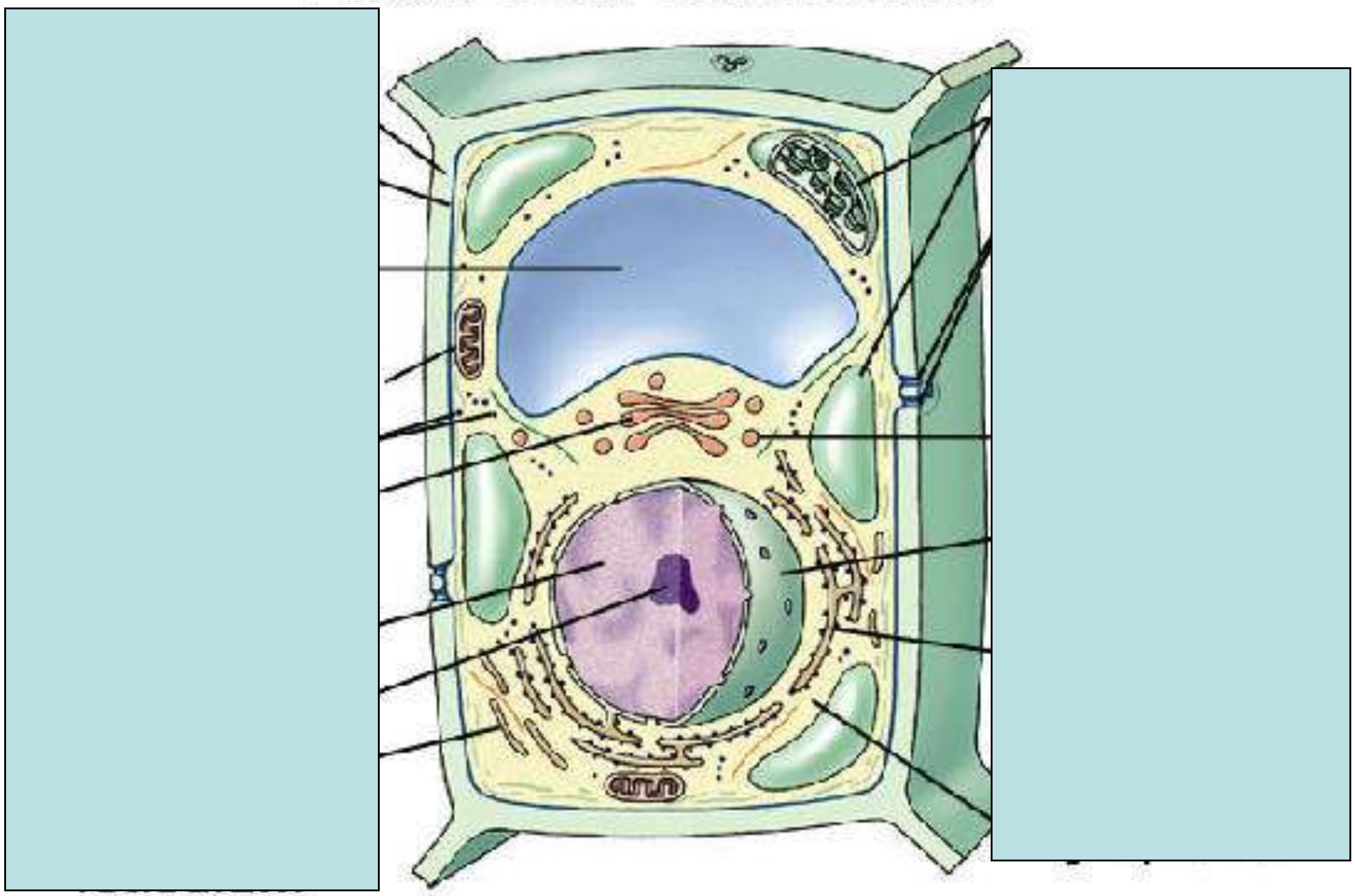
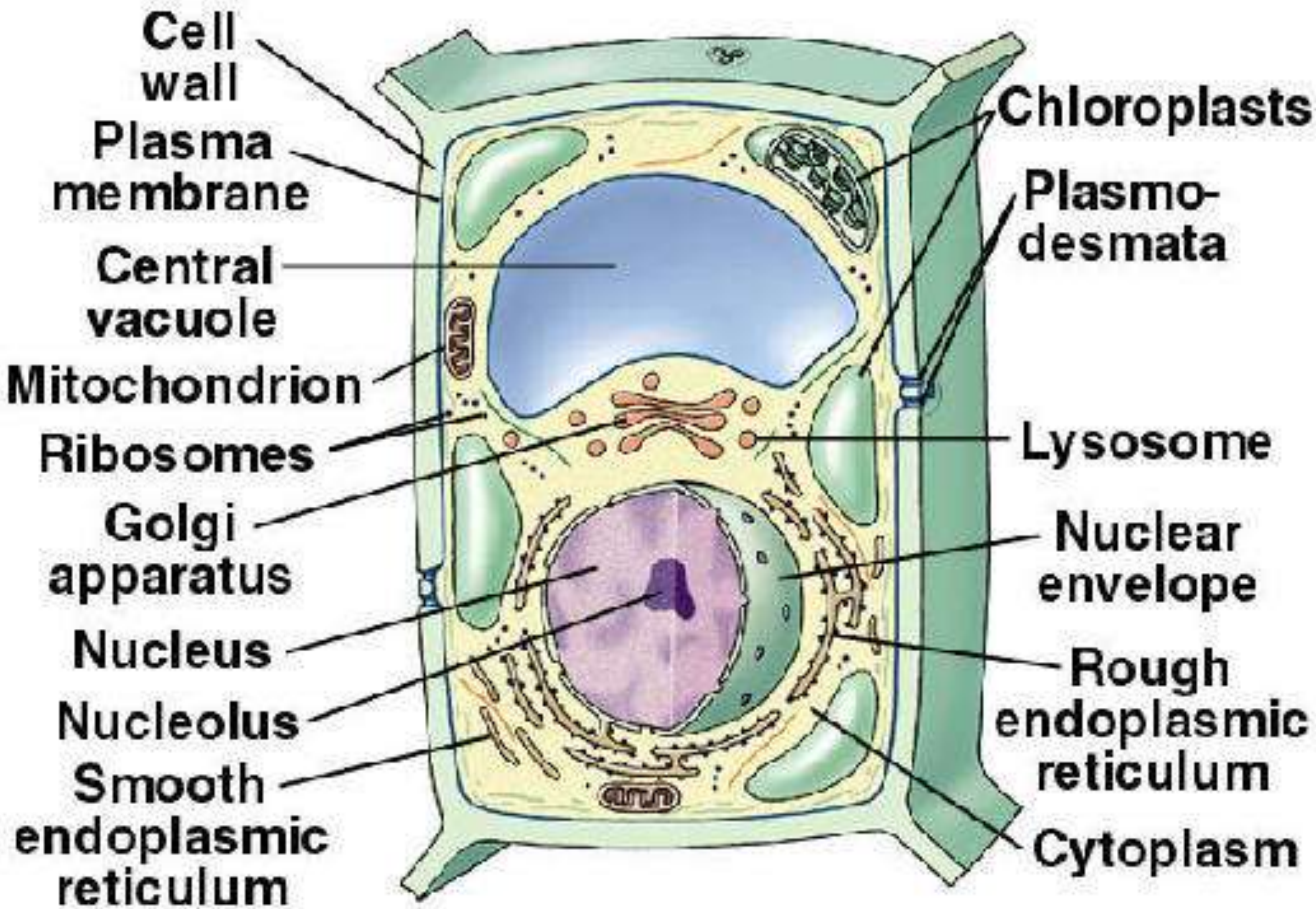
Chapter 1

The Plant Cell

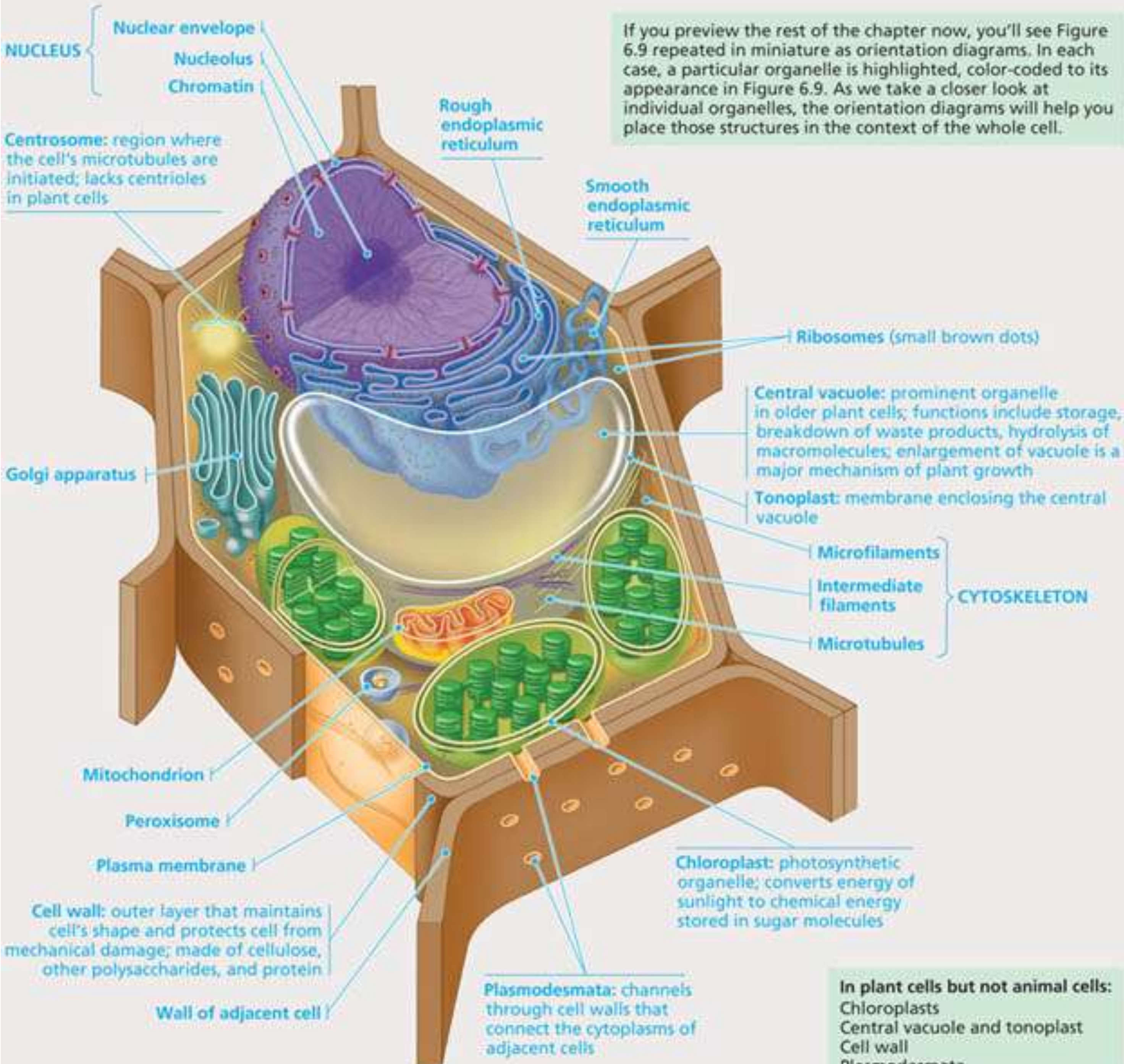
Plant Cell Structure



Plant Cell Structure



If you preview the rest of the chapter now, you'll see Figure 6.9 repeated in miniature as orientation diagrams. In each case, a particular organelle is highlighted, color-coded to its appearance in Figure 6.9. As we take a closer look at individual organelles, the orientation diagrams will help you place those structures in the context of the whole cell.



