodia

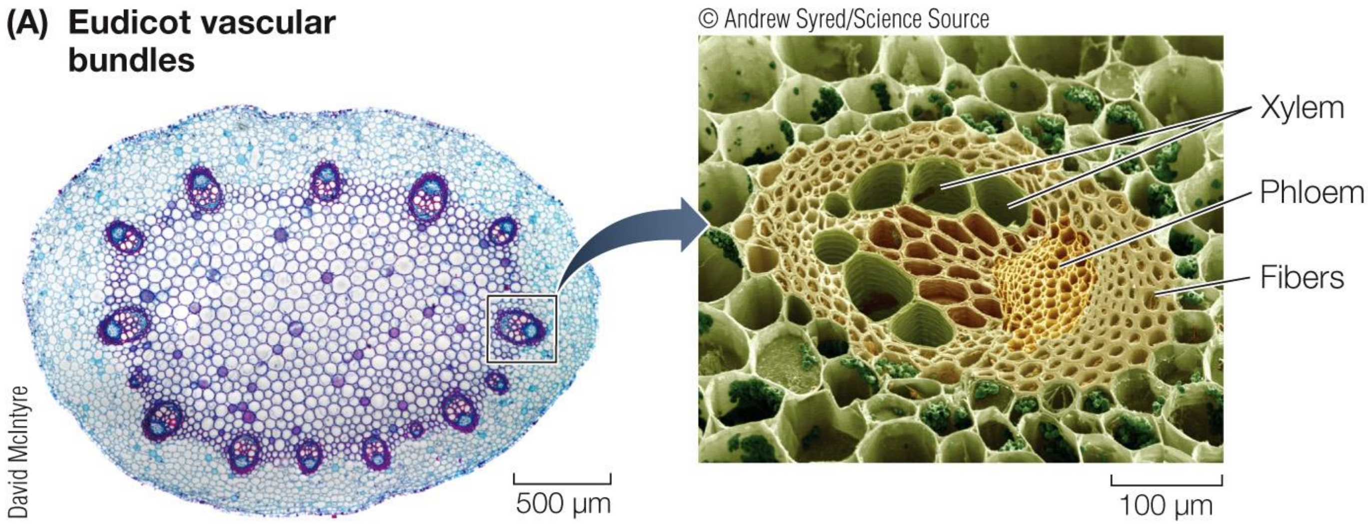
In young stems, vascular tissue is arranged in **vascular bundles** of both xylem and phloem.

Eudicots: Vascular bundles form a cylinder
Monocots: Bundles are scattered

In eudicots, pith is in the center and extends between the vascular bundles, forming pith rays. The cortex can contain supportive collenchyma cells with thickened walls. Pith and cortex constitute the ground tissue system. The outermost cell layer is the epidermis.

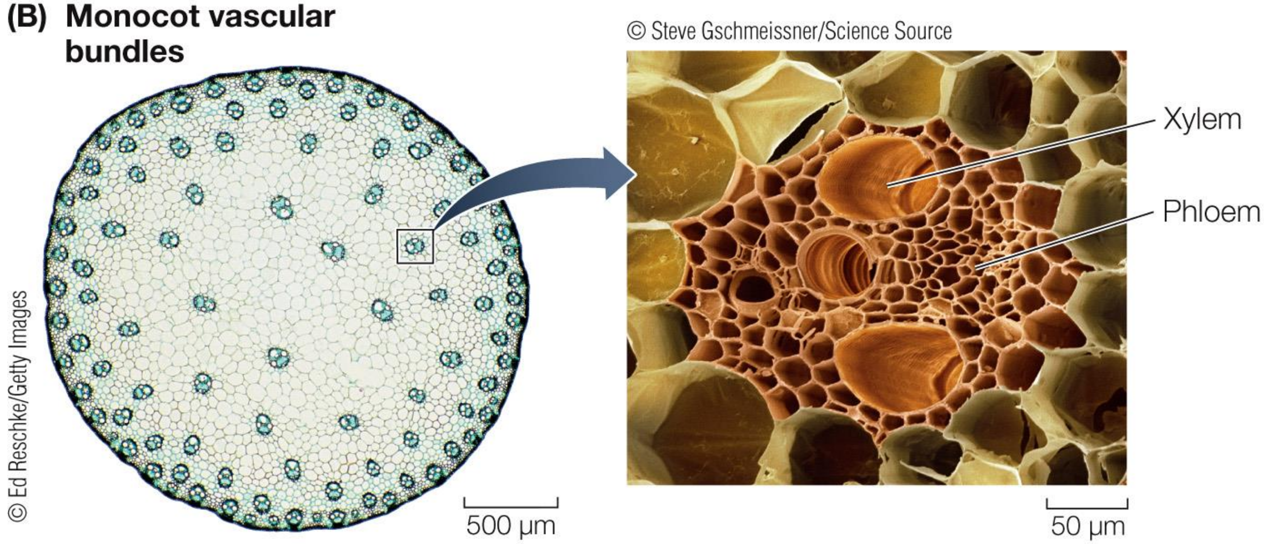
Stems elevate and support flowers and leaves. There are many modifications.

(A) Eudicot vascular bundles



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.14 (Part 1)

(B) Monocot vascular bundles



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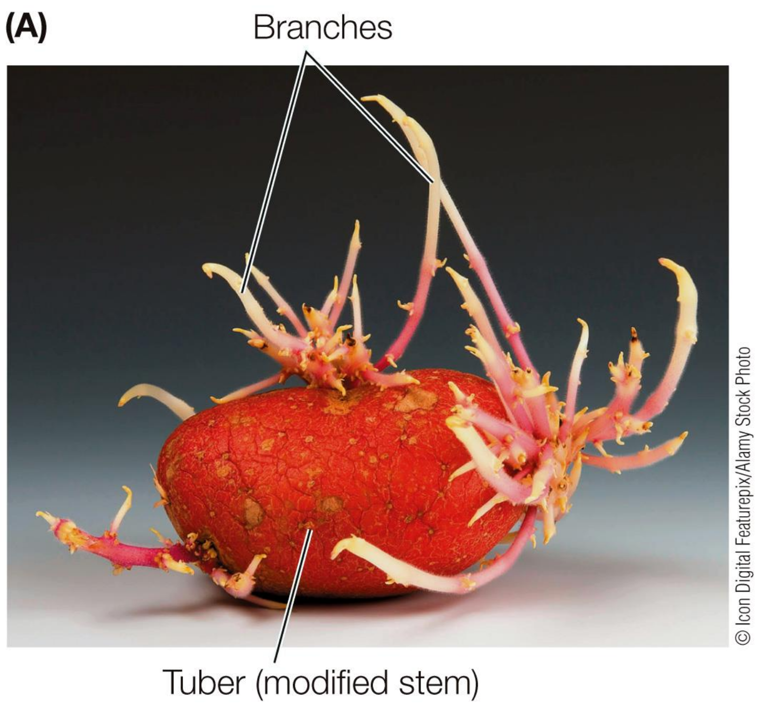
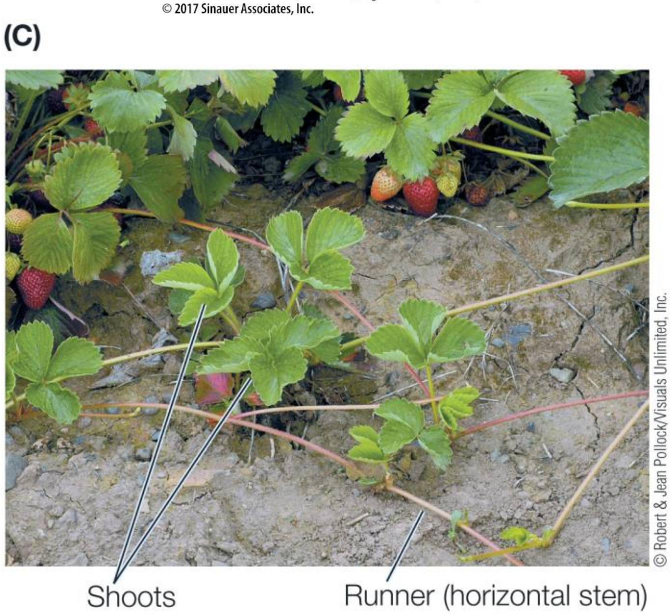


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.15 (Part 1)

LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.15 (Part 2)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.15 (Part 3)

Plant organ 3: leaf

Leaves are produced from apical meristems called vegetative meristems.

Growth of a leaf is determinate.

Leaf anatomy is adapted to carry out photosynthesis and exchange of O_2 and CO_2 with the environment, while limiting water losses.

Two zones of photosynthetic parenchyma cells make up the **mesophyll**:

- Palisade mesophyll
- Spongy mesophyll—includes air space for diffusion of gases

Vascular tissue forms a network of veins in leaves.

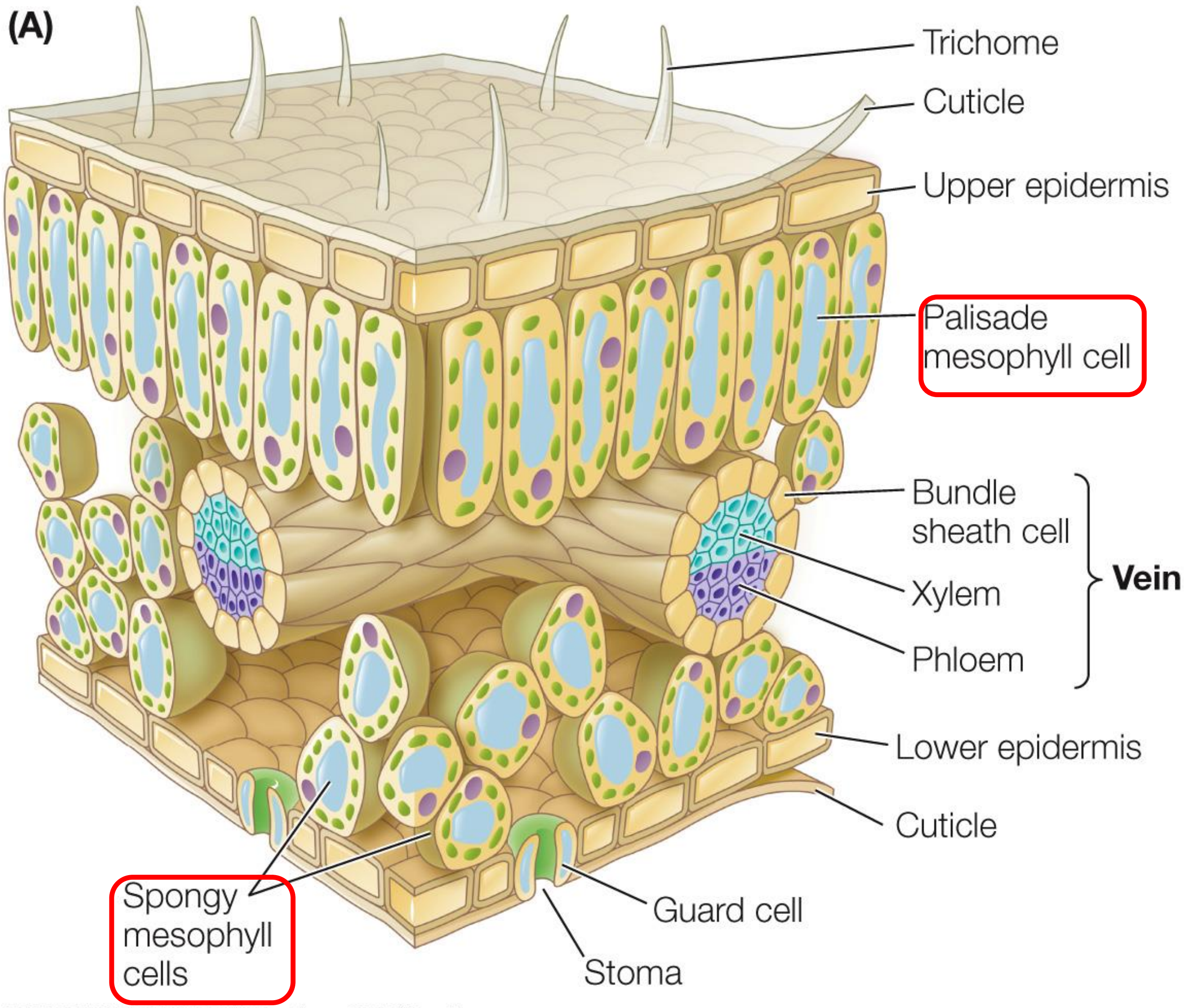
Veins extend to within a few cell diameters of all the cells, so mesophyll cells are well supplied with water and minerals, and the products of photosynthesis can be conducted to the phloem.

Leaves may also produce defensive chemicals, such as cyanide in the cassava plant.

Epidermal cells are nonphotosynthetic, and have a waxy cuticle that is impermeable to water.

The cuticle prevents water loss, but also prevents diffusion of gases.

Pores called **stomata** allow gas exchange. They are opened and closed by guard cells.



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LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 33.16 (Part 2)

Plant organ 4: flower

A complete flower has four concentric groups of organs arising from modified leaves:

Carpels are female sex organs; contain developing female gametophytes.

Stamens are male sex organs; contain developing male gametophytes.

Most angiosperms are “perfect”—flowers have both stamens and carpels.

Imperfect flowers have only stamens or only carpels.

Plants that bear both male and female flowers on an individual plant: **monoecious** (“one house”). Plants that bear either male-only or female-only flowers on an individual plant: **dioecious**.

The haploid gametophytes develop from haploid spores in the flower:

Megagametophytes (female) are called **embryo sacs**; develop in the ovules.

Microgametophytes (male) are called **pollen grains**; develop in anthers on the stamens.

Pollination: Transfer of pollen from anther to stigma. Germination of the pollen grain involves uptake of water from the stigma and growth of the **pollen tube** through the style to reach the ovule. Downward growth is guided by a chemical signal released by the synergids.