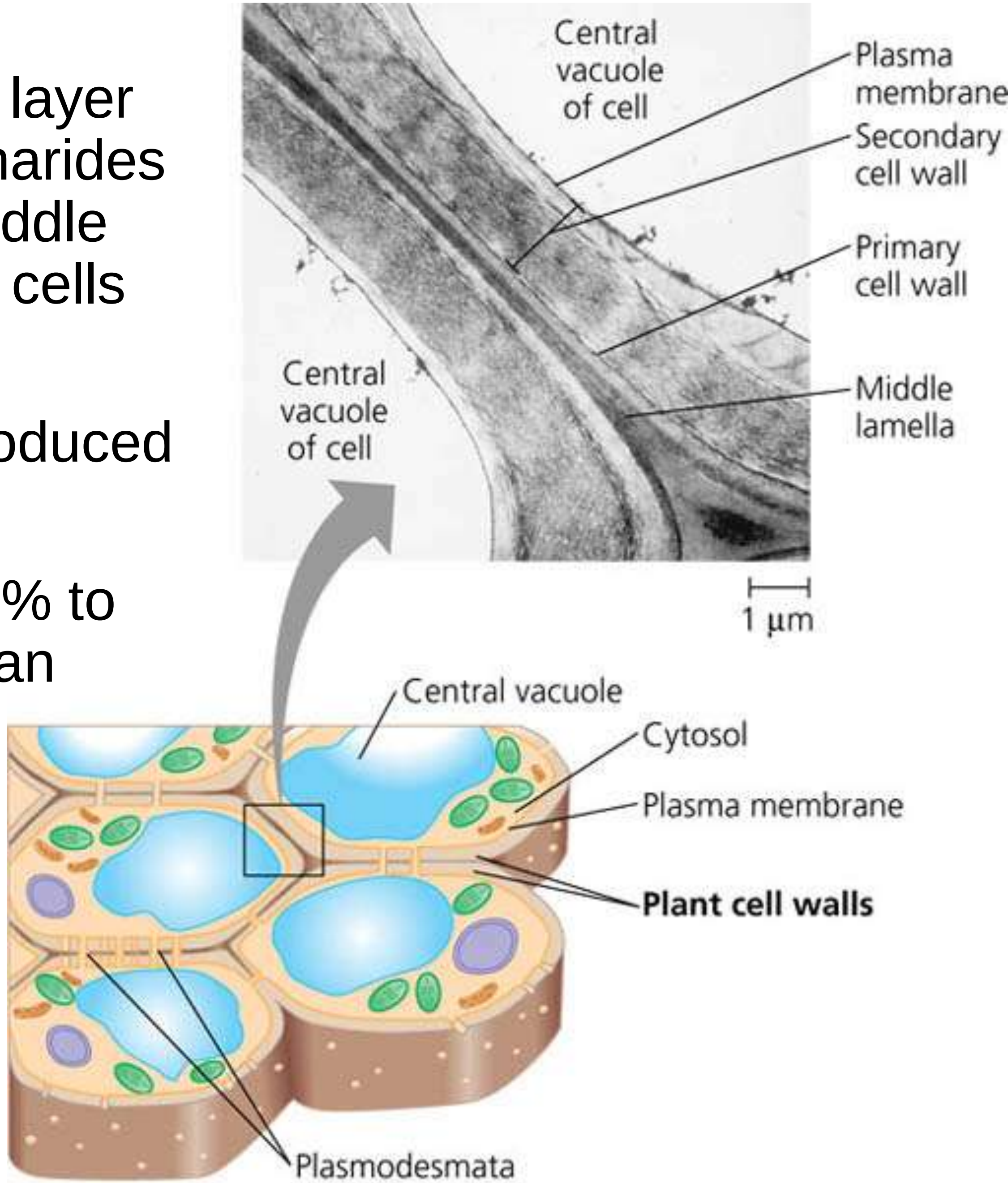
In plant cells but not animal cells:
Chloroplasts
Central vacuole and tonoplast
Cell wall
Plasmodesmata

- **Cell wall** components:
  - Cellulose (100 to 15000 glucose monomers)
  - Hemicelluloses (gluelike substance holds cellulose fibrils together)
  - Pectin
  - Glycoproteins

  The combination of these are responsible for cell rigidity and strength

  Cell wall functions:
  - The wall protects the plant cell
  - maintains its shape
  - prevents excessive uptake of water.
  - hold the plant up against the force of gravity.

- **middle lamella**, a thin layer rich in sticky polysaccharides called **pectins**. The middle lamella glues adjacent cells together
- Secondary cell wall produced by thickening of lignin
- Secondary CW has 40% to 80% more cellulose than primary CW



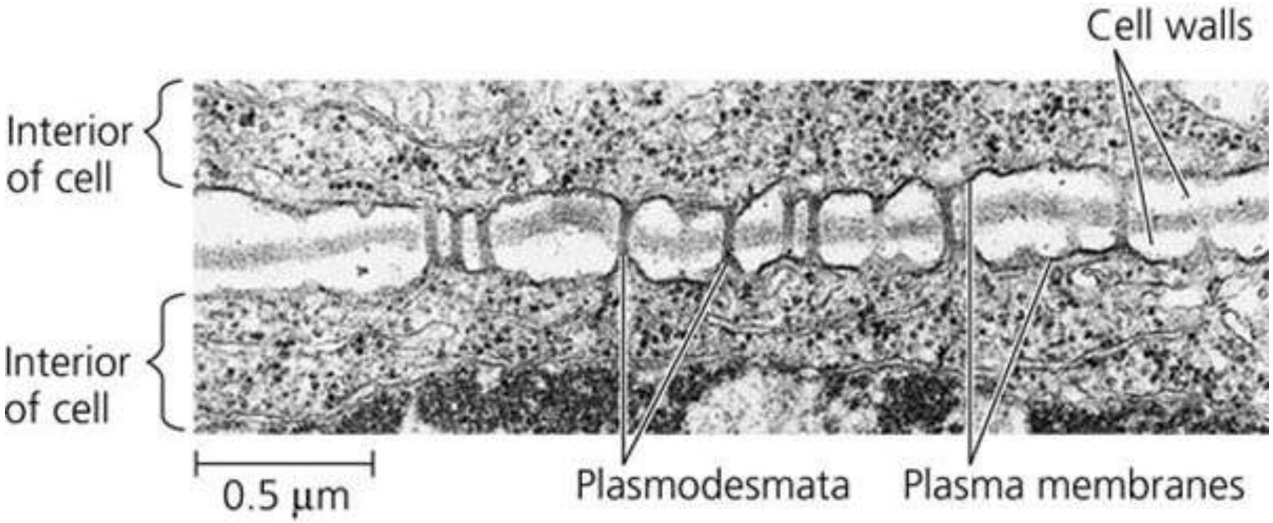
- **Plasmodesmata:** (Communication between cells)

  – Plant cell walls are perforated with channels called plasmodesmata.

  – Cytosol passes through the plasmodesmata and connects the chemical environments of adjacent cells.

  – The plasma membranes of adjacent cells line the channels of each plasmodesma and thus are continuous.

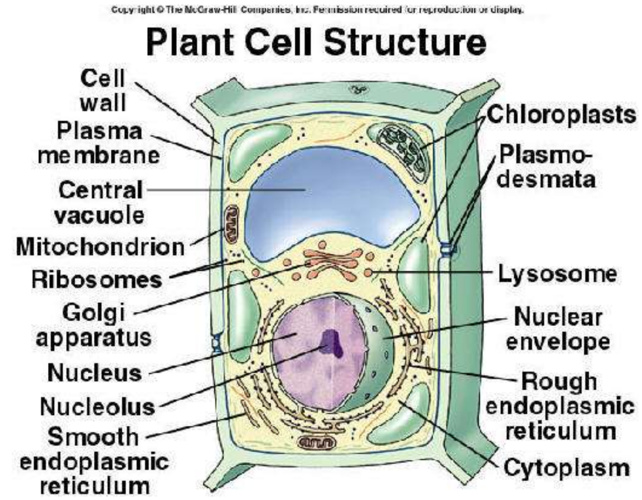
  – Water and small solutes can pass freely from cell to cell through plasmodesmata.



- **protoplast:** the contents of a plant cell exclusive of the cell wall.

•A cell is an aqueous solution of **protoplasm** surrounded by a **plasma membrane.**

•Protoplasm – nucleus = **cytoplasm**



Plasma membrane: boundary layer between living and nonliving world

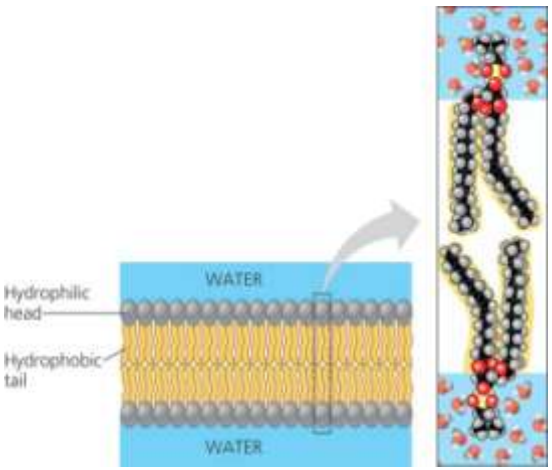
- **Selectively permeable** to control the exchange of material and maintain essential differences between the cell and its environment.

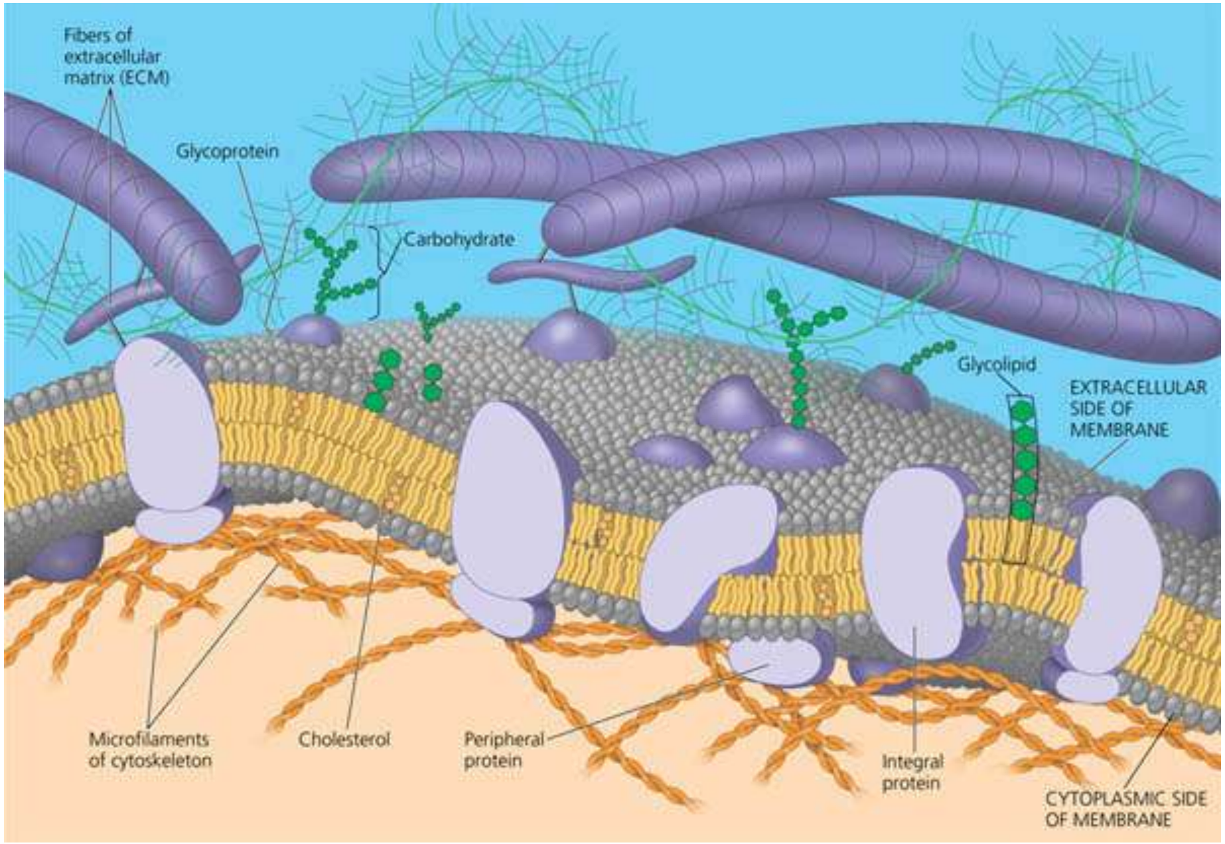
- **Physically limits the cell.**

Organelles: the subcellular structures that have selectively permeable membranes, (involved in **Metabolic activities**. **Respiration, photosynthesis, protein synthesis ..etc.)**

Nucleus: contains the genetic information.

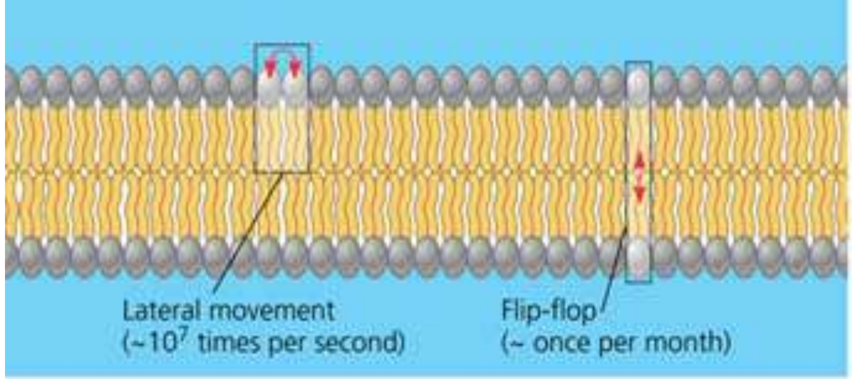
The membrane bilayer



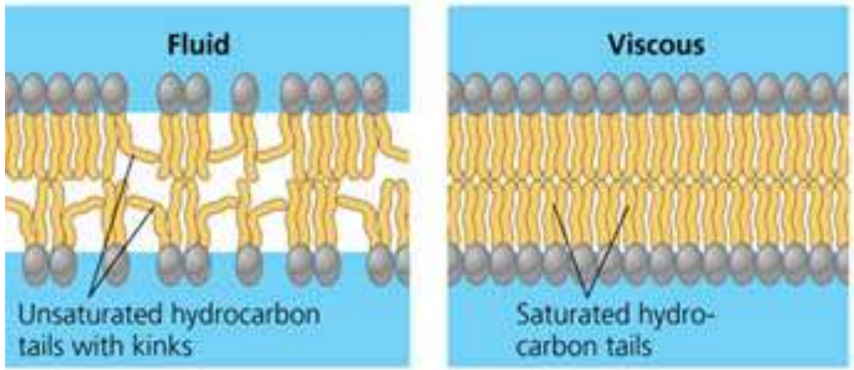


The membrane bilayer Cont'd

- Phospholipids are amphipathic molecules:
  - Hydrophobic- nonpolar hydrocarbon tail (buried in the interior)
  - Hydrophilic- polar head group (exposed to water).
- Properties of bilayer:
  - Stable structure
  - Highly fluid (high % of unsaturated fatty acids)
  - Impermeable to most polar (charged) molecules.