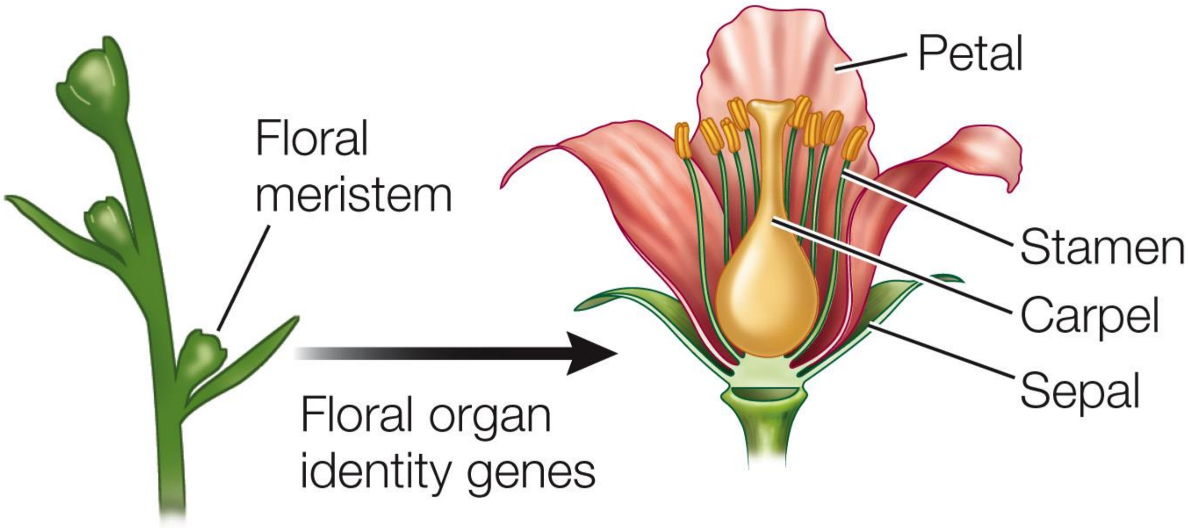
Double fertilization:

One synergid degenerates when the pollen tube arrives and the 2 sperm cells are released into its remains.

One sperm cell fuses with the egg cell, forming a diploid zygote.

The other sperm cell fuses with the two polar nuclei in the central cell, forming a **triploid** (**3n**) **cell**.

(C)



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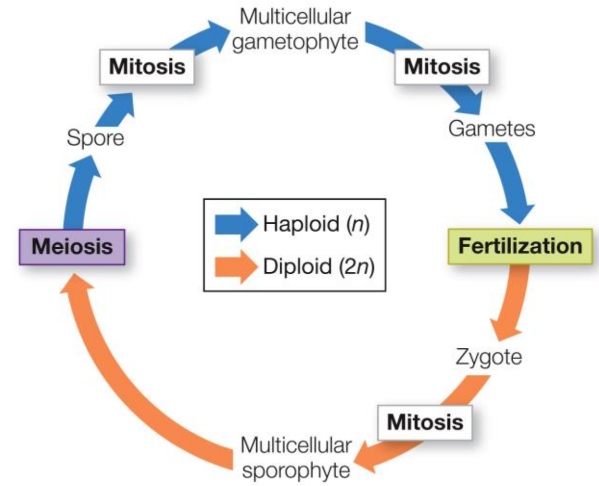

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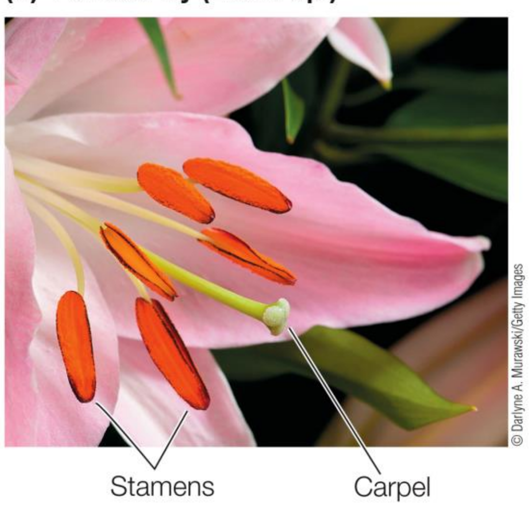
(A) Perfect: lily (*Lilium* sp.)



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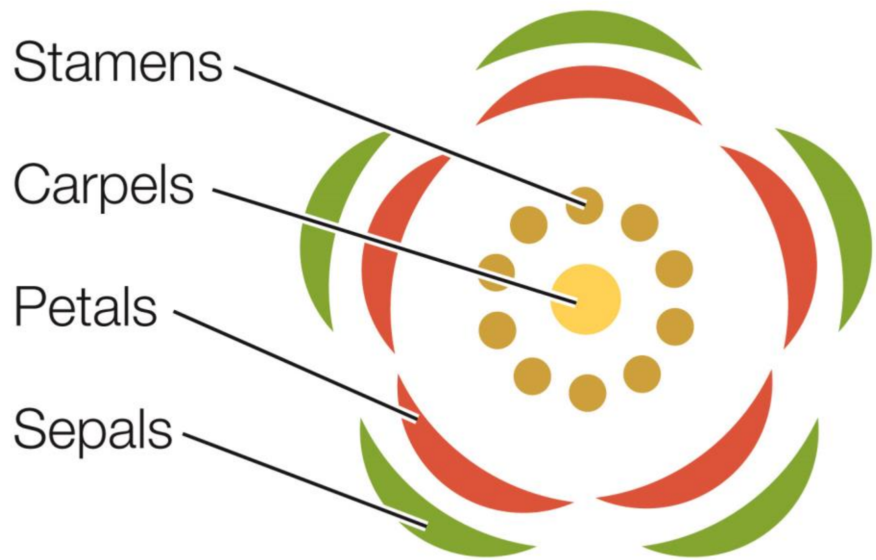

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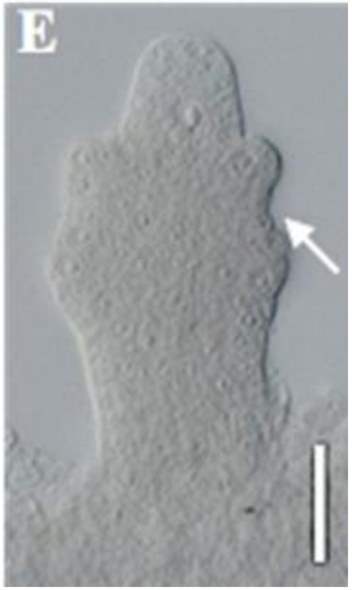
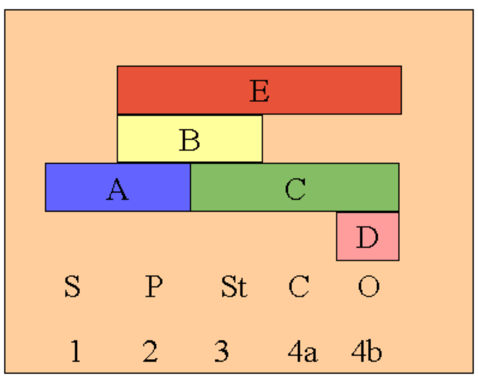
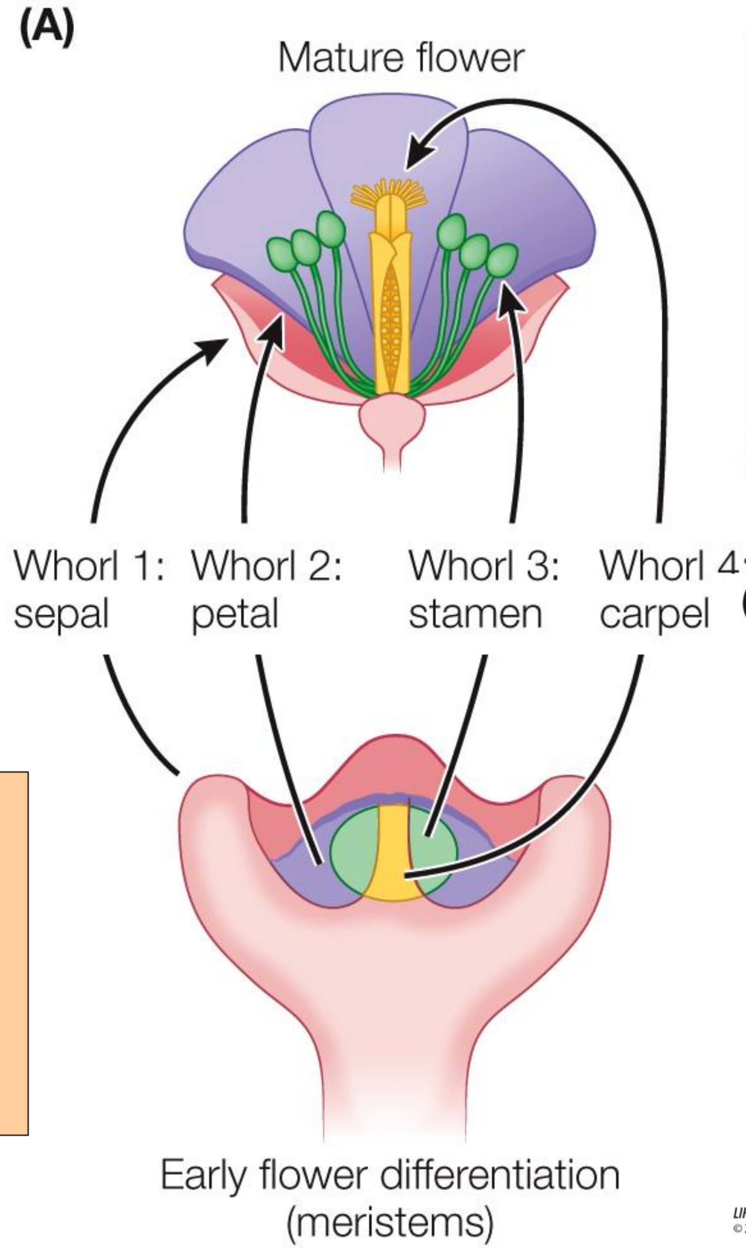
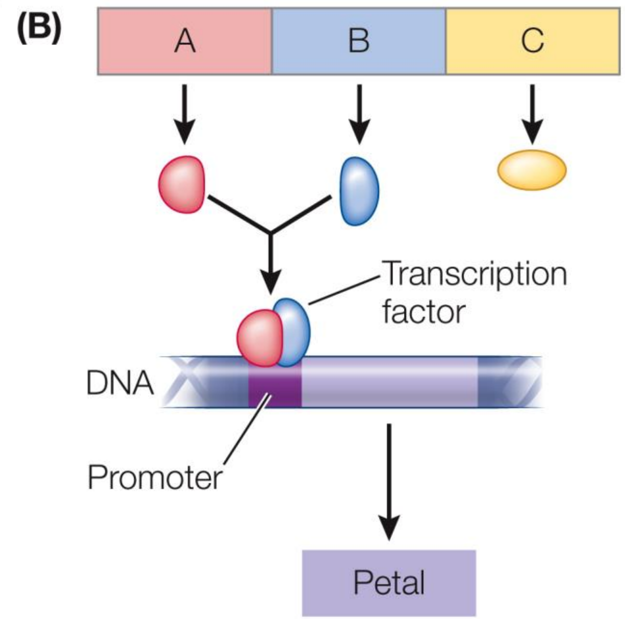




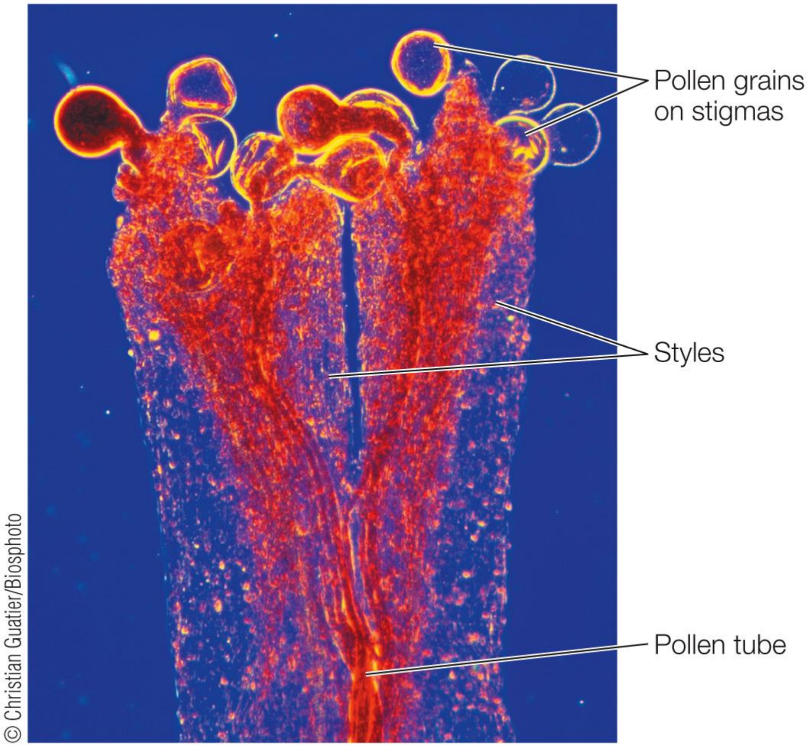


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 19.11 (Part 1)

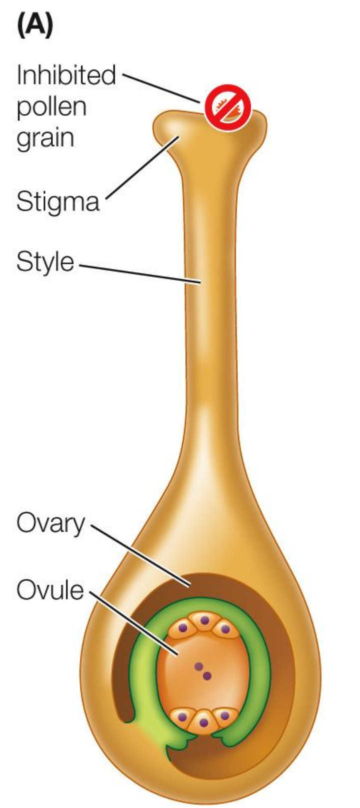
David McIntyre



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 19.11 (Part 2)

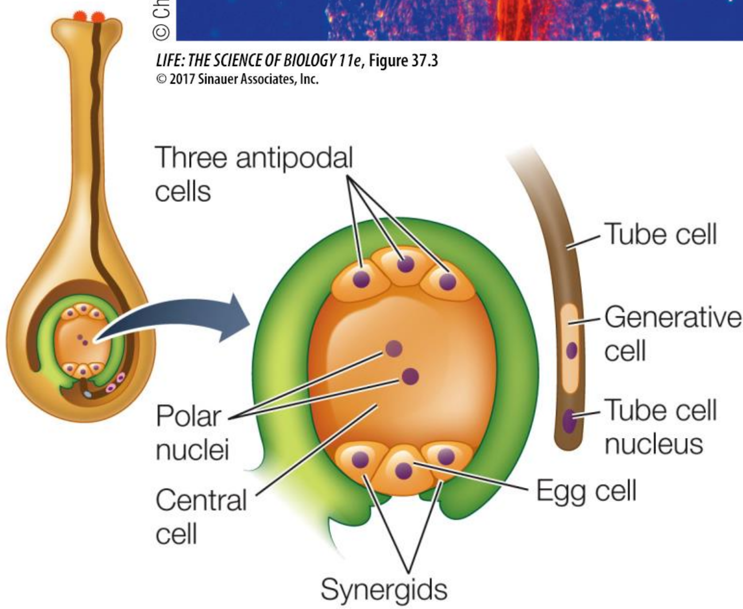


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.3

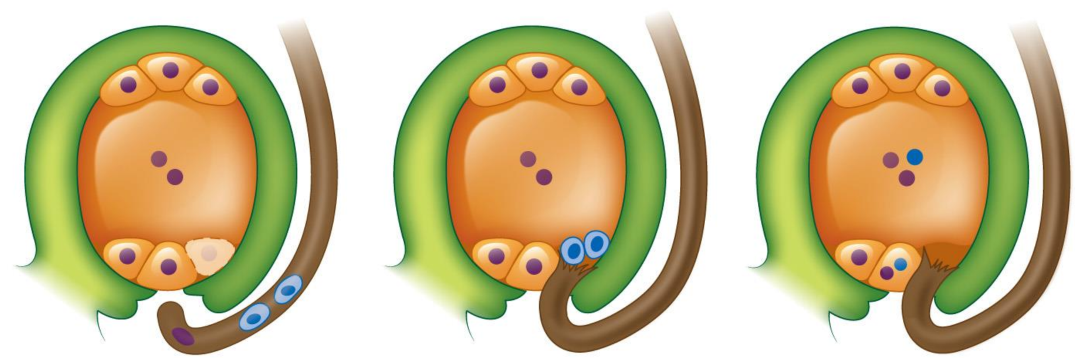


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.4 (Part 1

LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.4 (Part 2)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.5 (Part 1)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.5 (Part 2)

Plant organ 5&6: seed and fruit

The zygote nucleus begins mitotic division to form the new sporophyte embryo.