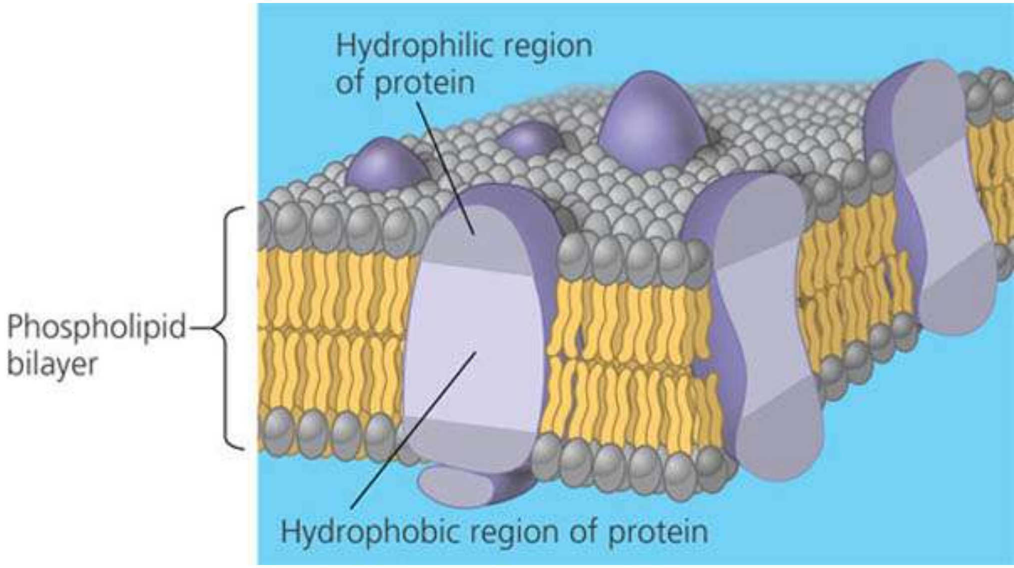
(a) Movement of phospholipids. Lipids move laterally in a membrane, but flip-flopping across the membrane is quite rare.



(b) Membrane fluidity. Unsaturated hydrocarbon tails of phospholipids have kinks that keep the molecules from packing together, enhancing membrane fluidity.

Membrane proteins

- 50% of the membranes are proteins (weight).



- Membranes protein types:

  1. integral protein (intrinsic)
     - Transmembrane proteins: Integral proteins that have access to both sides.
     - contains hydrophilic and hydrophobic domains
  2. Peripheral protein (contains hydrophilic domains).

- Roles of membrane proteins:
  - Structural role (integral proteins)
  - Functional role: responsible for all metabolic reactions associated with membranes.

  Examples:

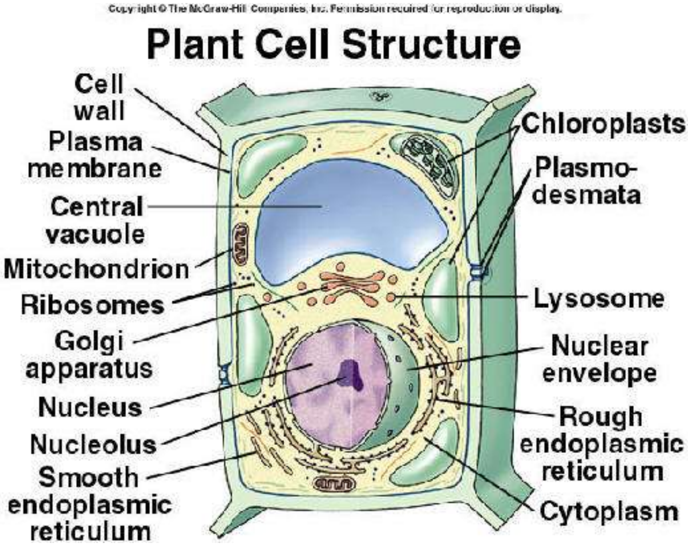
  1- Some proteins are enzymes.

  2- proteins assist in selective transport across the membrane.

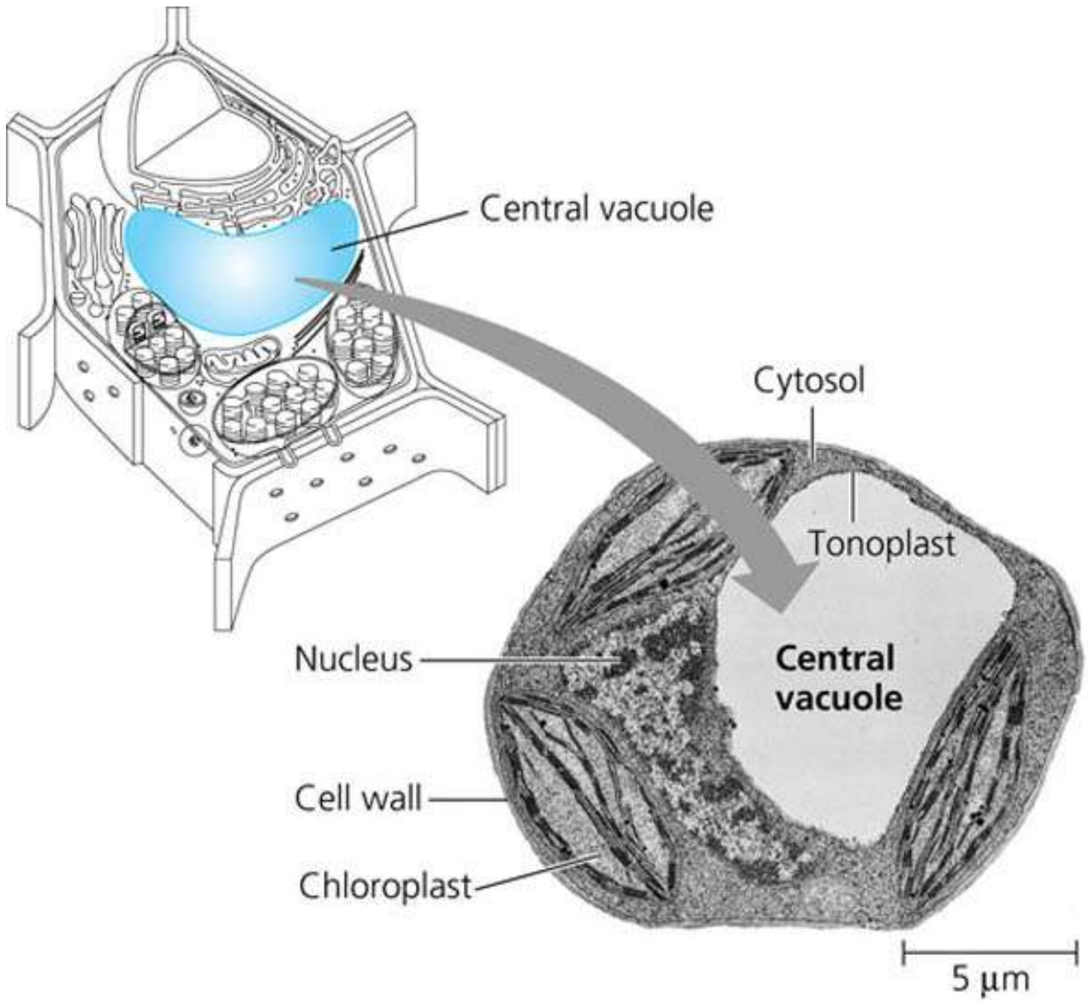
  3- proteins participate in energy transduction

Cellular organelles

- **Vacuole:**
  - May occupy 80-90% of the cell volume
  - Surrounded by a membrane called vacuolar membrane or tonoplast.
  - Contains inorganic ions, organic acids, sugars, enzymes and pigments.



Vacuoles

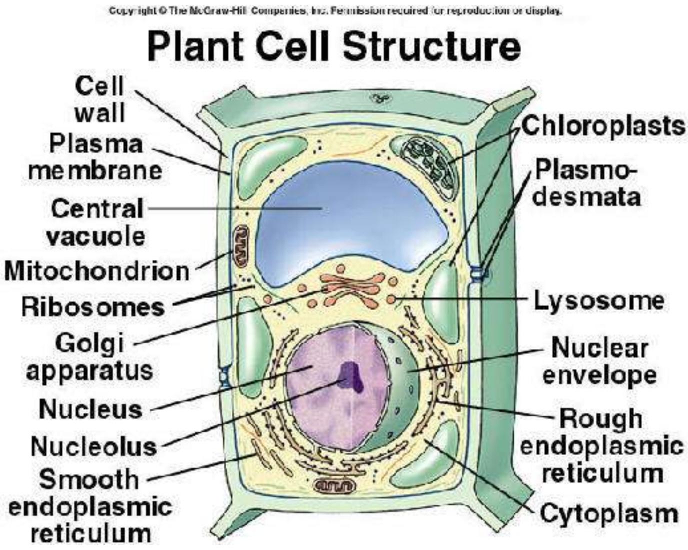

Central vacuole
Cytosol
Tonoplast
Central vacuole
Nucleus
Cell wall
Chloroplast
5 µm

- Some vacuoles contain pigments that color the cells, such as the red and blue pigments of petals that help attract pollinating insects to flowers.
- Many plant cells use their vacuoles as disposal sites for metabolic by–products that would endanger the cell if they accumulated in the cytosol.
- Vacuoles may also help protect the plant against predators by containing compounds that are poisonous or unpalatable to animals.

- **Nucleus:** Contains genetic material (DNA).
- **Endoplasmic reticulum (ER) and Golgi complex:** involved in lipid and protein synthesis and secretion.

- **Rough ER** = ER + ribosomes.
  - Place where proteins synthesized on

- **Smooth ER:**
  - place where proteins are modified and sugars added to form glycoproteins.
  - place for lipid synthesis

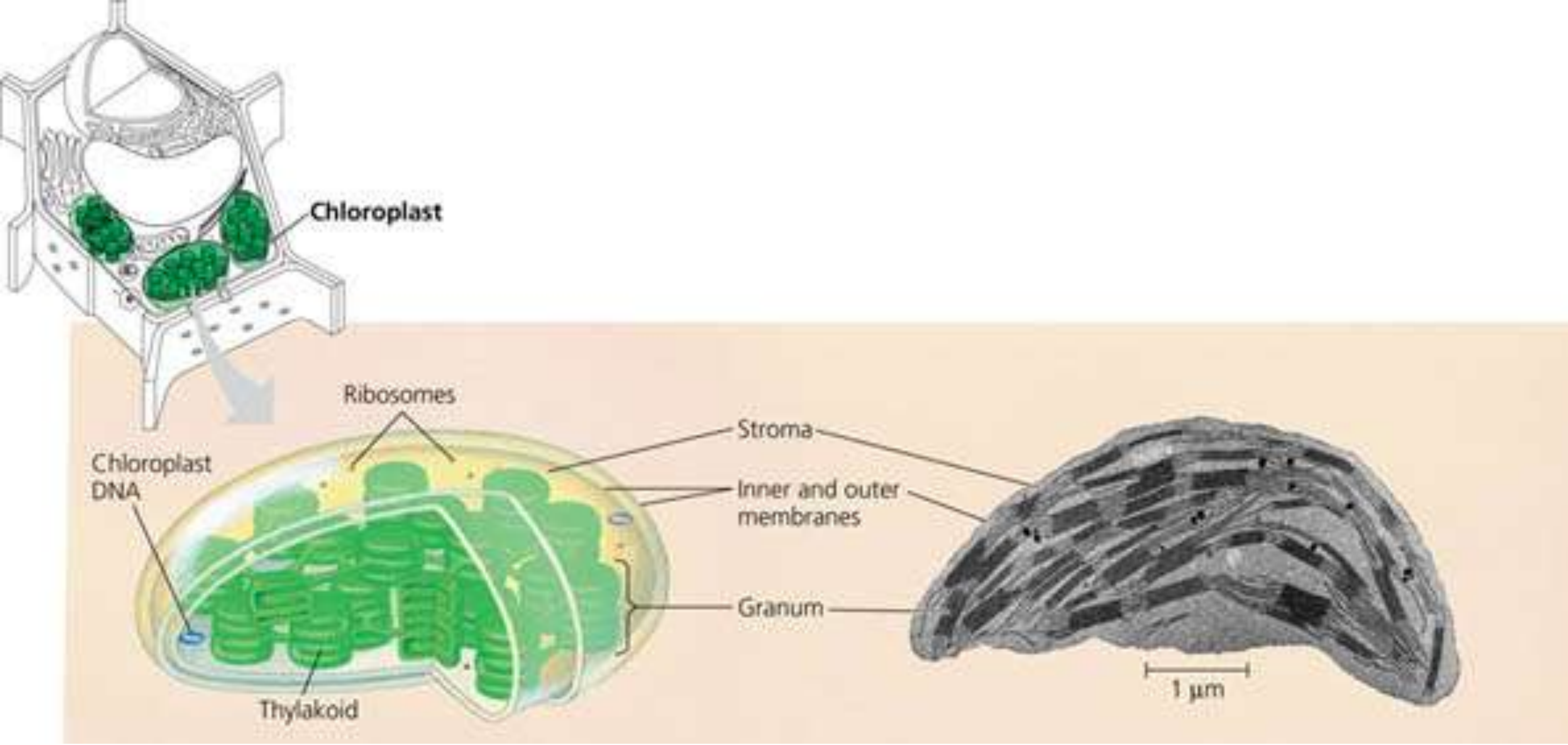


Golgi complex: Receive glycoproteins from Smooth ER and synthesize carbohydrates

Plastids

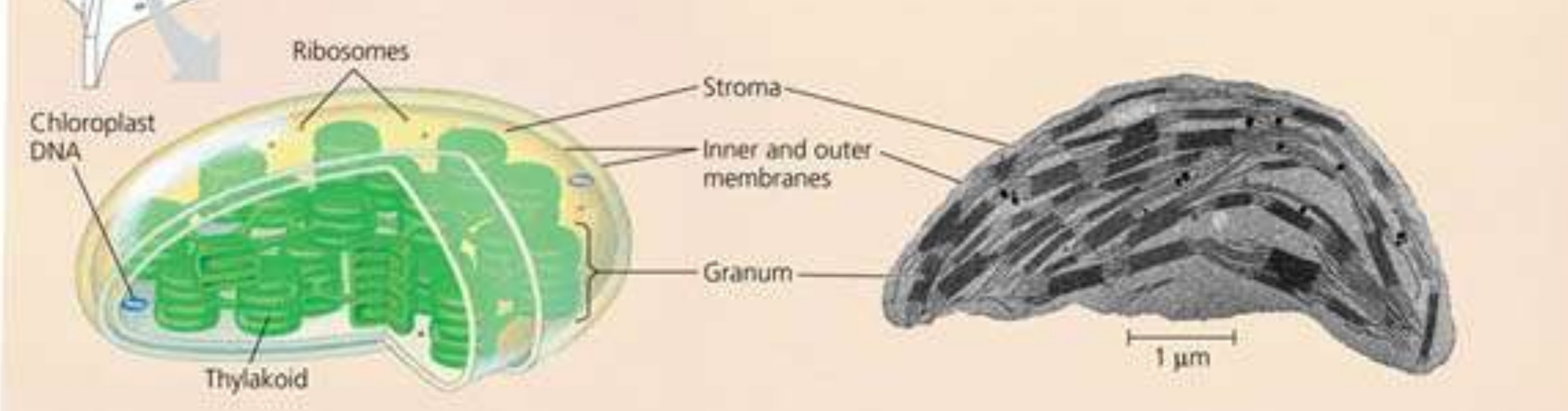
- **Plastids:** A family of related plant organelles develop from **proplastids.**

1. **Chloroplasts** (**Most prominent)** contain the green pigment chlorophyll, enzymes and molecules that function in the photosynthetic production of sugar.
2. **Leucoplast colorless plastid include:**
   1. **Amyloplasts,** store starch (amylose), particularly in roots and tubers.
   2. **Elaioplasts,** synthesize oils.
3. **Chromoplasts** have pigments that give fruits and flowers their orange, red, and yellow color which results from carotenoids pigments that synthesize.

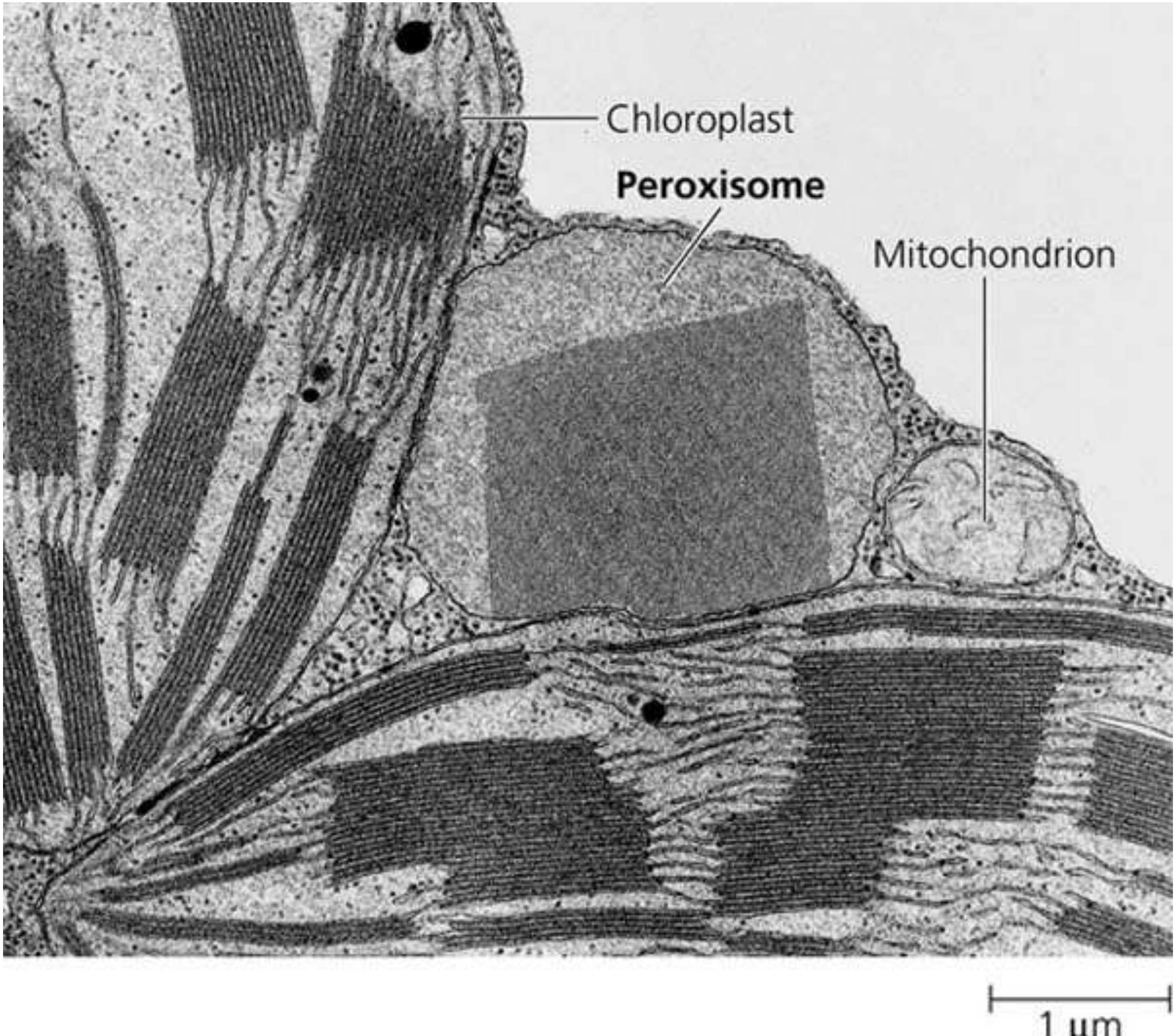


Chloroplats:

- Lens–shaped
- About 2 µm by 5 µm
- Found in leaves and other green organs of plants and in algae



- **Thylakoids:** a membranous system Inside the chloroplast form flattened, interconnected sacs. Contain chlorophyll and other pigments.
- **Granum** Thylakoids stack (plural, grana) 40-60.
- **Stroma:** The fluid outside the thylakoids, which contains the chloroplast DNA, ribosomes and many enzymes.
- The membranes of the chloroplast divide the chloroplast space into three compartments:


Chloroplast
Peroxisome
Mitochondrion
1 µm

Mitochondria and chloroplasts

- Mitochondria and chloroplasts change energy from one form to another. contain a small amount of DNA
- **Mitochondria** are the sites of cellular **respiration**, the metabolic process that generates ATP by extracting energy from sugars, fats, and other fuels with the help of **oxygen**.
- **Chloroplasts**, found only in plants and algae, are the sites of photosynthesis. They convert solar energy to chemical energy by absorbing sunlight and using it to drive the synthesis of organic compounds such as sugars from carbon dioxide and water.

Cells and tissues

- Cells are organized in groups to form tissues.
- Epidermis: a tissue of continuous layer over the surface of the primary plant body.
  - Hairs (trichomes) are specialized epidermal cells.
- Parenchyma
- Supporting tissues: (collenchyma and sclernchyma).

Vascular tissues

- Distribution of nutrients, water and products of photosynthesis.
- 2 types of vascular tissues: (xylem and phloem).

  1- xylem (primarily water conduction)

  2- Phloem (distribution of organic molecules between **sources** and **sinks**)

Plant organs

- Roots

functions:

  - Anchorage
  - Storage
  - Absorption of water and nutrients

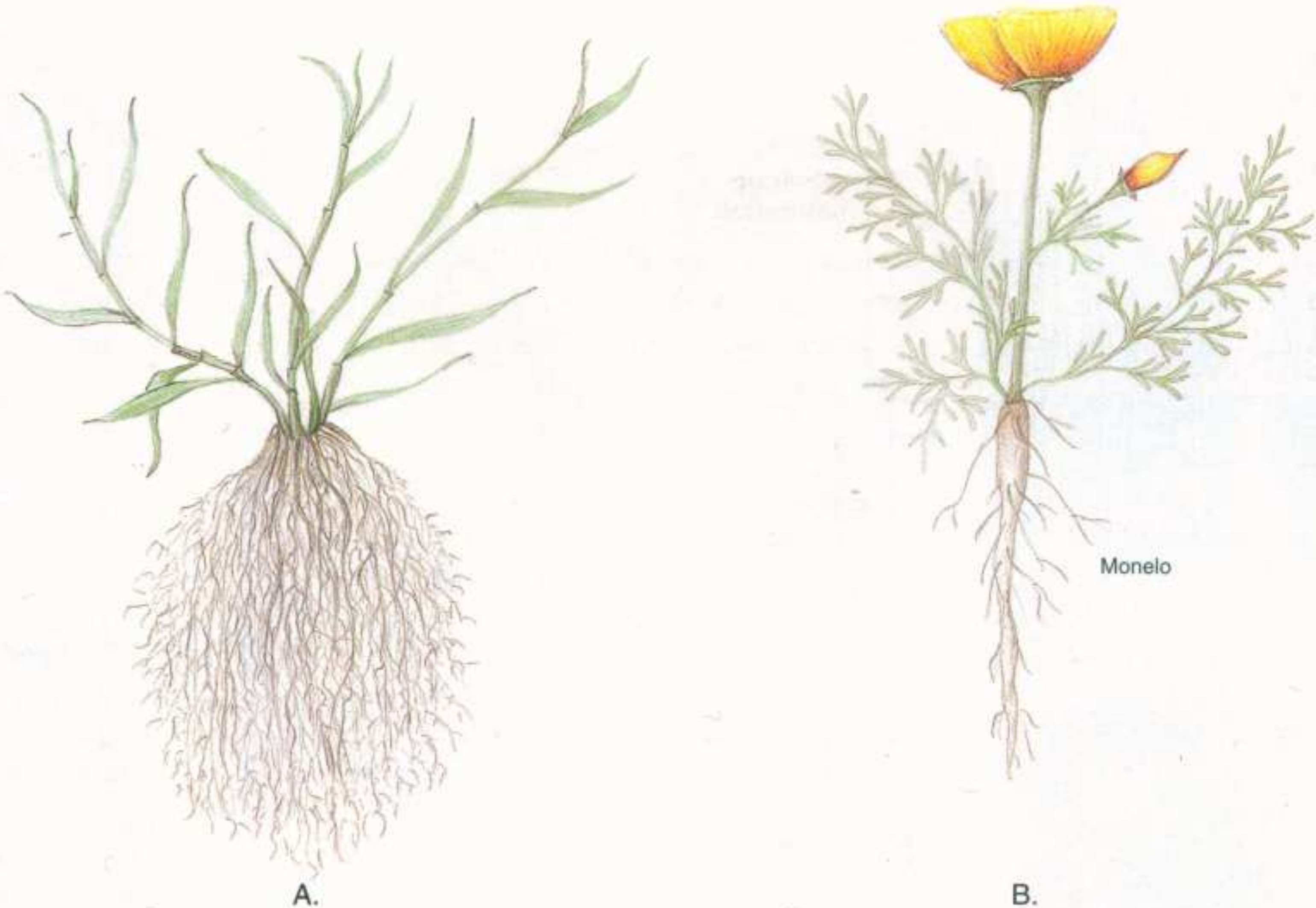


Figure 5.1 Root systems. *A.* A fibrous root system of a grass. *B.* A taproot system of a poppy.