The triploid nucleus undergoes mitosis to form the **endosperm**. It will later be digested by the developing embryo for energy and building blocks.

Fertilization initiates growth and development of the embryo, endosperm, integuments, and carpel.

Integuments are tissues surrounding the ovule that develop into the seed coat.

The carpel becomes the wall of the fruit that surrounds the seed.

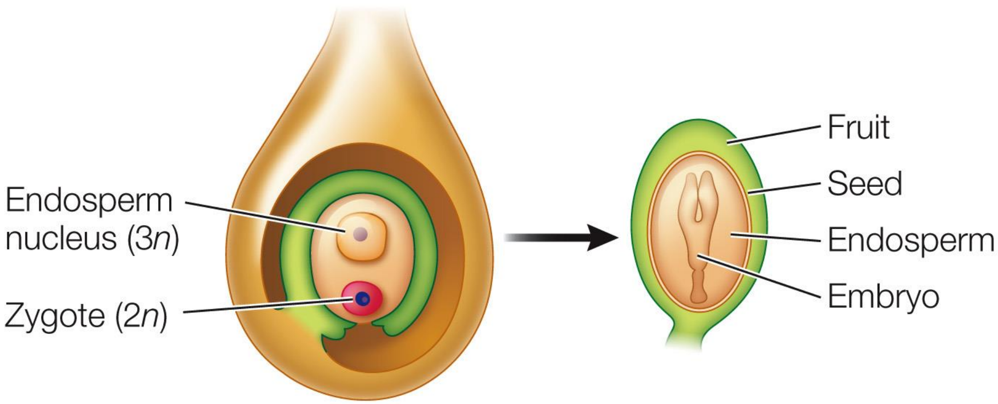
As seeds develop, they lose water and become dormant.

The ovary and seeds develop into a fruit.

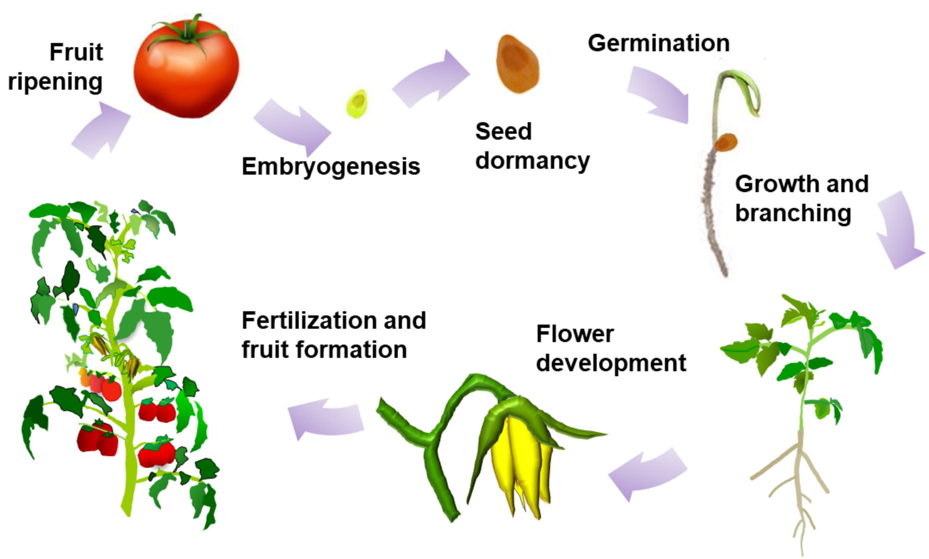
Fruits function to

- Protect the seed from damage and infection
- Aid in seed dispersal

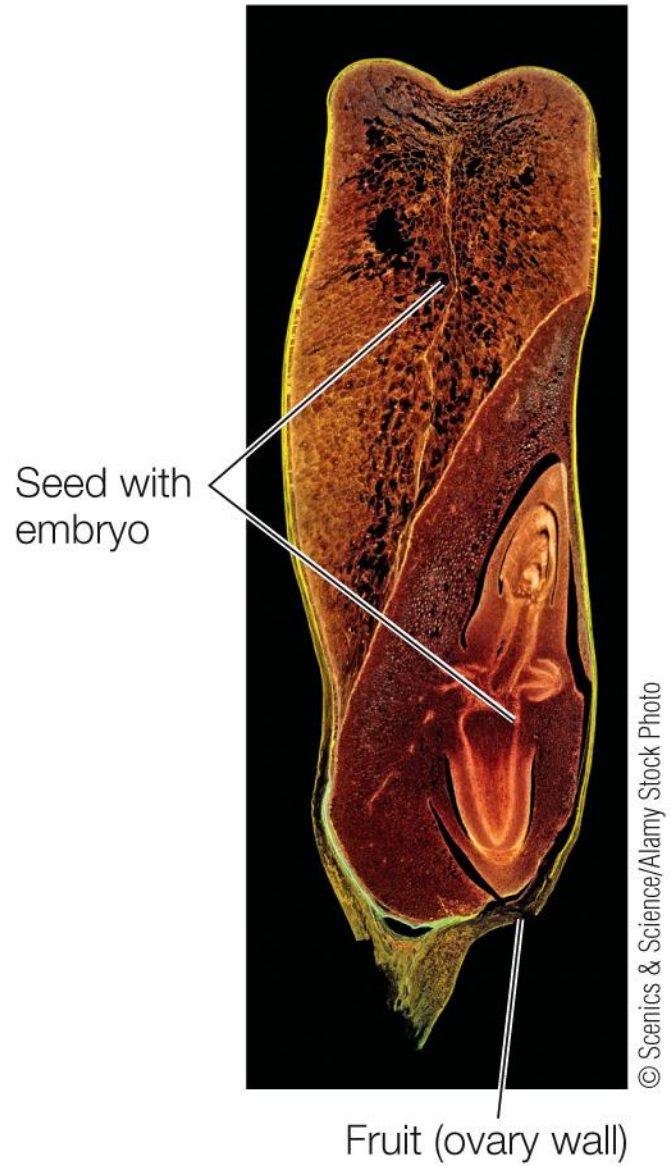
(A) Seed and fuit



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.6 (Part 1)



(D) Corn



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 37.6 (Part 4)

Some fruits consist only of ovary and seeds, some include other flower parts.

Some species produce fleshy edible fruits; some fruits are dry and inedible.

Many fruits help seeds disperse over long distances.

Some fruits have “wings” (e.g., maple) or feathery structures (e.g., thistle) for wind dispersal.

Some fruits hitch rides on animals as burs.

Water disperses fruits such as coconuts; they can float thousands of miles between islands.

Seeds may travel through an animal’s digestive tract and be deposited at some distance from the parent plant.

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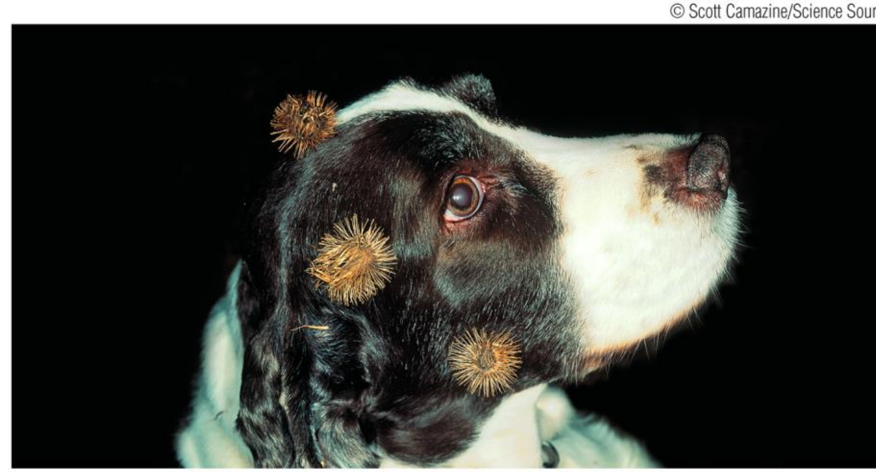

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Transport in Plant

34.1 Plants Acquire Water and Minerals from the Soil

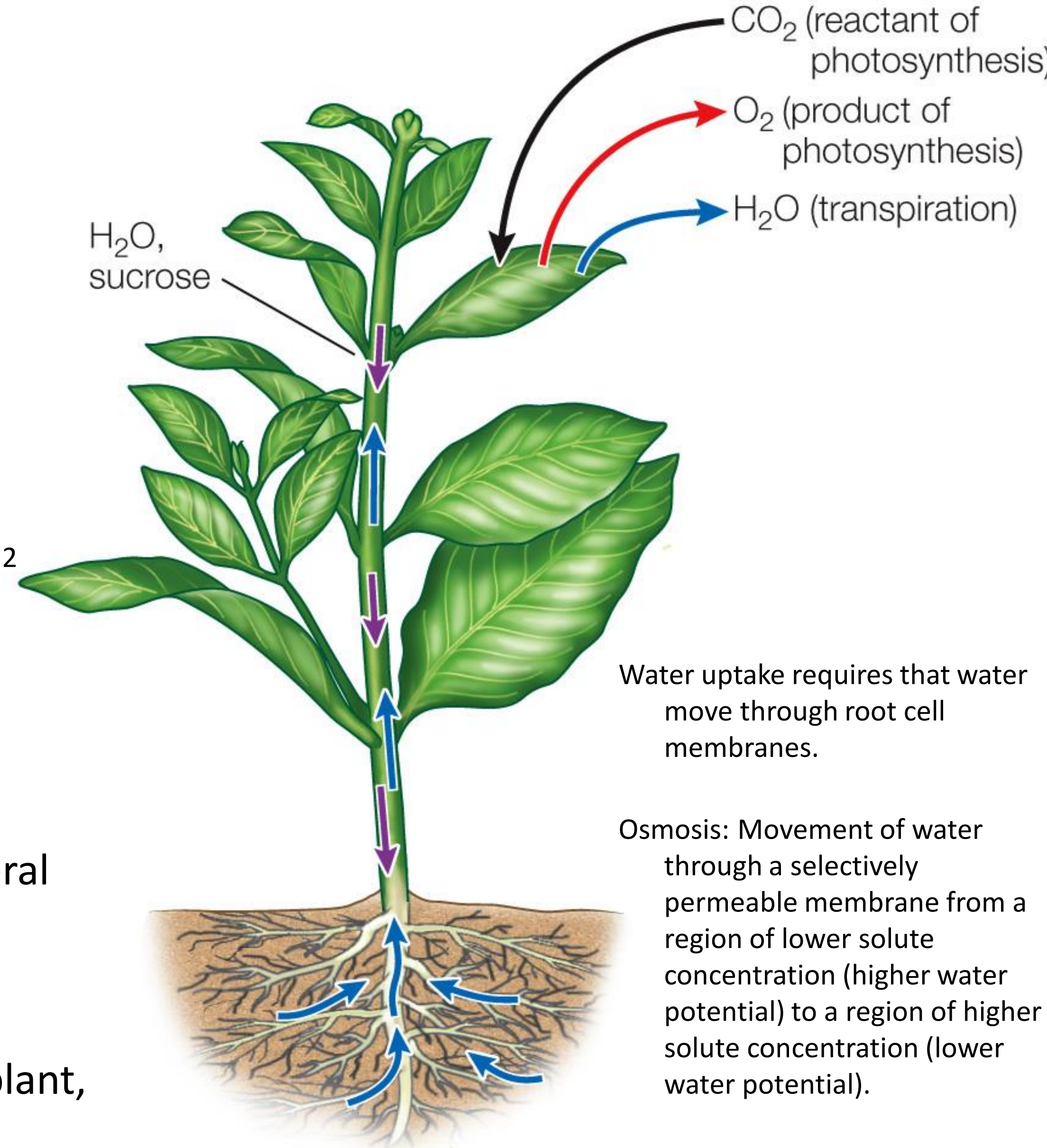
34.2 Water and Minerals Are Transported in the Xylem

34.3 Stomata Control the Loss of Water and the Uptake of CO_2

34.4 Solutes Are Transported in the Phloem

Terrestrial plants obtain water and mineral nutrients from the soil.

Water is needed for photosynthesis, for transporting solutes, for cooling the plant, and for internal pressure for support.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.1

Water uptake requires that water move through root cell membranes.

Osmosis: Movement of water through a selectively permeable membrane from a region of lower solute concentration (higher water potential) to a region of higher solute concentration (lower water potential).

$$\psi = \psi_s + \psi_p$$

Plants Acquire Water and Minerals from the Soil

Water potential is determined by solute potential and pressure potential.

- Membrane proteins form channels (aquaporins, ion channels) and act as pumps that help move materials across cell membranes.

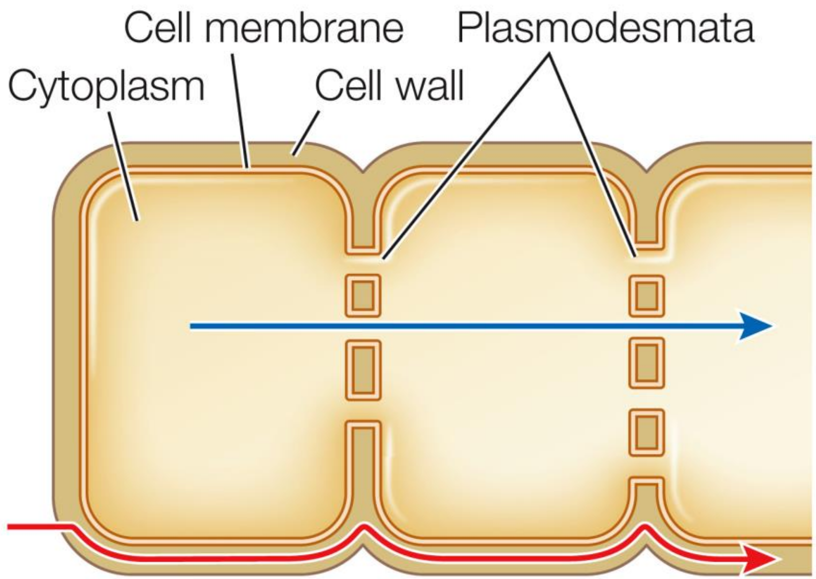
- The two main pathways to get water from the soil into the xylem are the apoplast (质外体) and the symplast (共质体).

Movement of water and ions across a cell membrane can be impeded.

- The Casparian strip (凯式带) prevents water and ions in the apoplast from crossing the endodermis; to reach the xylem, they must enter the symplast.

Water uptake requires that water move through root cell membranes.

Osmosis: Movement of water through a selectively permeable membrane from a region of lower solute concentration (higher water potential) to a region of higher solute concentration (lower water potential).



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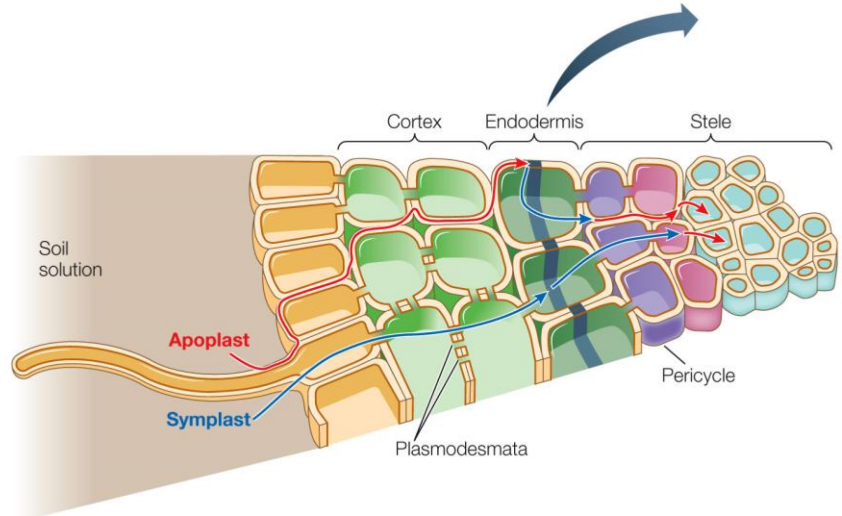
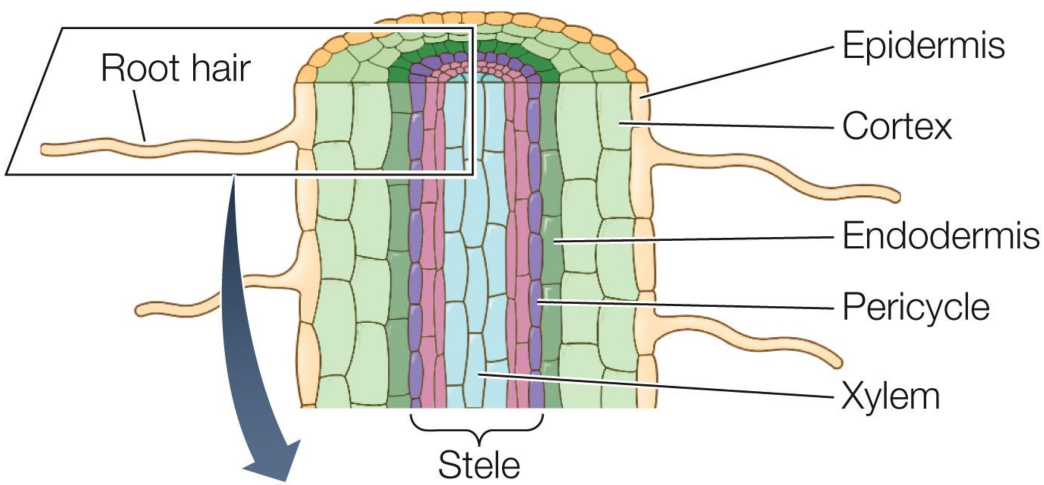


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.6 (Part 2)



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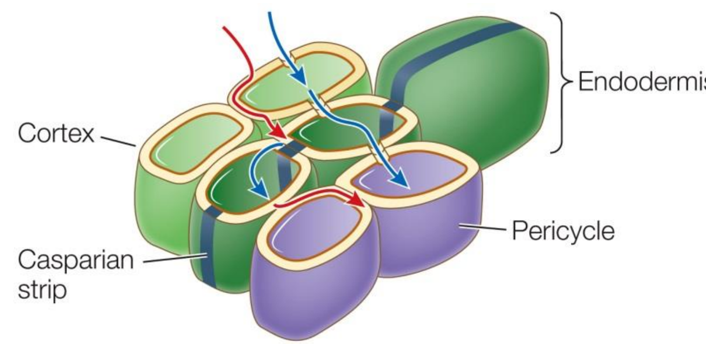


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.6 (Part 3)

Membrane proteins assist in moving water and minerals into root cells.

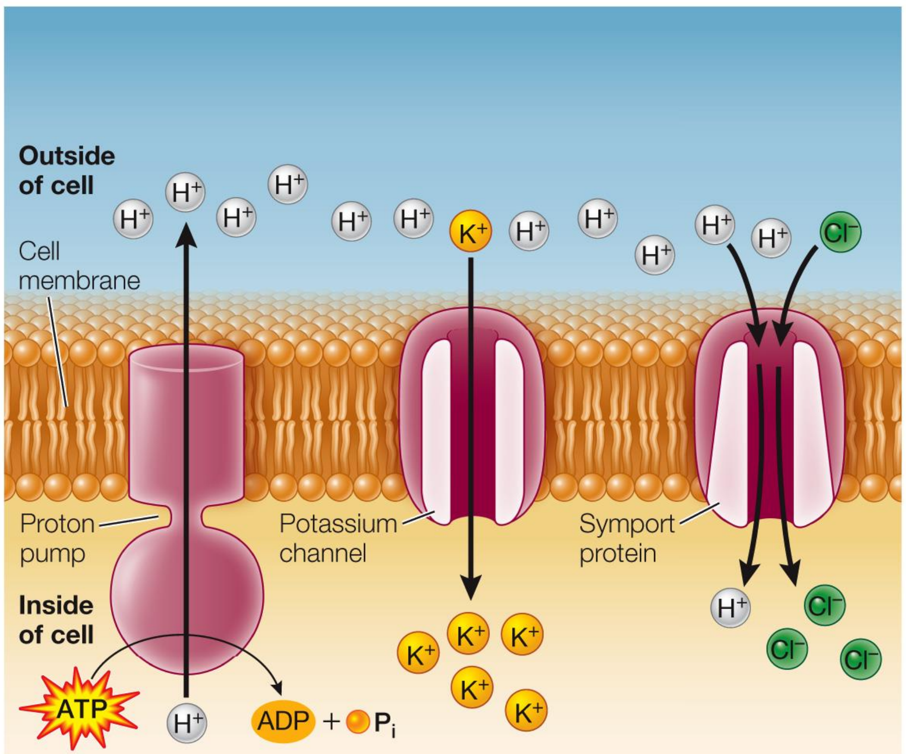
Aquaporins in cell membranes and tonoplast (vacuole membrane) allow water to diffuse rapidly.

Abundance and permeability of aquaporins determine rate of water movement, but not the direction—it is always passive.

Water potential in plant cells is dependent on water potential of the soil.

The physical structures of many plants are maintained by the positive pressure potential of water in their cells.

If the pressure potential drops, the plant wilts.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.4

LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.3

Water Potential, Solute Potential, and Pressure Potential

Tendency of a solution to take up water from pure water, across a membrane, is called **water potential** (ψ).

Two components:

Solute potential (Ψ_s)—solute potential of pure water is zero. The greater the solute concentration, the lower the water potential, and the lower (more negative) the solute potential.

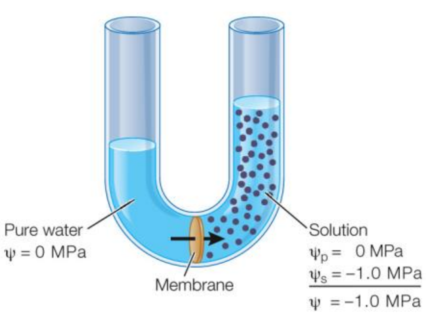
Pressure potential (Ψp)—as plant cells take up water, they swell, but cell walls provide resistance.

Pressure increases inside the cell (**turgor pressure**), which decreases the tendency of the cell to take up more water.

Therefore the pressure potential within a plant cell is usually positive.

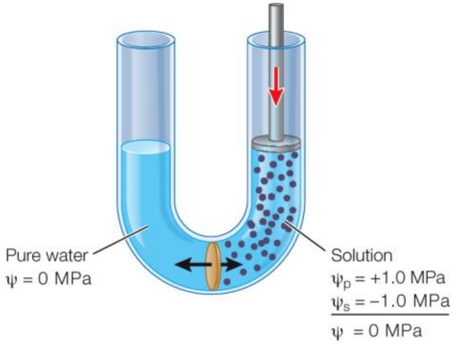
Water potential is the sum of its negative solute potential and positive pressure potential.

(A) A theoretical illustration of water potential



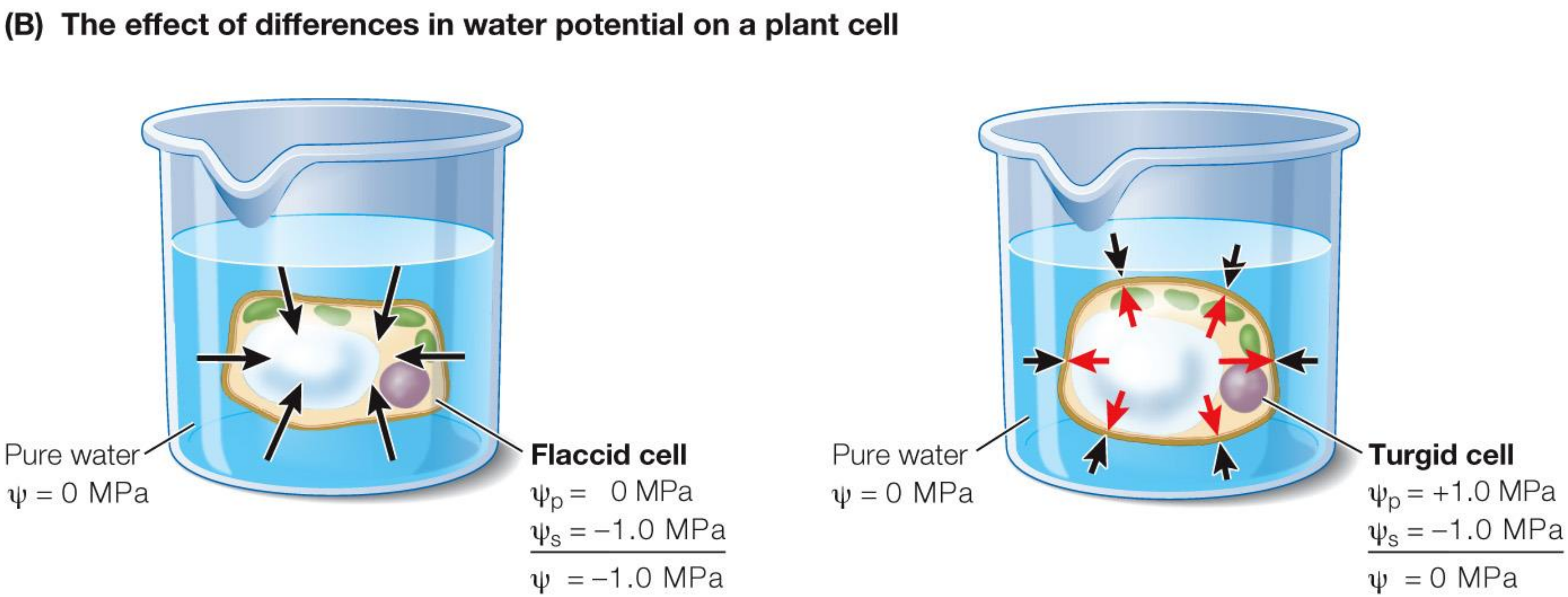
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.2 (Part 1)

$$\psi = \psi_s + \psi_p$$



When a plant cell is immersed in pure water, water enters the cell by osmosis until the pressure potential exactly balances the solute potential and the water potential is zero.

At this point the cell is **turgid**—it has a positive pressure potential.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.2 (Part 2)

Water and Minerals Are Transported in the Xylem

In plant tissues, water moves from cell to cell along a gradient of water potential.
Over long distances, such as in xylem vessels, water moves along a gradient of pressure potential.

Bulk flow (集流): Movement of water from a region of higher pressure potential to a region of lower pressure potential.