ROOT STRUCTURE

- Developing young roots usually reveals four regions or zones:

(1) the *root cap*

(2) the *region of cell division*

(3) the *region of elongation,*

(4) the *region of maturation*

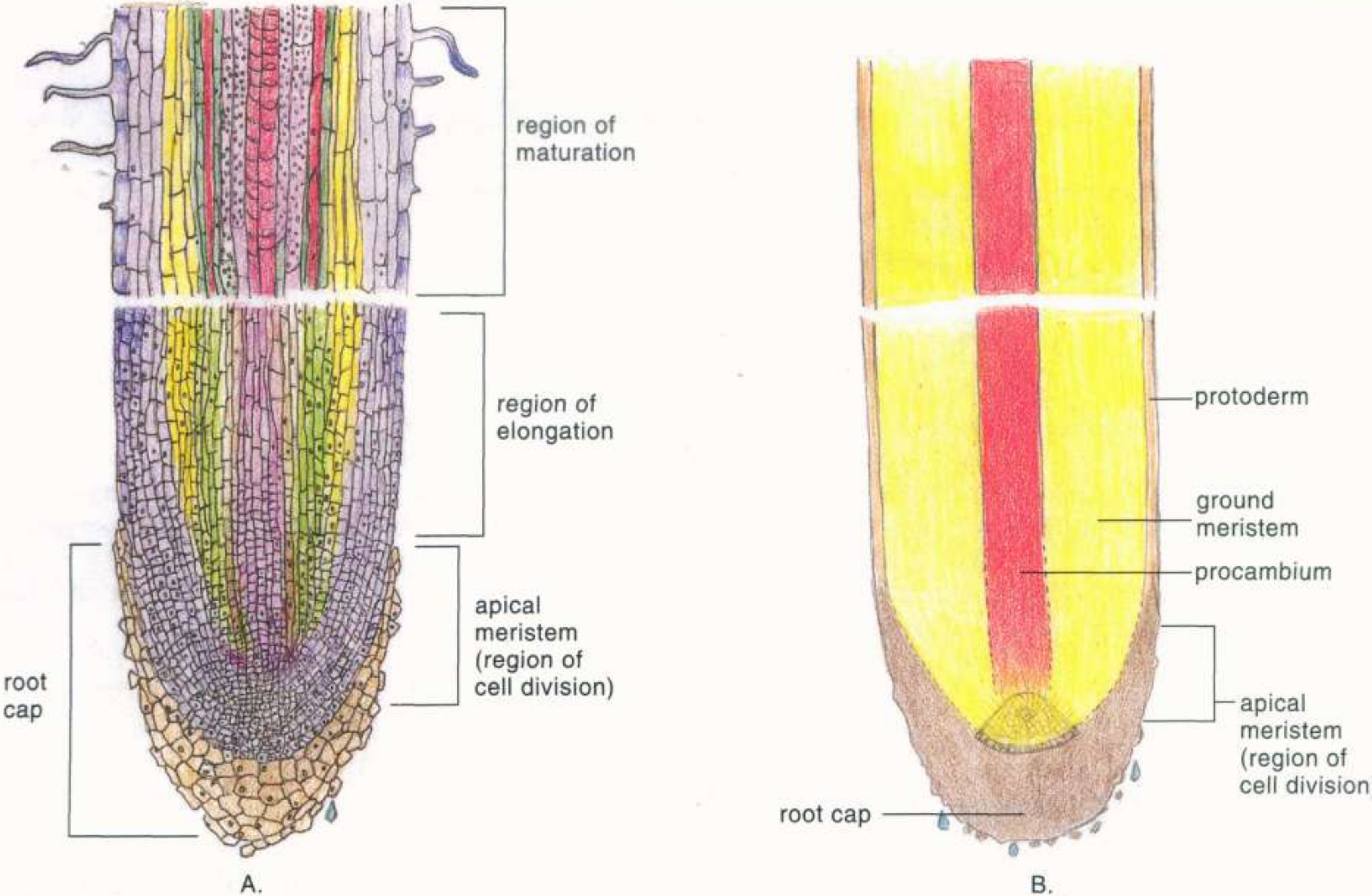


Figure 5.2 A longitudinal section through a dicot root tip. *A.* Regions of the root. *B.* Locations of the primary meristems of the root.

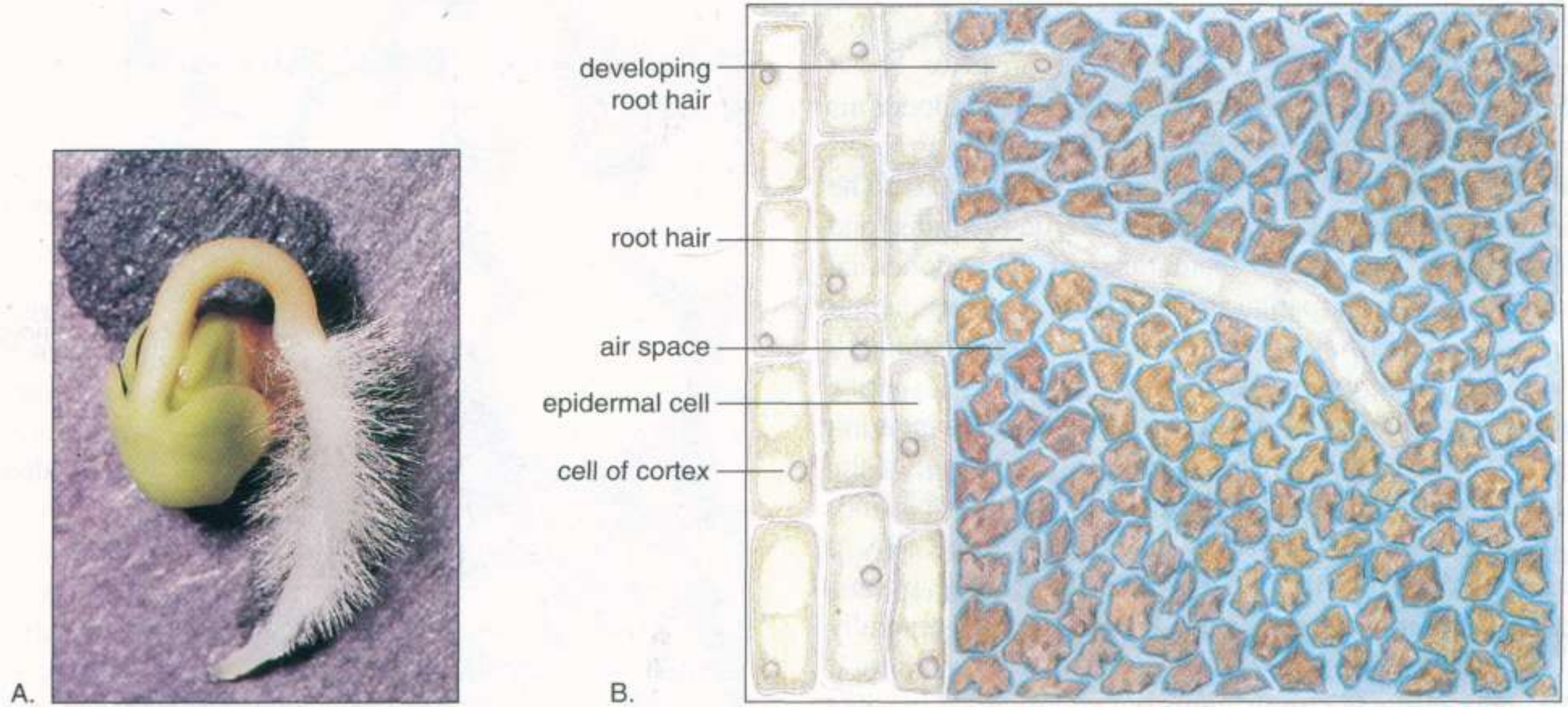


Figure 5.4 A. A radish (*Raphanus*) seedling shortly after germination, showing the root hair zone. *B.* A diagram of an enlargement of a longitudinal section through a small portion of a root hair zone, showing root hairs in contact with soil particles.

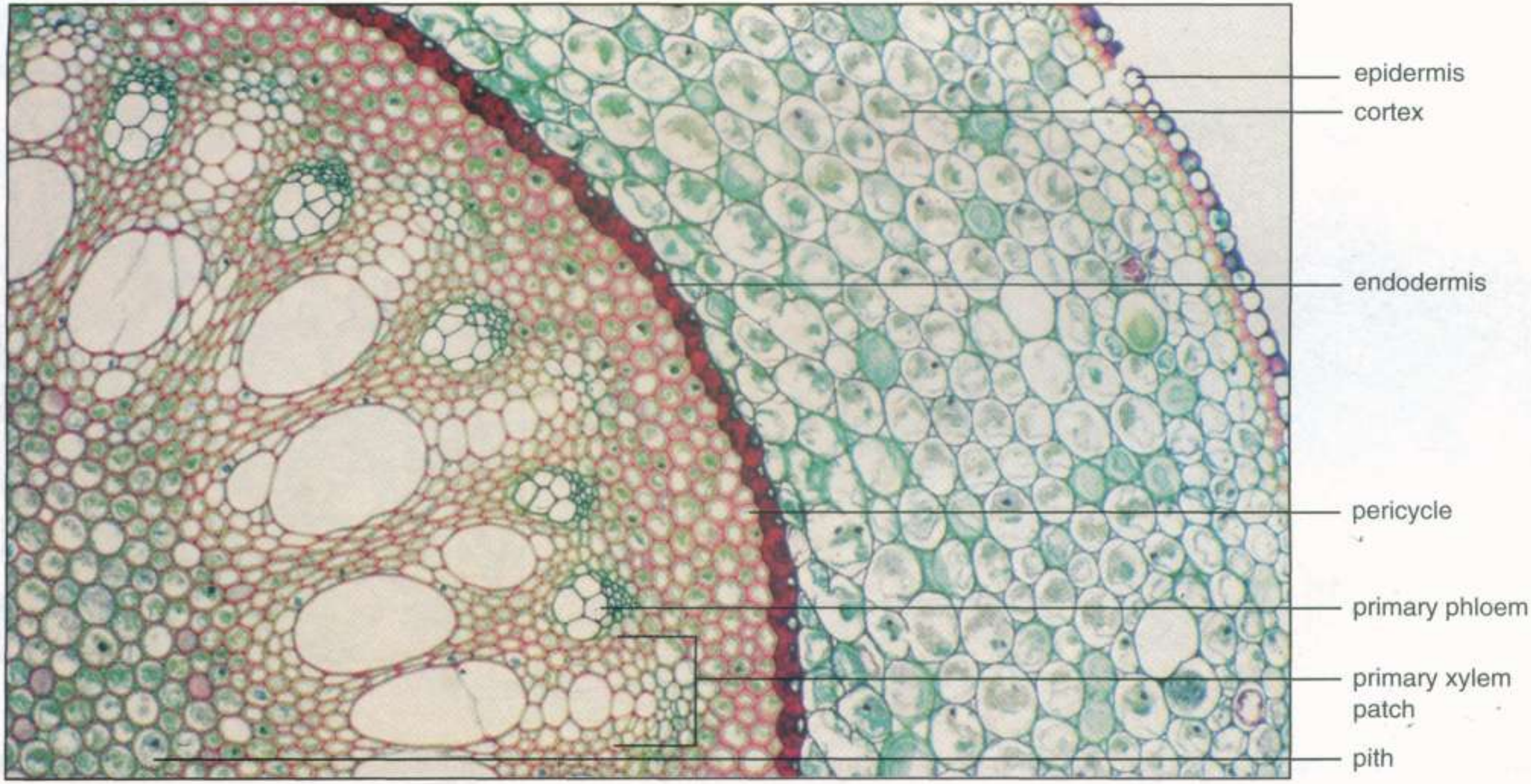


Figure 5.3 A cross section of a portion of a root of greenbrier (*Smilax*), a monocot, ×500. (*Photomicrograph by G. S. Ellmore*)