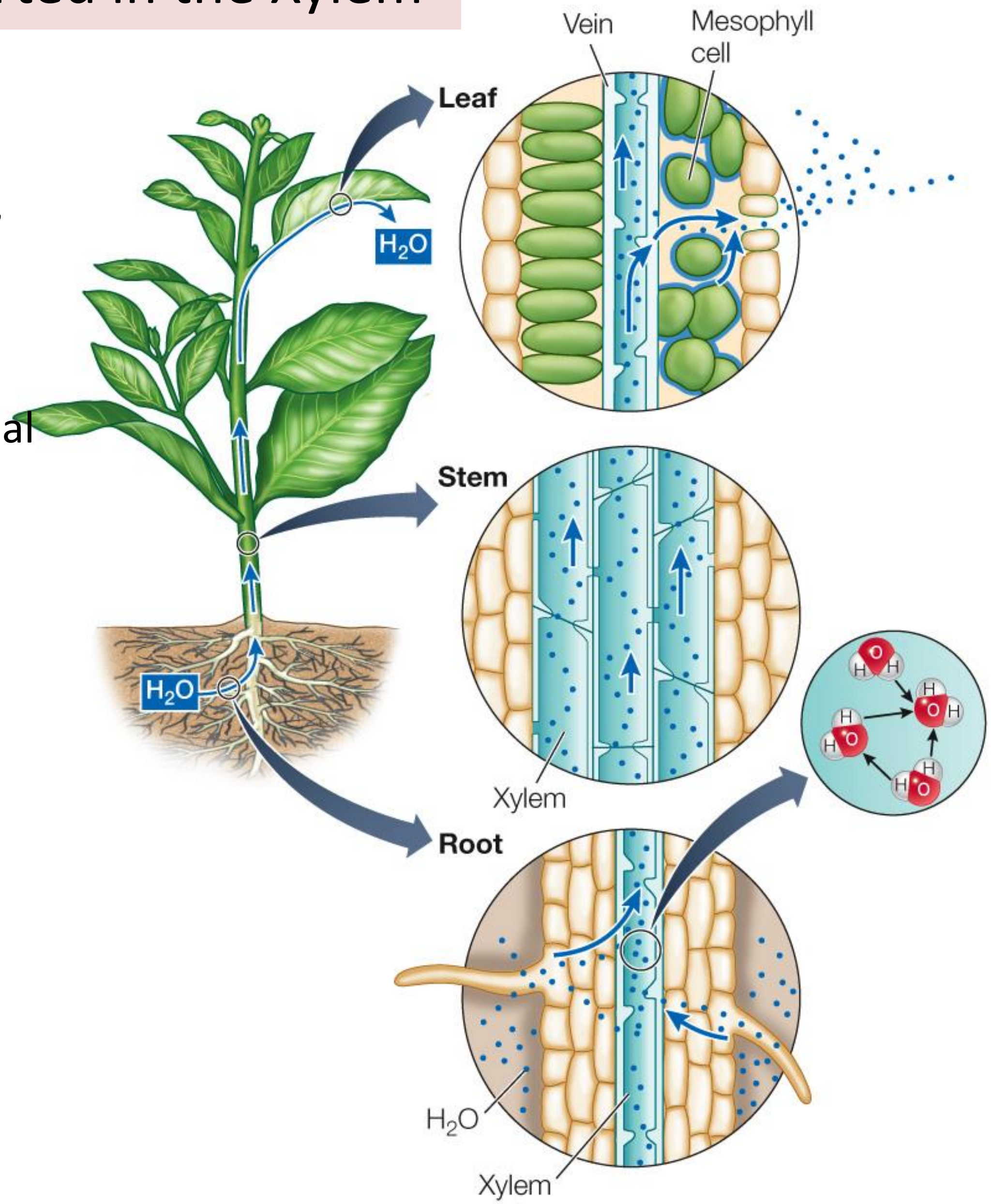
Hypothesis：the transpiration (蒸腾作用)–cohesion (内聚力)–tension (表明张力) mechanism.

Current model involves 3 processes:

Transpiration of water molecules from the leaves by evaporation

Tension in the xylem sap resulting from transpiration

Cohesion of water molecules in xylem sap, from the leaves to the roots



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.7

Transpiration: Water vapor diffuses from leaf to the outside air.

Stomata Control the Loss of Water and the Uptake of CO_2

As water evaporates from walls of mesophyll cells, surface tension of remaining water increases.

The increased *tension* (negative pressure potential) draws more water into the walls from the cells.

The resulting tension in mesophyll draws water from the xylem of the nearest vein into the apoplast of the mesophyll cells.

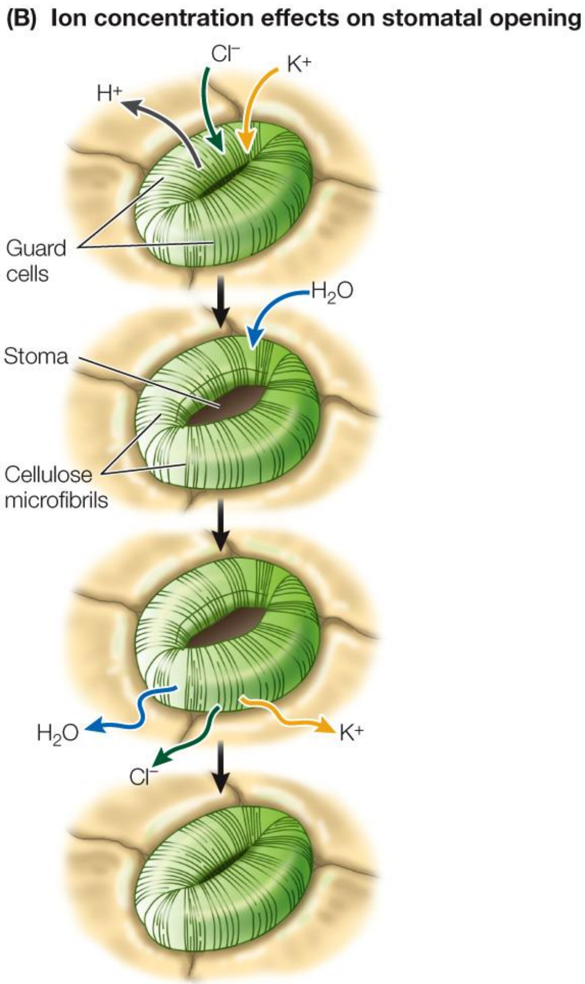
Removal of water from the veins establishes tension on the entire column of water in the xylem.

Cohesion between water molecules in the column prevents the column from breaking.

Plants close stomata in response to water availability.

When water potential of mesophyll cells is too negative, they release the hormone abscisic acid, which acts on guard cells and causes them to close.

Plants can also regulate water loss over longer times periods by adjusting the number of stomata.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.8 (Part 2)

Solutes Are Transported in the Phloem

Movement of carbohydrates and other solutes through the phloem is called **translocation**.

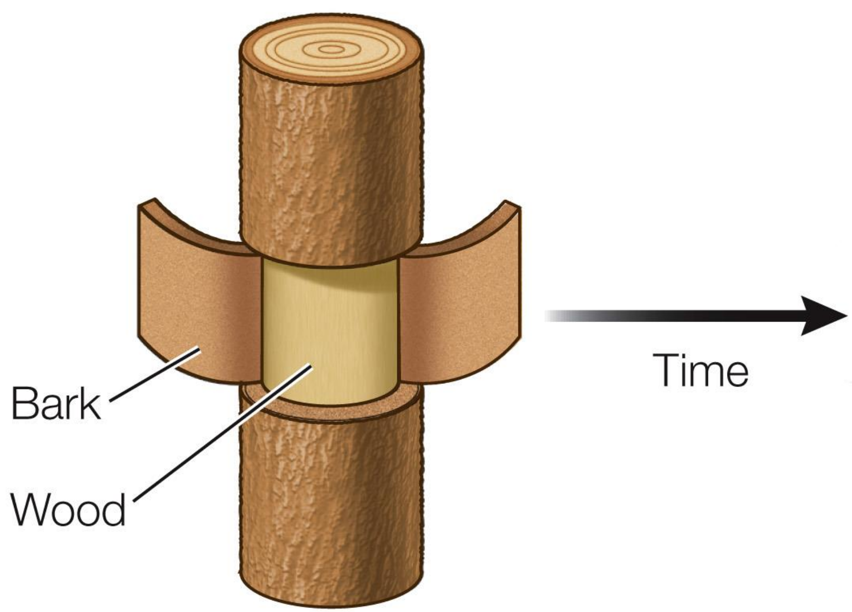
Products of photosynthesis are called **photosynthates**.

Content of the phloem is called **phloem sap**.

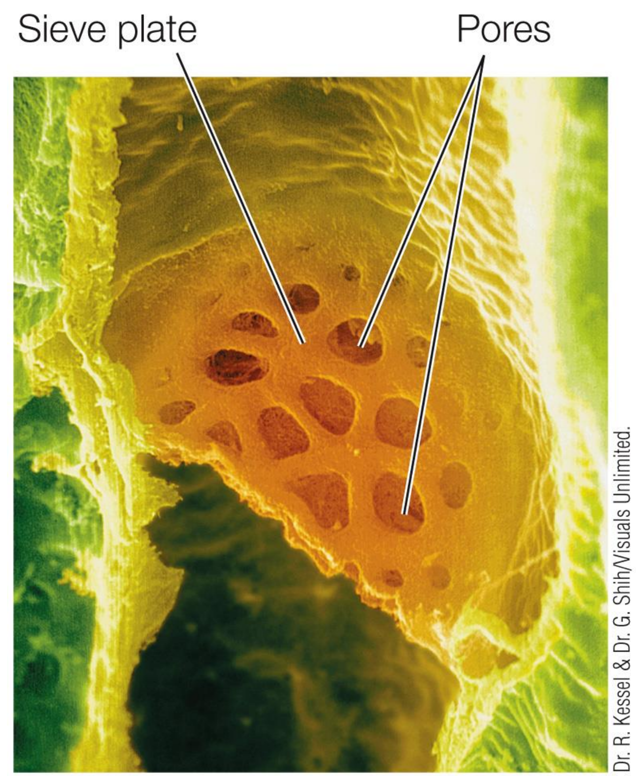
Phloem sap is translocated by bulk flow from sources to sinks:

Sources: Organs that *produce* more sugars than they require (e.g., a leaf).

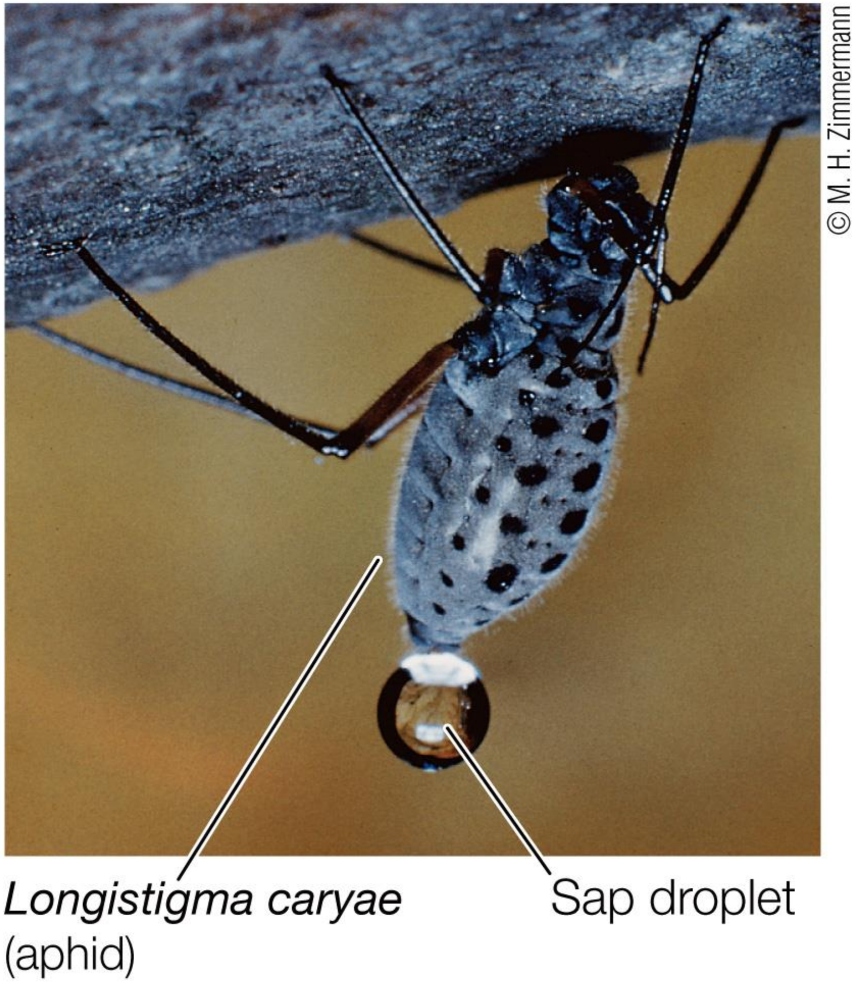
Sinks: *Consume* sugars for growth or storage.



LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 34, p. 745



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.9 (Part 2)



LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 34, p. 746 (Part 1)

LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 34, p. 746 (Part 2)

To study translocation, plant biologists have used aphids to sample phloem sap from individual sieve tube elements.

Sucrose makes up 90% of phloem sap solutes; also contains hormones, amino acids, mineral nutrients, and viruses. Flow rate of phloem sap can be very high. The movement in the phloem is bidirectional.

Pressure flow model of translocation:

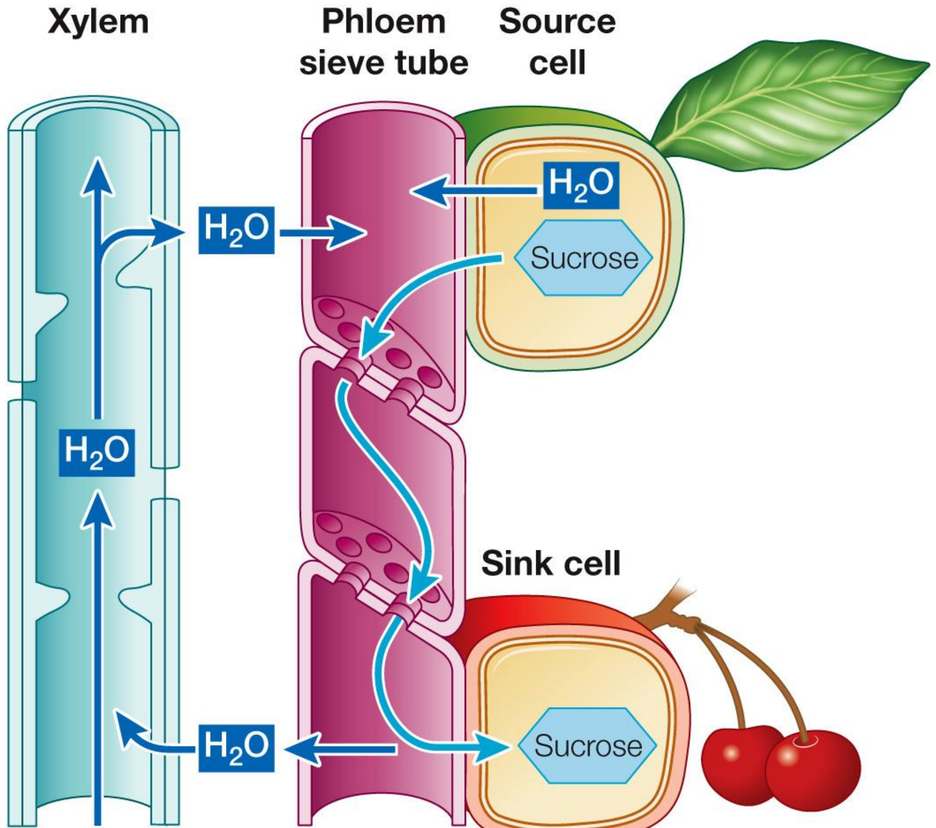
1. At a source, sucrose is actively transported into companion cells and moves into sieve tubes via plasmodesmata.

2. The sieve tubes have higher solute concentration and lower Pressure potential than surrounding cells; water enters the sieve tube by osmosis.

3. Entry of water results in a greater pressure potential, so fluid in the sieve tube is pushed toward the sink.

4. At the sink, solutes are unloaded passively and actively; water moves back into xylem vessels.

Thus, the gradient of solute and pressure potential needed for translocation is maintained.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 34.10

Plant Nutrition

35.1 Plants Require Nutrients

35.2 Plants Acquire Nutrients from the Soil

35.3 Soil Structure Affects Plant Nutrition

35.4 Soil Organisms Increase Nutrient Uptake by Plant Roots

35.5 Carnivorous and Parasitic Plants Obtain Nutrients in Unique Ways

Plants Require Nutrients

Plants are autotrophs.

Nutrients are elements required to build macromolecules.

Carbon and oxygen come from atmospheric CO_2.

Hydrogen comes from water.

Nitrogen—mostly from the soil.

Mineral nutrients: Inorganic elements, obtained mostly from the soil.

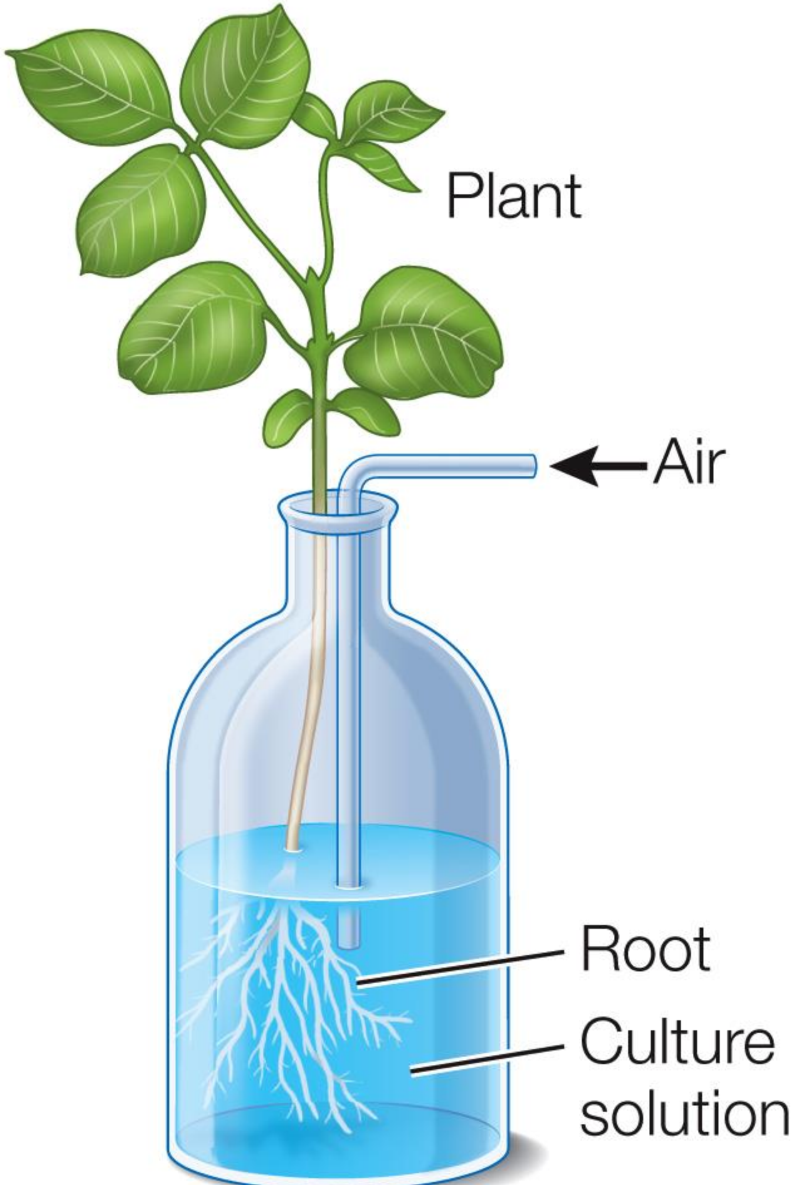
Includes nitrogen (N), sulfur (S), phosphorus (P), magnesium (Mg), iron (Fe), and calcium (Ca).

In the soil, these and other minerals are dissolved as ions in the **soil solution**.

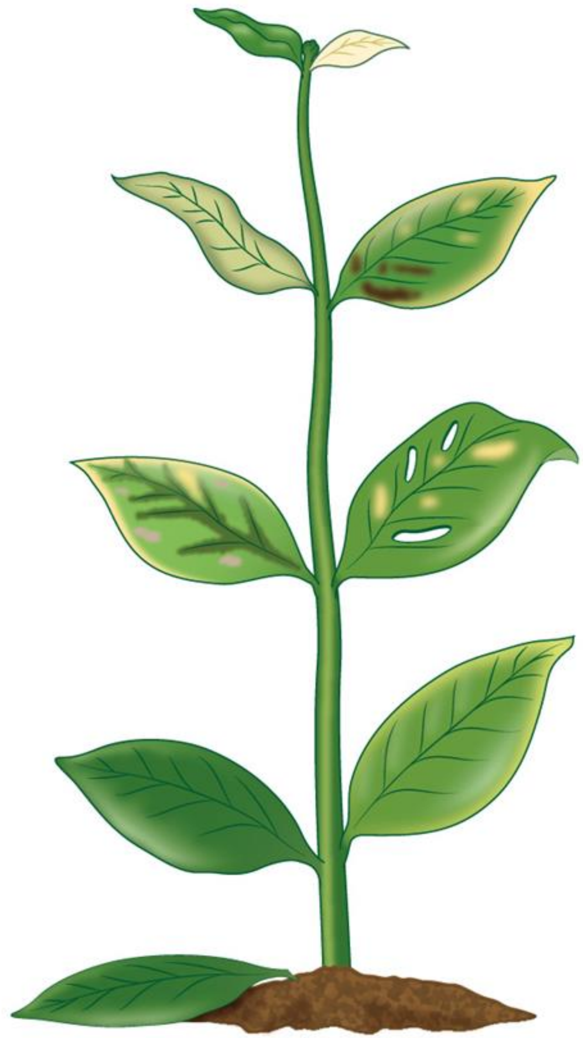
An **essential element** is one required for the plant to complete its life cycle, and no other element can substitute.

Macronutrients—at least 1 g per kg of dry plant matter is needed.

Micronutrients—less than 100 mg per kg is needed.



LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 35, p. 751



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.1

Experiments using hydroponic growth conditions have allowed scientists to determine the essential elements plants need for growth.

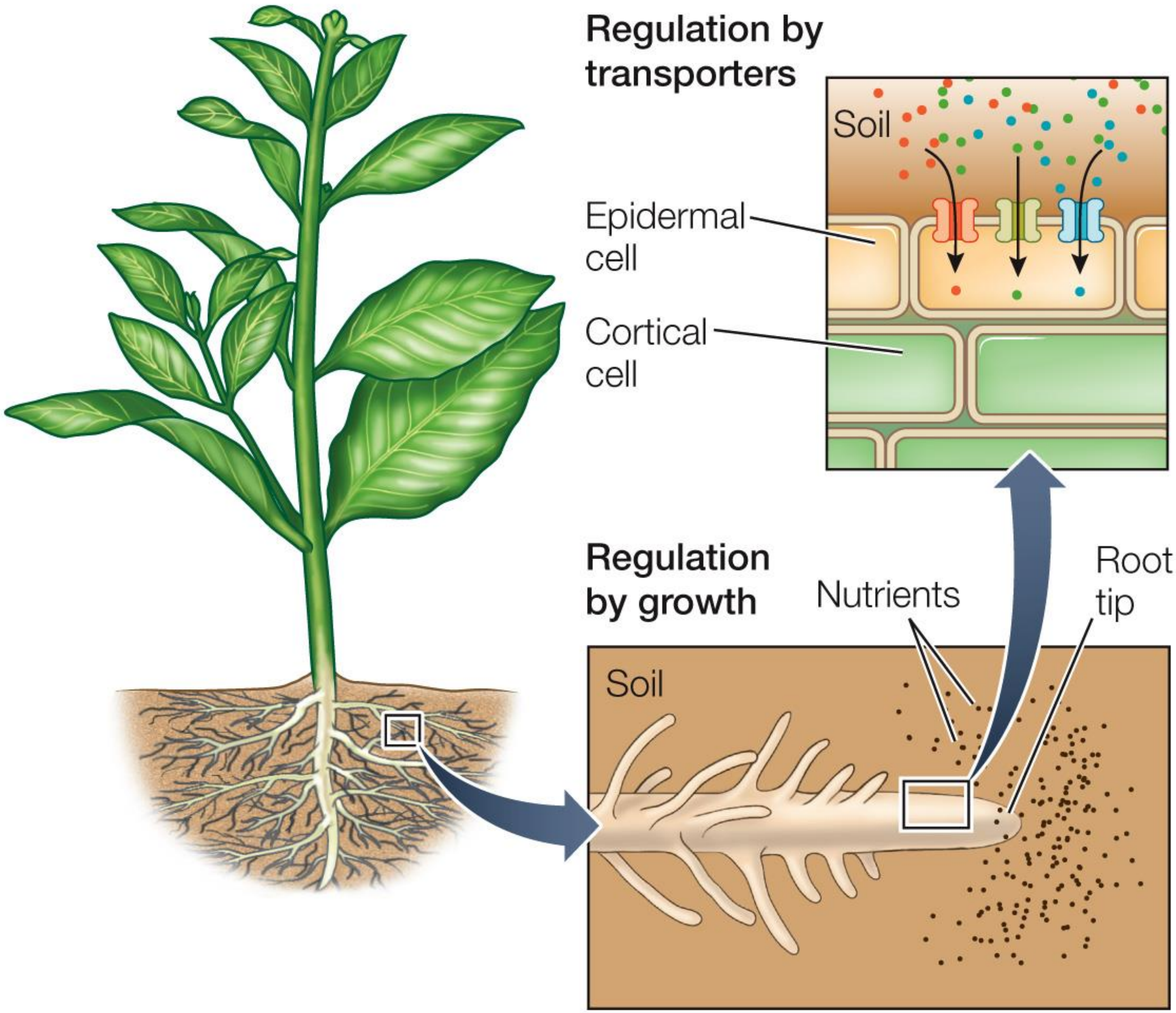
The six macronutrients (N, P, K, S, Ca, and Mg) were easily identified. Iron was the first micronutrient to be identified (1840s), nickel was the last (1983).

table 35.1 Mineral Elements Required by Plants

Element (abbreviation; absorbed form)	Typical amount in plant (g/kg dry wt)	Major functions	Deficiency symptoms
Macronutrients			
Nitrogen (N; NO_3^- and NH_4^+)	15	In proteins, nucleic acids	Oldest leaves turn yellow and die prematurely; plant is stunted
Phosphorus (P; $H_2PO_4^-$ and HPO_4^{2-})	2	In nucleic acids, ATP, phospholipids, and phosphoproteins	Plant is dark green with purple veins and is stunted
Potassium (K; K^+)	10	Enzyme activation; water balance; ion balance; stomatal opening	Older leaves have dead edges
Sulfur (S; SO_2^{4-})	1	In proteins and coenzymes	Young leaves are yellow to white with yellow veins
Calcium (Ca; Ca^{2+})	5	Affects the cytoskeleton, membranes, and many enzymes; second messenger	Growing points die back; young leaves are yellow and crinkly
Magnesium (Mg; Mg^{2+})	2	In chlorophyll; required by many enzymes; stabilizes ribosomes	Older leaves have yellow stripes between veins
Micronutrients			
Iron (Fe; Fe^{2+} and Fe^{3+})	0.1	In active site of many redox enzymes and electron carriers; chlorophyll synthesis	Young leaves are white or yellow
Chlorine (Cl; Cl^-)	0.1	Photosynthesis; ion balance	Leaf tips wilt; leaves turn yellow and die
Manganese (Mn; Mn^{2+})	0.05	Cofactor for many enzymes	Younger leaves are pale with green veins
Boron [B; $B(OH)_3$]	0.02	Required for proper cell wall formation and expansion	Poor growth of leaves and roots
Zinc (Zn; Zn^{2+})	0.02	Enzyme activation; auxin synthesis	Young leaves are abnormally small; older leaves have many dead spots
Copper (Cu; Cu^{2+})	0.006	Cofactor for some redox enzymes and electron carriers	New leaves are dark green, may have dead spots
Nickel (Ni; Ni^{2+})	0.001	Activation of the enzyme urease	Leaf tips die; deficiency is rare
Molybdenum (Mo; MoO_4^{2-})	0.0001	Cofactor of enzymes involved in nitrogen reduction	Leaves turn yellow between veins; older leaves die

LIFE: THE SCIENCE OF BIOLOGY 11e, Table 35.1

Plants Acquire Nutrients from the Soil



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.2

Plants are sessile and cannot change location to find nutrients.

Except for carbon and oxygen, plants' nutrient supply is localized—how can they find scarce nutrients?

Plants can grow throughout their lifetimes and thus rely on growth instead of movement.

Plants alter their direction of root growth, depending on the availability of dissolved nutrients in the soil.

Plant cells use gene regulation to control the numbers of membrane transporters and enzyme regulation to control the rate of incorporation of nutrients into complex biomolecules.

Roots mine the soil for minerals and water as they grow.