Monocot root

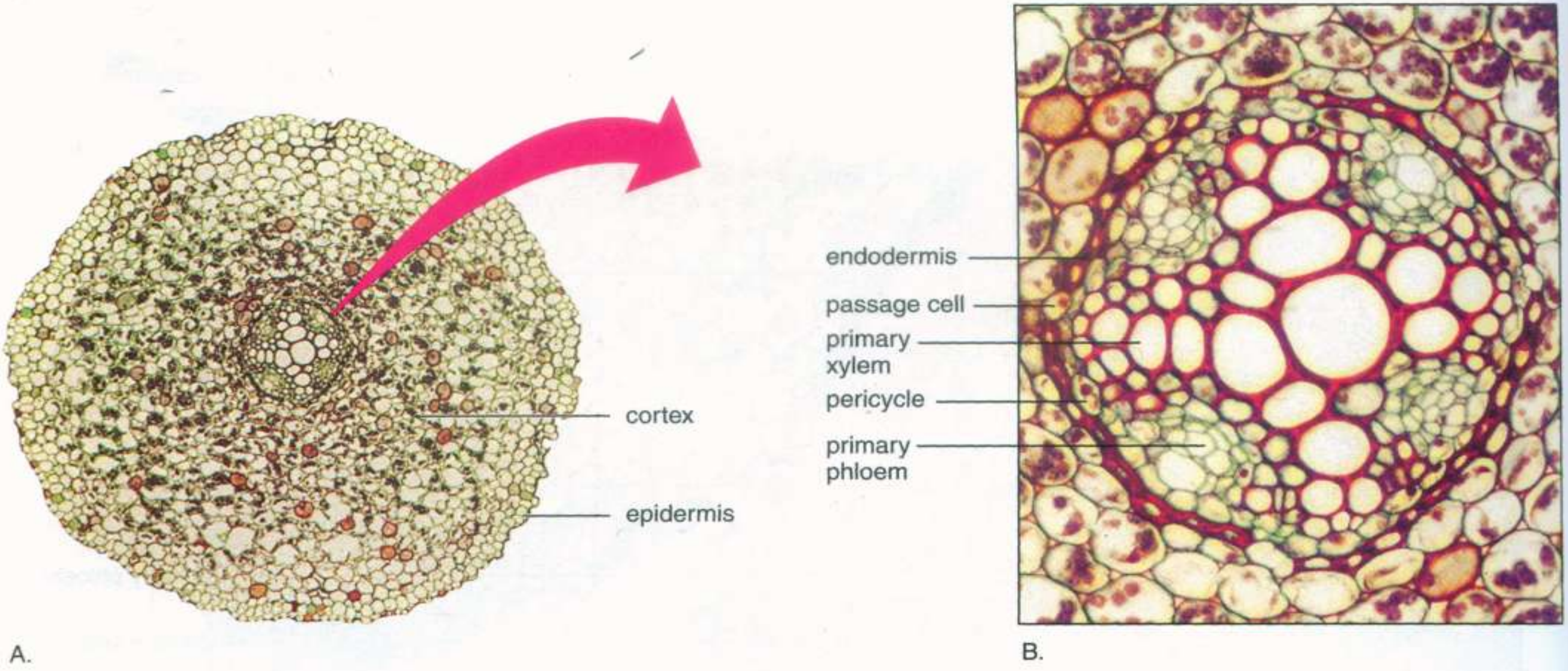


Figure 5.5 A cross section through the region of maturation of a dicot (buttercup—*Ranunculus*) root. *A*. Complete view, ×100. *B*. Enlargement of the root center, ×500.

dicot root

• Stems

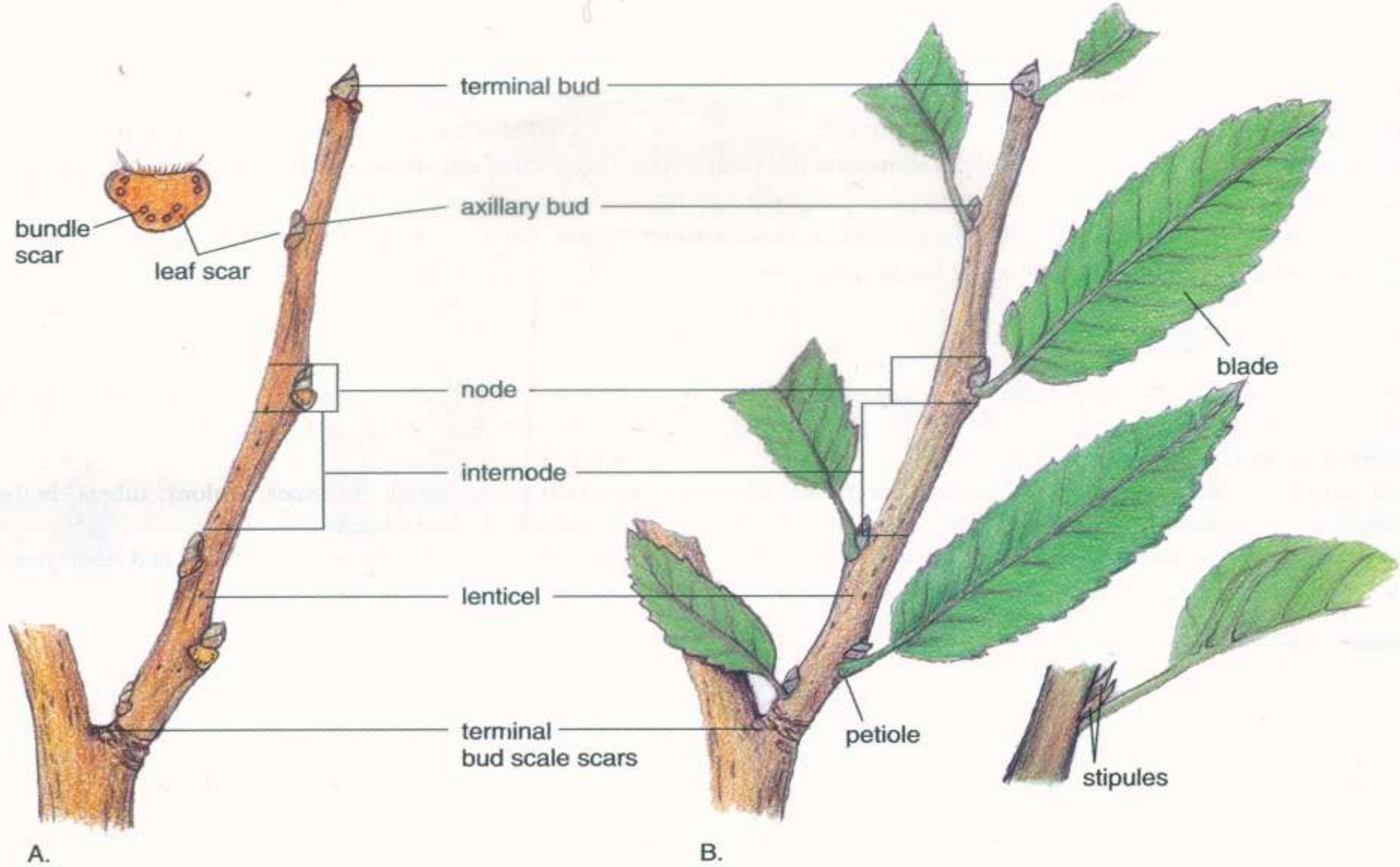
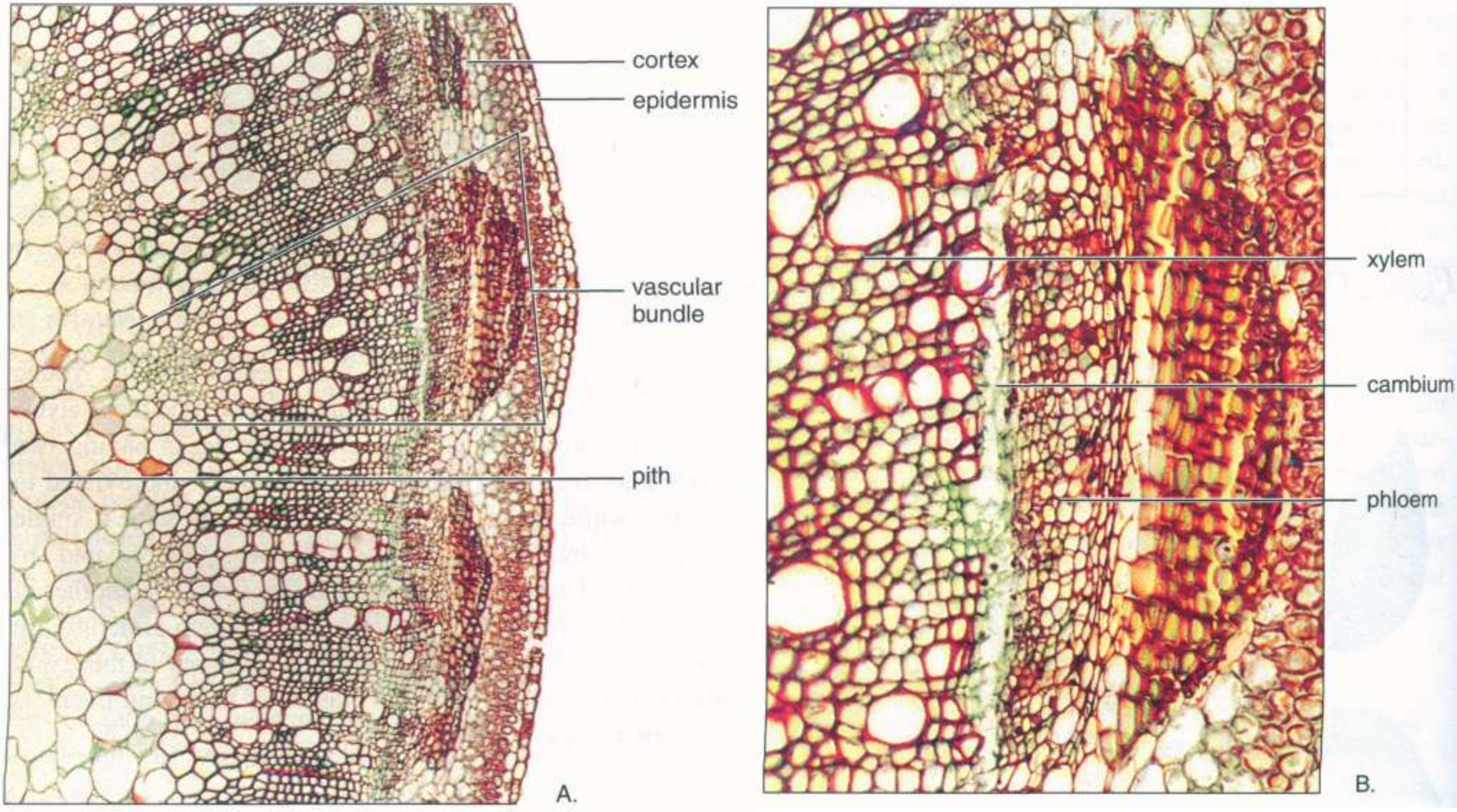


Figure 6.1 **A woody twig.** *A*. The twig in its winter condition. *B*. The twig as it appeared the summer before.

base of the petiole. Stipules are paired, often somewhat primordium), the tiny embryonic leaves that will develop



A cross section of an alfalfa *(Medicago]* stem

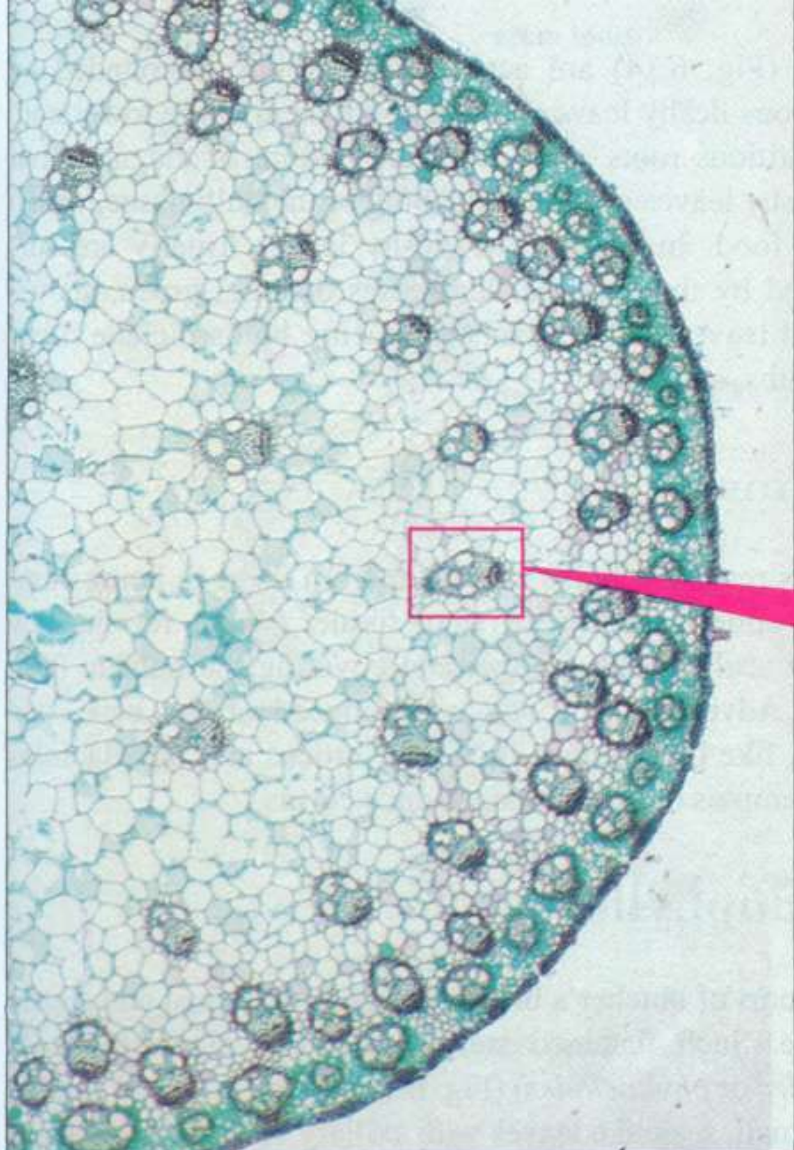


Figure 6.12 A portion of a cross section of a monocot (corn—*Zea mays*) stem, ca. ×100. *(Photomicrograph by G.S. Ellmore)*