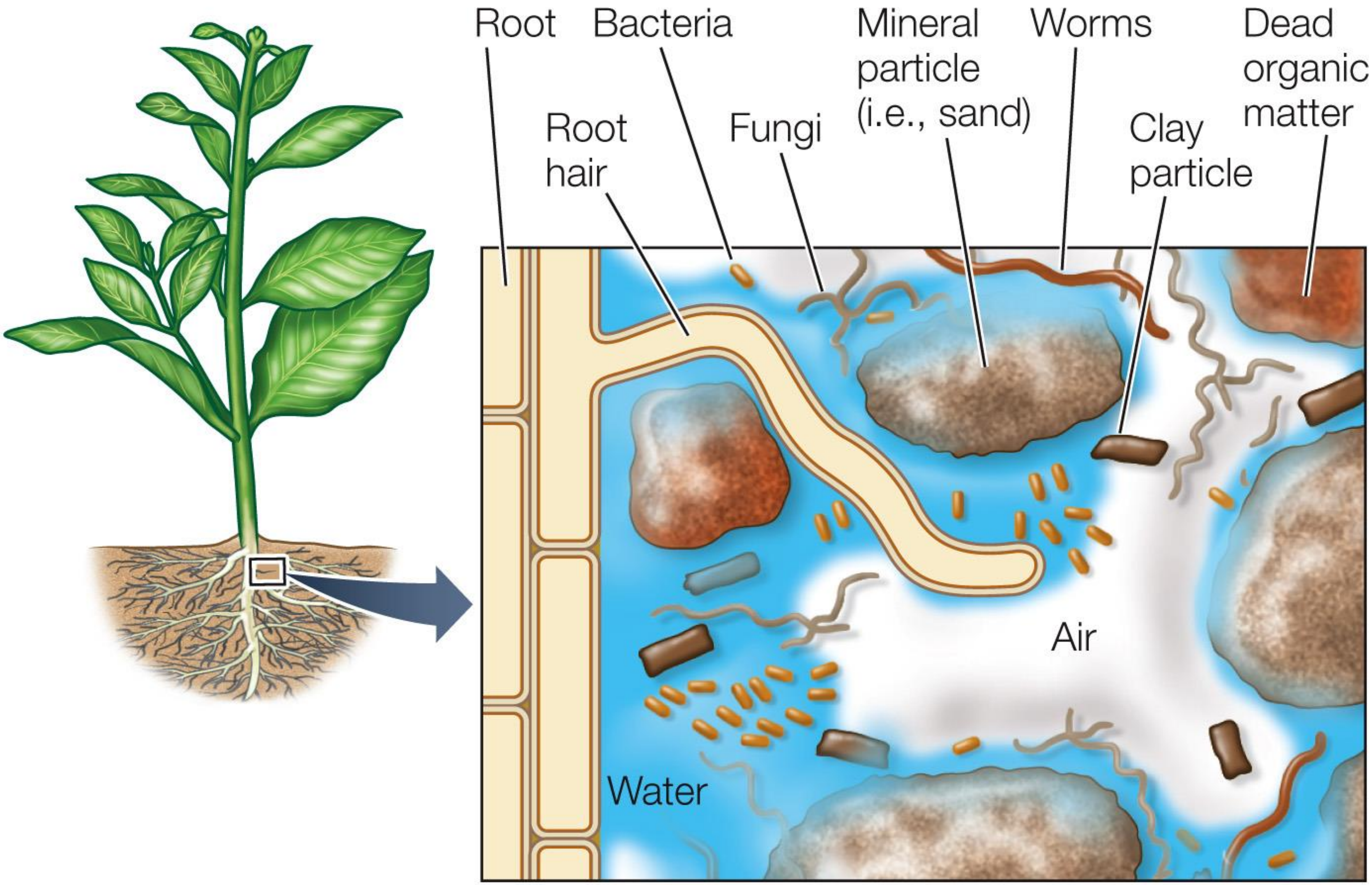
Growth of stems and leaves helps the plant get sunlight and CO_2.

Plants must also deal with variation in microenvironments.

Example: Animal droppings can create an area of high nitrogen concentration.

Efforts are underway to understand the signaling pathways that allow roots to grow towards nutrients.

Soil Structure Affects Plant Nutrition



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.3

Most terrestrial plants grow in soil.

Soils provide:

Mechanical support

Mineral nutrients and water

O_2 for root respiration

Soils have both living and nonliving components.

Living components include plant roots, bacteria, fungi, protists, and animals such as insects and earthworms.

Nonliving components: rock fragments and pebbles, sand, silt, and clay.

Soil also contains water and dissolved minerals, air spaces, and dead organic matter.

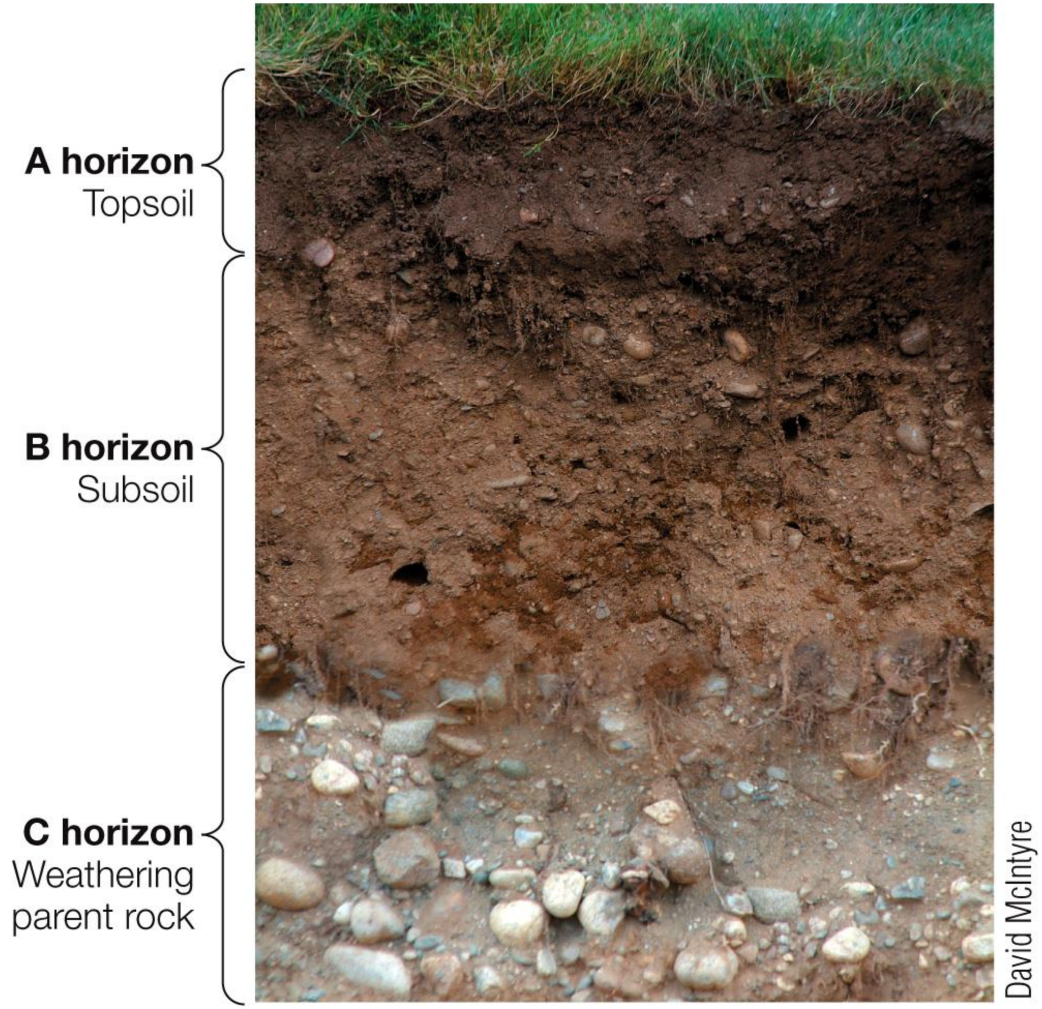
The air spaces are important sources of oxygen for plant roots.

Most soils have recognizable layers or **horizons**, called the soil profile.

A horizon or **topsoil**: Layer from which plants get nutrients; has most of the living organisms and dead organic matter.

B horizon or **subsoil**: Accumulates materials from the topsoil above and parent rock below.

C horizon, **parent rock**, or bedrock: Is in the process of breaking down to form soil.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.4

Soil fertility: Ability to support plant growth.

Partly determined by proportions of sand, silt, and clay.

Loam has an optimal mix of sand, silt, and clay, and also organic matter. Best for agriculture.

Soil organic matter, or **humus**, is used as a food source by microbes that break down complex organic molecules and release simpler molecules into the soil solution.

Humus also provides air spaces that increase O_2 availability to plant roots.

Rocks are broken down into soil particles (**weathered**) in two ways:

- Mechanical weathering—physical breakdown by wetting, drying, freezing
- Chemical weathering:
  - Oxidation by atmospheric O_2
  - Hydrolysis (reaction with water)
  - Acids (carbonic acid)

Parent rock and weathering processes determine the basic structure and composition of soil.

Nutrient availability is a key characteristic for plants.

Nutrients must be dissolved in the soil solution for uptake.

Humus and clay particles carry negative charges and form ionic attractions with positively charged mineral nutrients (cations): K^+, Mg^{2+}, Ca^{2+}.

These cations must be detached from the clay particles to become available to plants.

Root hair cells have membrane transporters that pump protons (H^+) out of the cell.

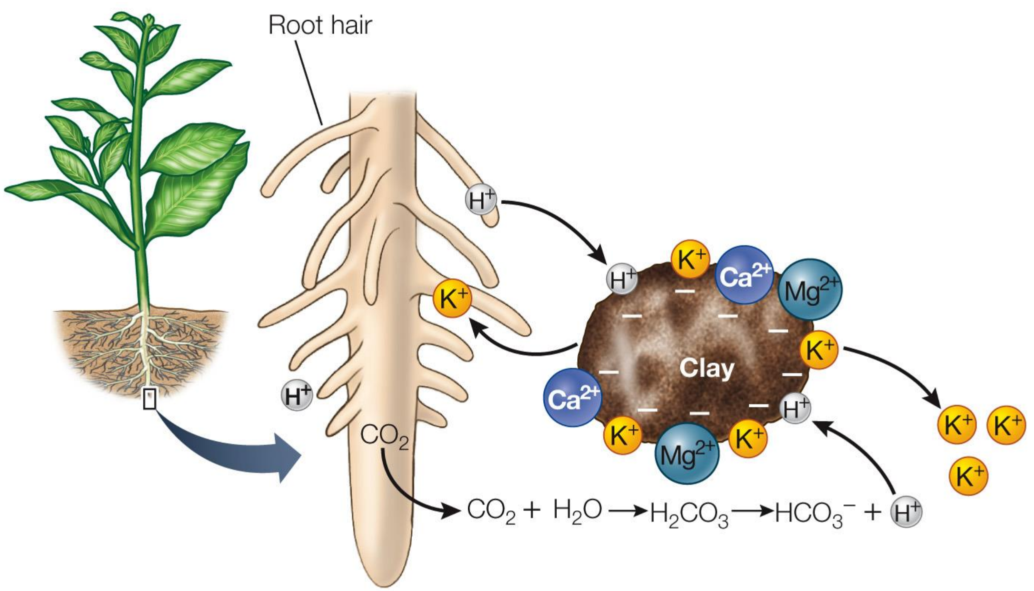
Roots also release CO_2 through cellular respiration. It reacts with soil water to from carbonic acid, which ionizes: $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

Proton concentration increases around the root.

The protons bind more strongly to clay particles than the mineral cations, and they trade places: **cation exchange**. Cation exchange capacity affects soil fertility.

Cations are retained in the A horizon, but anions such as SO_4^{2-} and NO_3^- can be leached rapidly.

Soil pH affects binding of ions and solubility of other nutrients such as iron, as well as absorption of nutrients by roots.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.5

Leaching and crop harvesting can deplete soil nutrients.

Soil fertility can be restored or increased by shifting agriculture or applying fertilizers.

Shifting agriculture

When soil can no longer support plant growth, people move to another location.

The first field is allowed to lie fallow, and nutrients are replenished by weathering and organic matter from plant growth.

The process of shifting agriculture takes a long time; it is not feasible today to feed a growing population.

Chemical fertilizers are now commonly used to improve soil fertility.

Organic fertilizers such as manure, compost, or crop residues release nutrients slowly.

Soil microorganisms break down organic molecules into smaller, simpler molecules that dissolve in soil water and enter plant roots.

Inorganic fertilizers supply mineral nutrients in forms that can be taken up immediately by plants.

Allows farmers to control amount of a particular nutrient supplied to each crop, depending on the needs of the crop and the type of soil.

Soil Organisms Increase Nutrient Uptake by Plant Roots

Plants actively encourage some species of fungi and bacteria to infect their roots and even invade root cells, in symbiotic relationships.

Mycorrhizae are associations of fungi with plant roots; occur in more than 90% of terrestrial plants.

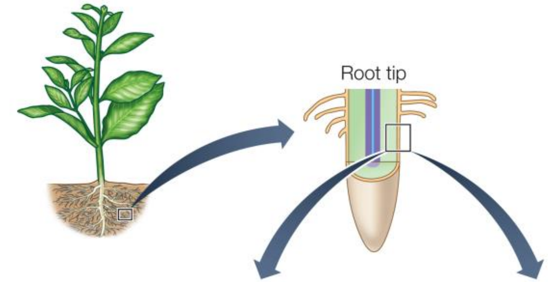
Some plants form associations with nitrogen-fixing bacteria.

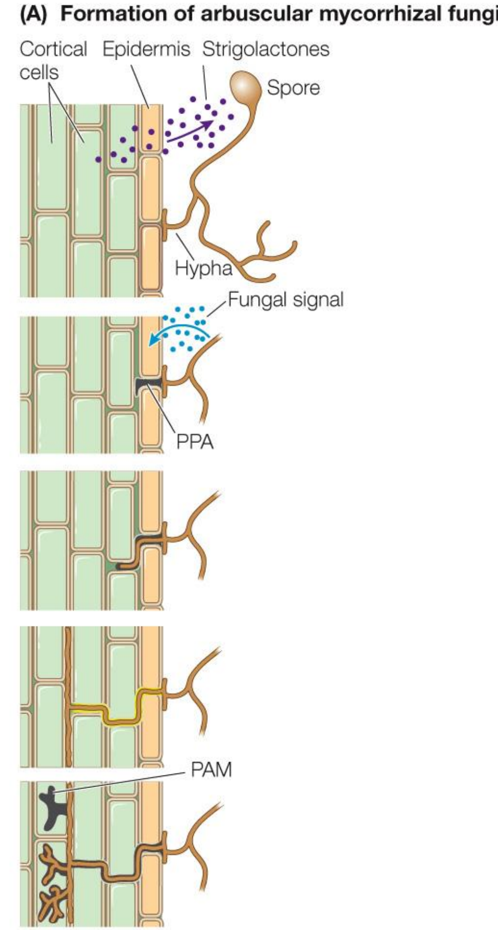
These associations are initiated by signals from plant roots to attract soil organisms, and they involve similar genes and pathways.

Formation of arbuscular mycorrhizae:

Plant roots secrete **strigolactones** that stimulate rapid growth of fungal hyphae toward the root.

In response, fungi produce signals that stimulate expression of plant symbiosis-related genes. The prepenetration apparatus (PPA) guides the growth of the fungal hyphae into the root cortex.





LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.6 (Part 2)

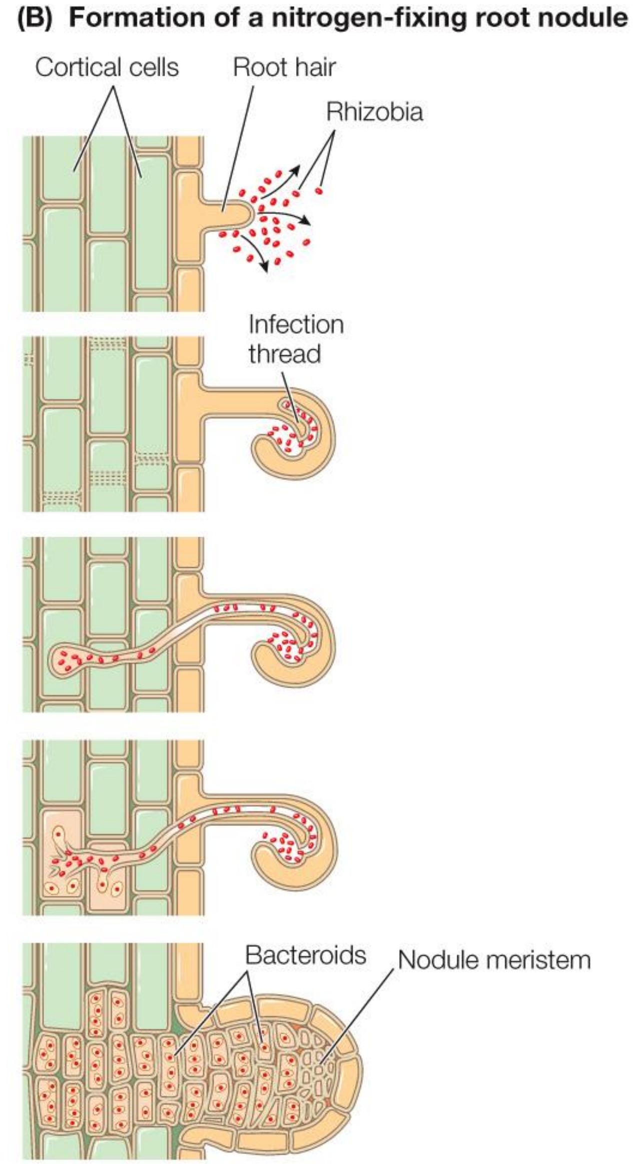
Arbuscules form within root cortical cells and are the sites of nutrient exchange.

Plant and fungal cytoplasms never mix—they are separated by the fungal cell membrane and the periarbuscular membrane (PAM), which is continuous with the plant cell membrane. Formation of nitrogen-fixing nodules:

Legume plants form symbioses with rhizobia bacteria.

The roots release flavenoids and other signals to attract rhizobia.

Flavenoids also trigger transcription of bacterial *nod* genes, which encode nodulation factors.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.6 (Part 3)

Nodulation factors cause cells in root cortex to divide and form a primary nodule meristem, which gives rise to the **root nodule**.

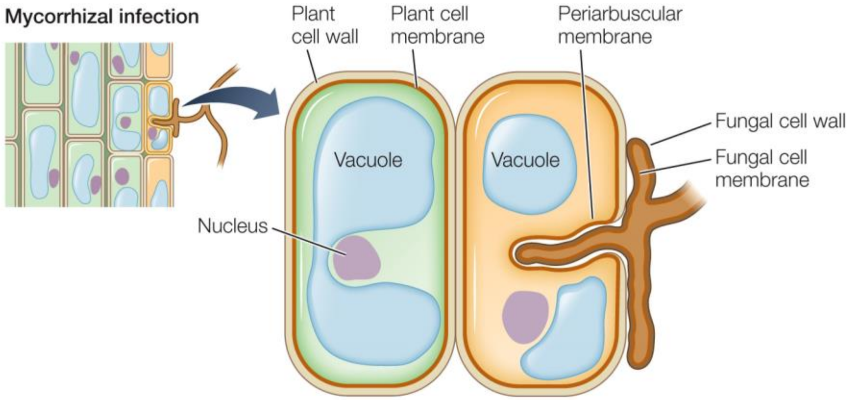
Bacteria enter the root via an infection thread and eventually reach cells in the interior of the nodule.

Bacteria are released into the nodule cells enclosed in vesicles, where they differentiate into **bacteroids**—the form that can fix nitrogen.

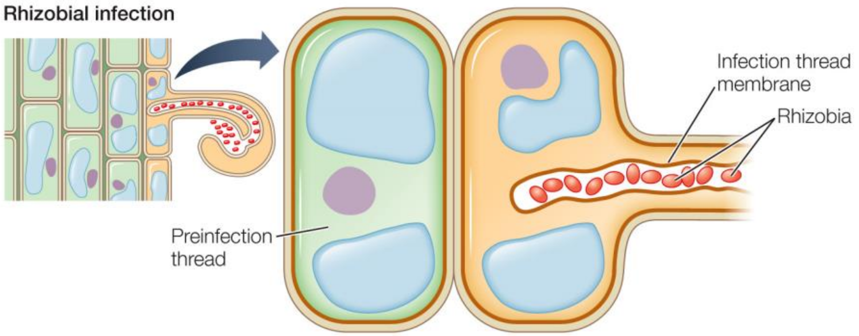
Nodule formation and mycorrhizae development depend on some of the same genes and mechanisms.

Both involve invagination of the cell membrane to allow entry of fungal hyphae or rhizobia.

The similarities are striking, considering that they involve members of two different kingdoms.



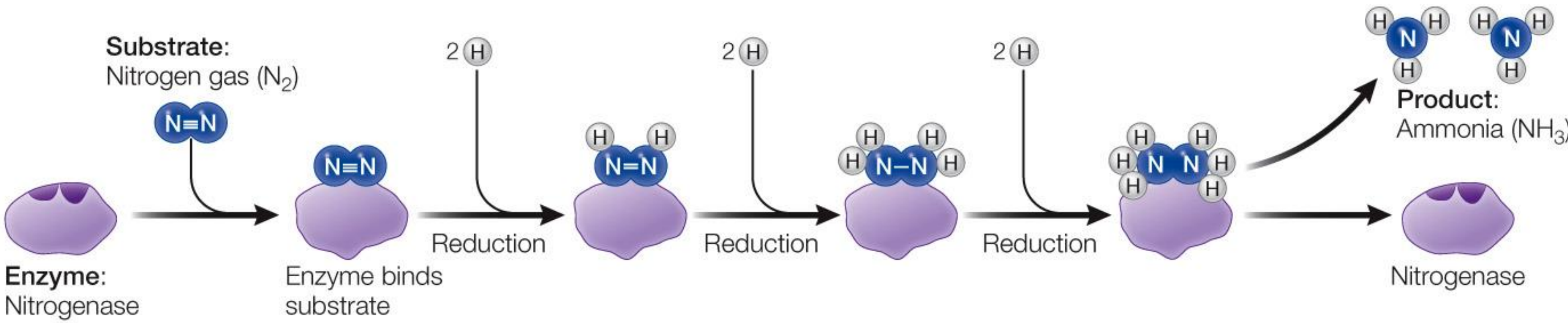
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.7 (Part 1)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.7 (Part 2)

Nitrogen fixation: $N_2 + 6\ H + 6\ e^- \rightarrow 2\ NH_3$

Nitrogen fixers fix about 170 million metric tons of N per year. Some is also fixed by lightening, volcanic activity, and forest fires.



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.8

N fixation is the reduction of N_2 gas by stepwise addition of 3 pairs of hydrogen atoms.

Requirements: Strong reducing agent to transfer H atoms to N_2 and intermediate products; Energy supplied by ATP; **Nitrogenase** to catalyze the reaction

Two types of organisms can fix nitrogen:

Free-living organisms in soil and water (*Azotobacter* bacteria and *Nostoc* cyanobacteria); Symbiotic organisms living in other organisms (rhizobia in legume roots and *Anabaena* cyanobacteria in aquatic ferns)

Carnivorous and Parasitic Plants Obtain Nutrients in Unique Ways

Carnivorous plants augment their nutrient supply by capturing and digesting insects.

They are found in boggy habitats that are acidic and nutrient deficient.

They get nitrogen by capturing animals and digesting the proteins.

Carnivorous plants can survive without capturing insects, but growth is much better with the extra nitrogen obtained from insects.

Some plants are **parasitic**—getting water, mineral nutrients, or photosynthate from the bodies of other plants.

Absorptive organs called **haustoria** invade the host and tap into vascular tissues in the root or stem.

Hemiparasites can photosynthesize, but get water and mineral nutrients from other living plants. Example: Mistletoe

Holoparasites are completely parasitic and do not perform photosynthesis.

The dodder family has small leaf and flower remnants.

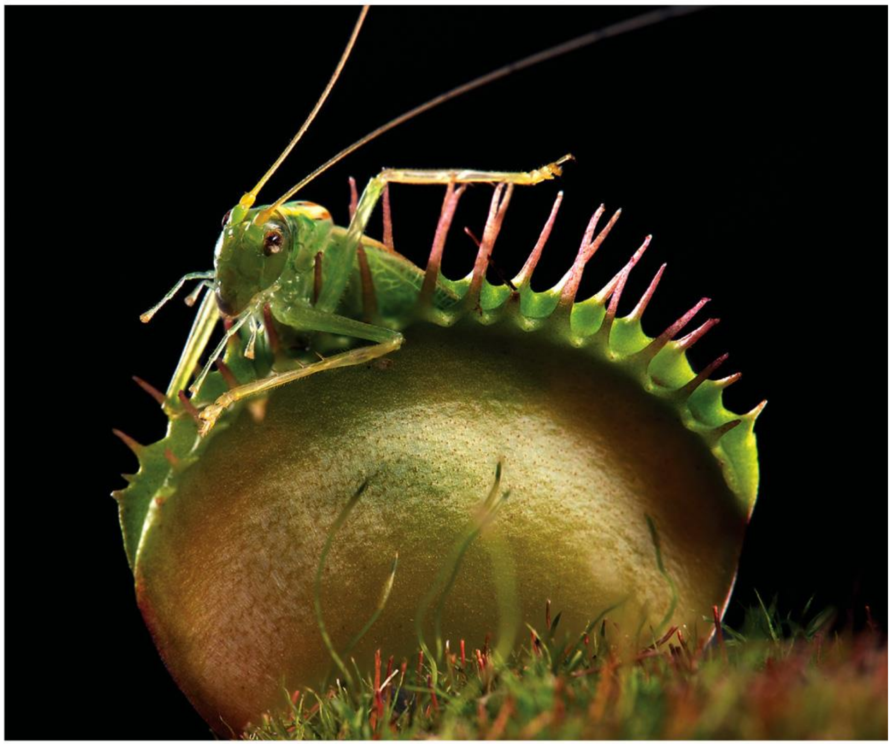
The plant–parasite relationship is similar to plant–fungus and plant–bacteria associations.

A Parasitic Plant一种寄生植物菟丝子

Hemiparasites: Mistletoe

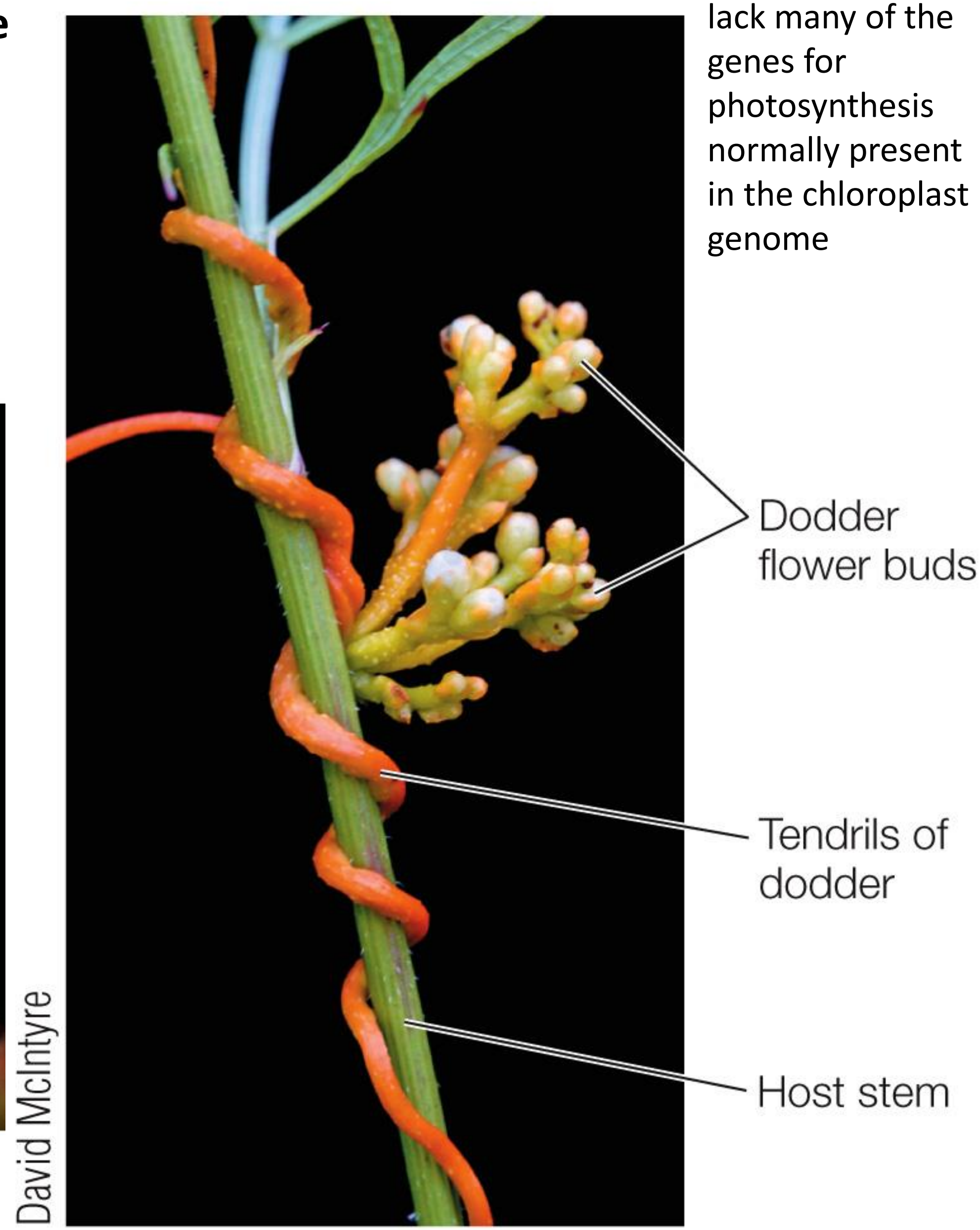
Holoparasites: Dodder

(A) Carnivorous plants肉食性植物



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.9 (Part 1)

augment their nutrient supply by capturing and digesting insects



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 35.10

lack many of the genes for photosynthesis normally present in the chloroplast genome