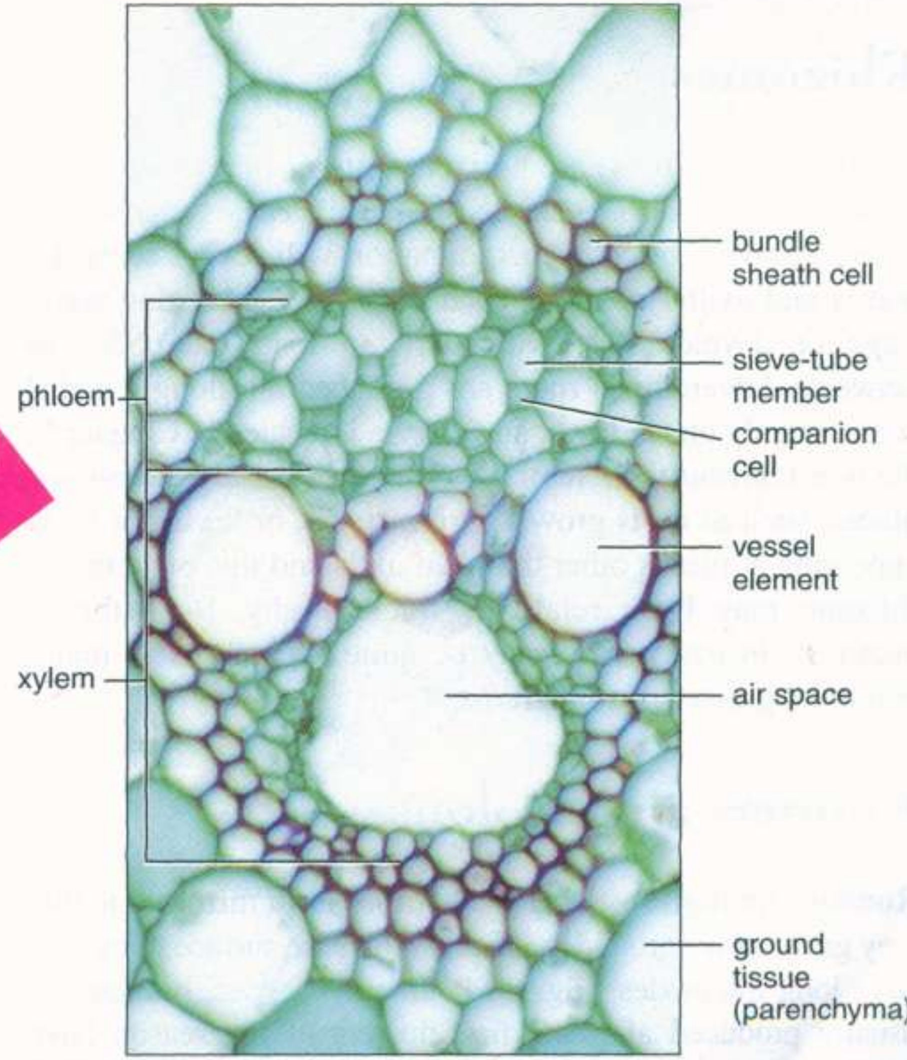


Figure 6.13 A single vascular bundle of corn (*Zea m*ʳ enlarged, ca. ×800.

- Leaves

- The lower surfaces of leaves (and in some plants, the upper surfaces as well) have **stomata**
- Stomata allow entry for the carbon dioxide gas needed for photosynthesis
- Stomata diffuse oxygen produced during photosynthesis out of the leaf.
- Water vapor escape via the stomata (**cooling).**
- The **s*tomatal apparatus*** *,* controls the water loss when the guard cells inflate or deflate, opening or closing the pore.

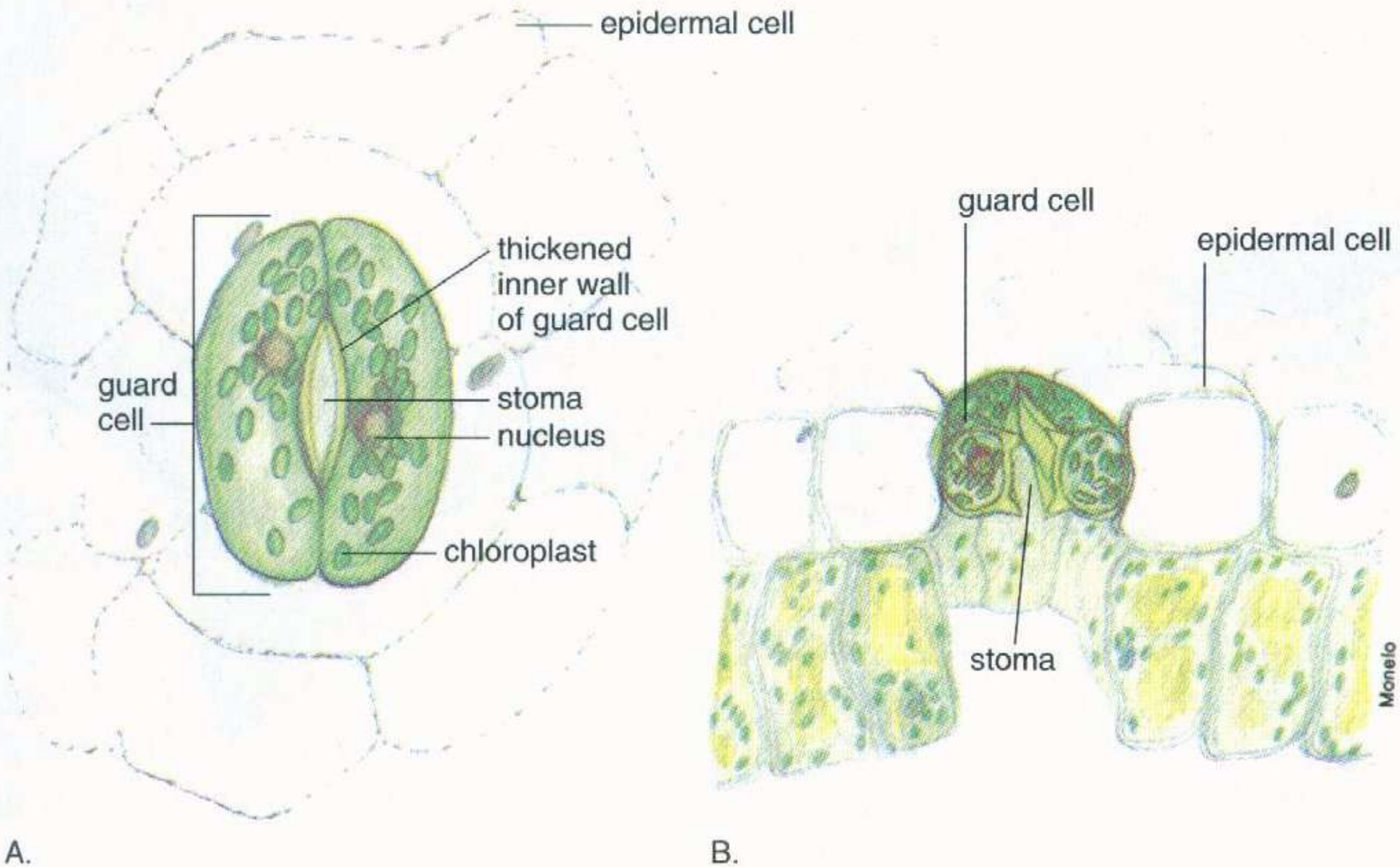
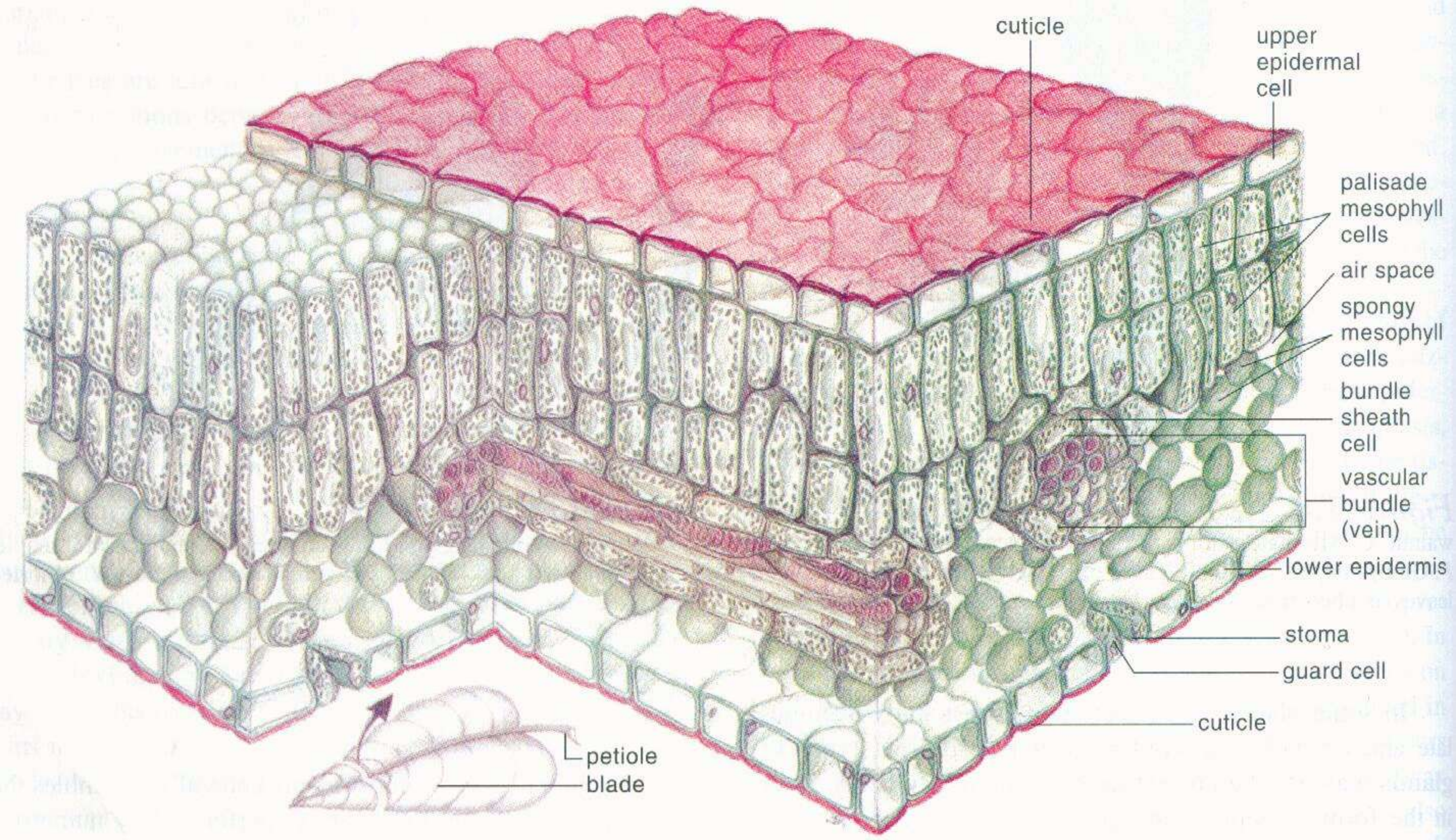


Figure 7.8. A typical dicot stoma. *A*. Surface view. *B*. View in transverse section.

- Leaves also perform other functions:
- waste products produced from respiration and other metabolic activities accumulate in the leaves and disposed off when the leaves are shed.
- Leaves play a major role in the movement of water absorbed by roots and transported throughout the plant.
- Most of the water reaching the leaves evaporates in vapor form into the atmosphere by a process known as **transpiration**

Internal structure of leaves

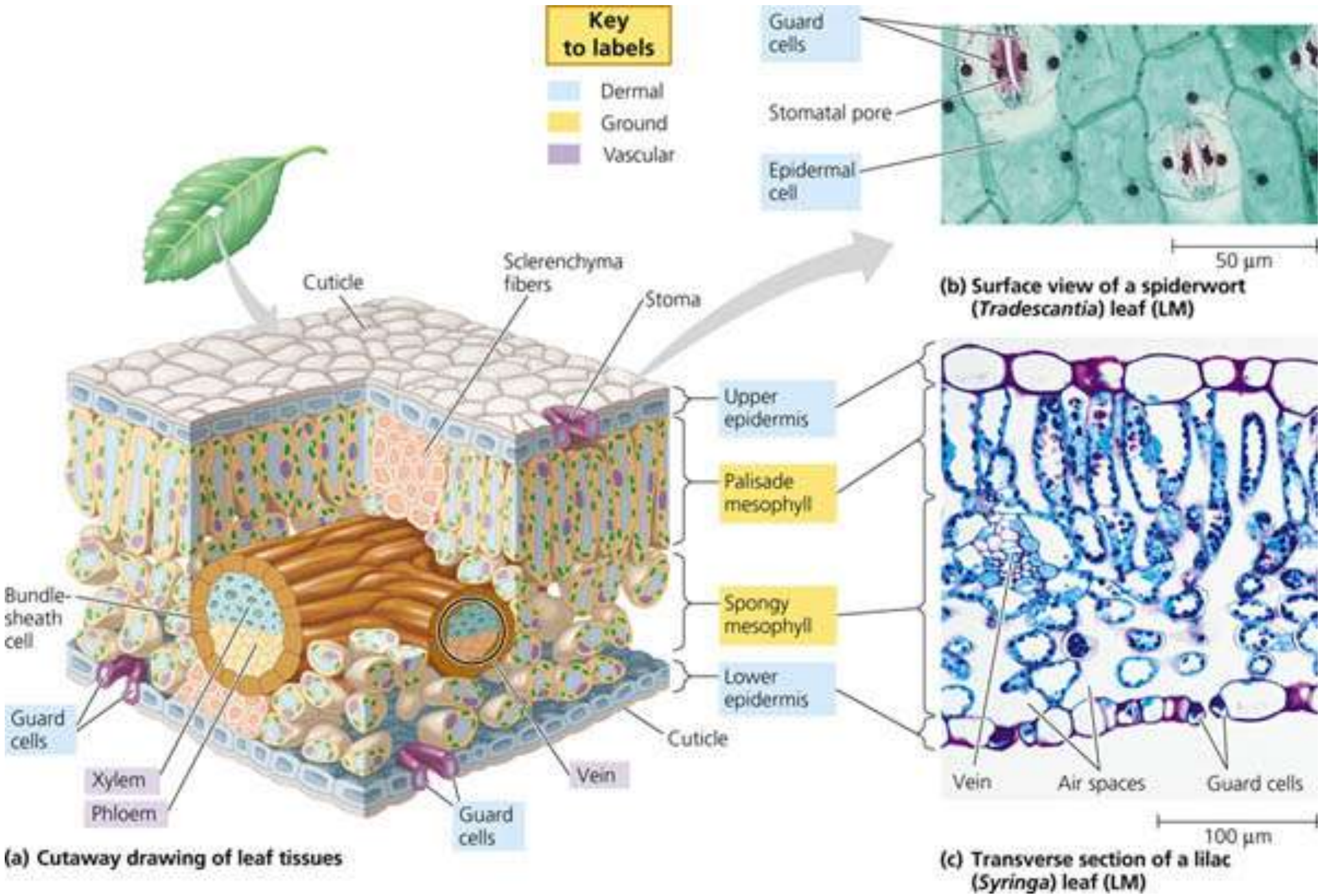
- a typical leaf has three regions stand out: ***epidermis, mesophyll,* and *veins***
- The epidermis is a single layer of cells covering the entire surface of the leaf.
- The epidermis on the lower surface of the blade can be distinguished from the upper epidermis by the presence of tiny pores called ***stomata***
- A coating of waxy **cutin** (the **cuticle**) is normally present


cuticle
upper epidermal cell
palisade mesophyll cells
air space
spongy mesophyll cells
bundle sheath cell
vascular bundle (vein)
lower epidermis
stoma
guard cell
cuticle
petiole
blade

MESOPHYLL AND VEINS

- Most photosynthesis takes place in the **mesophyll** between the two epidermal layers, with two regions.
- The uppermost mesophyll (**palisade mesophyll)** consists of compactly stacked, barrel-shaped parenchyma cells that are commonly in two rows.
- **palisade mesophyll** may contain more than 80% of the leaf's chloroplasts.
- The lower region, consisting of loosely arranged parenehyma cells with abundant air spaces between them, is called the **spongy mesophyll.** Its cells also have **numerous chloroplasts**.

- Veins *(vascular bundles)* of various sizes are scattered throughout the mesophyll.
- They consist of xylem and phloem tissues surrounded by a jacket of thicker-walled parenchyma cells called the **bundle sheath.**
- The veins give the leaf its "skeleton."
- The phloem transports throughout the plant carbohydrates produced in the mesophyll cells.
- Water is brought up to the leaf by the xylem



Key to labels
Dermal
Ground
Vascular
Guard cells
Stomatal pore
Epidermal cell
50 µm
(b) Surface view of a spiderwort (*Tradescantia*) leaf (LM)
Cuticle
Sclerenchyma fibers
Stoma
Upper epidermis
Palisade mesophyll
Spongy mesophyll
Lower epidermis
Bundle-sheath cell
Guard cells
Xylem
Phloem
Guard cells
Vein
Cuticle
(a) Cutaway drawing of leaf tissues
Vein
Air spaces
Guard cells
100 µm
(c) Transverse section of a lilac (*Syringa*) leaf (LM)

Plant cells and water

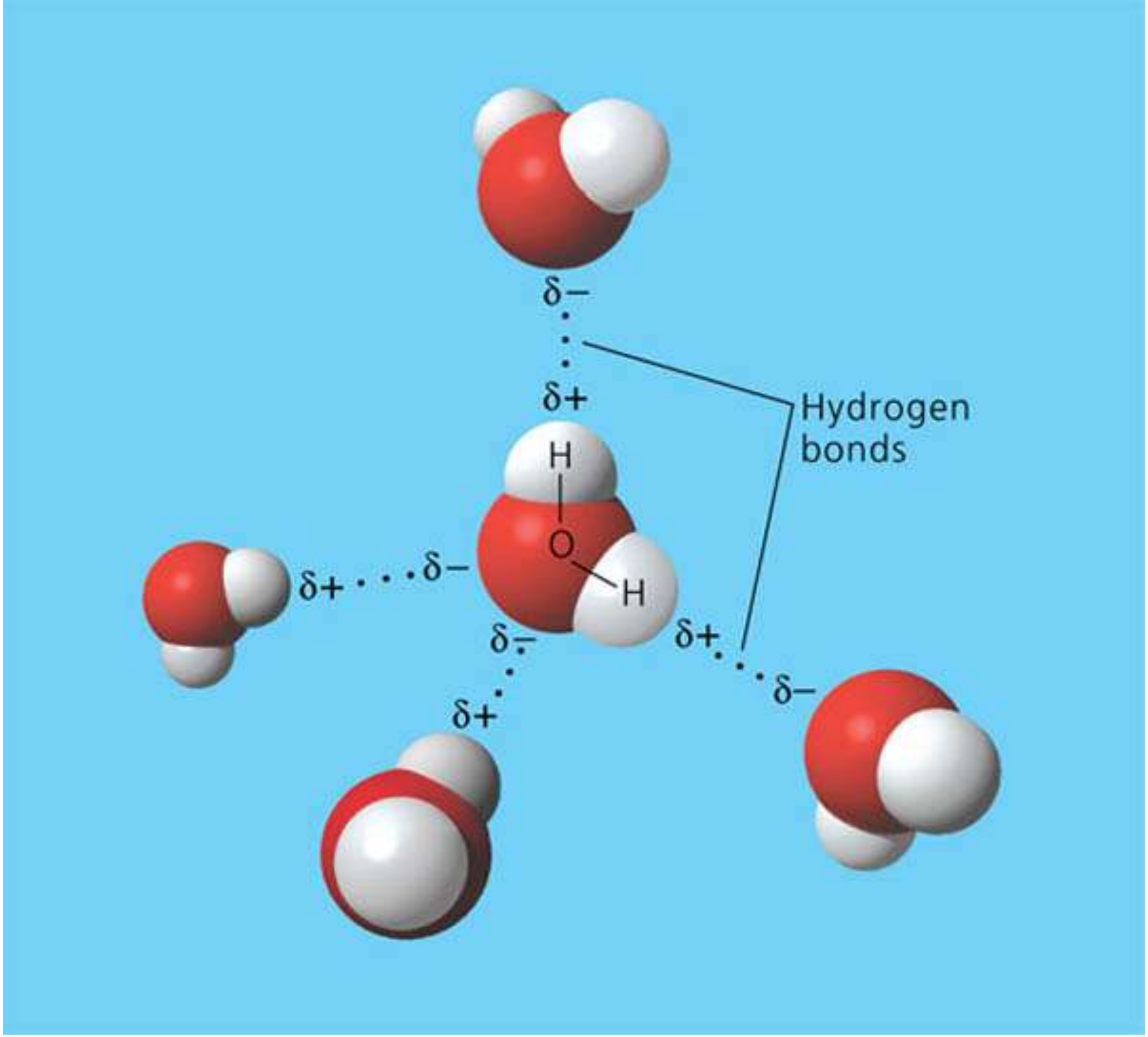
- The unique chemical and physical properties of H_2O arise from its structure.
- The oxygen atom is strongly **electronegative** (has the tendency to attract electrons).
- In H_2O oxygen tend to draw electrons away from the H^+. (electrons closer to O_2).

- The polarity of water molecules results in **hydrogen bonding**

  - **Hydrogen bonding,** electrical attraction between water molecules or between other polar molecules (20Kj mol^{-1}). H-Bond is responsible for the many unique water properties (see table 1.1).

  - Hydrogen bonding is the basis for **hydration shells** (bound water) that form around biologically important molecules such as proteins, carbohydrates and nucleic acids

  - The oxygen region of the molecule has a partial negative charge ($\delta-$), and the hydrogens have a partial positive charge ($\delta+$).


δ−
δ+
Hydrogen bonds
H
O
H
δ+
δ−
δ−
δ+
δ+
δ−

Thermal properties of water are biologically important

- Water is liquid over the range of temperatures most compatible with life

- Melting and boiling points are higher than expected when compared with other molecules of similar size (Table 1.1).

Water exhibits a unique thermal capacity

- **kinetic energy**, the energy of motion. Atoms and molecules have kinetic energy.
- The faster a molecule moves, the greater its kinetic energy.
- **Heat** is a measure of the total amount of kinetic energy due to molecular motion in a body of matter.

- **Temperature** measures the intensity of heat due to the average kinetic energy of the molecules.
- **heat** passes from the warmer to the cooler object until the two are the same temperature
- Heat and temperature are not the same
- e.g., an ice cube cools a drink not by adding coldness to the liquid, but by absorbing heat from the liquid as the ice itself melts.

- **Celsius scale (**°C) used to indicate temperature At sea level,
- water freezes at 0°C and boils at 100°C.
- **Calorie (cal)** used to indicate heat.
- A calorie is the amount of heat it takes to raise the temperature of 1 g of water by 1°C. Conversely, a calorie is also the amount of heat that 1 g of water releases when it cools by 1°C.
- **Joule (J)** used to indicate for heat. One joule equals 0.239 cal; one calorie equals 4.184 J.

Water exhibits a unique thermal capacity, cont’d

- **Specific heat,** a term used to describe the thermal capacity .
- **Specific heat** = the amount of heat that must be absorbed or lost for 1 g of a substance to change its temperature by 1°C
- The specific heat of water is 1 cal/g/°C.

- Compared with most other substances, water has high specific heat. (Table 1.1).

- Because of the **high** specific heat of water, water will change its temperature less when it absorbs or loses a given amount of heat

- **Absorption and dissipation.**
- Specific heat of water is high (4.184 J g^{-1})$^{o}C^{-1}$.
- High **thermal conductivity** (rapidly conduct heat away from the point of application).
- Large amount of heat can be exchanged between cells and their environment without extreme variation in the internal temperature.

- **Water has high specific heat due to hydrogen bonding, how??**
- Heat must be absorbed in order **to break hydrogen bonds**, and heat is released when hydrogen bonds form.
- A calorie of heat causes a relatively small change in the temperature of water because **much of the heat is used to disrupt hydrogen bonds before the water molecules can begin moving faster.**
- when the temperature of water drops slightly, many additional hydrogen bonds form, releasing a considerable amount of energy in the form of heat.

Water exhibits a high heat of fusion and heat of vaporization

- **Heat of fusion**: energy required to convert a substance from a solid to a liquid state.
- Heat of fusion for water is 335 jg^{-1} (to covert 1 g ice to 1 g liquid water) (6.0 kj mol^{-1})
- Density of ice (max density of water at 4 ^{o}C)
- **Heat of vaporization:** the energy required to covert one mole of liquid water to one mole of water vapor. About 44 kj mol^{-1} at 25 ^{o}C


Hydrogen
bond
Ice
Hydrogen bonds are stable
Liquid water
Hydrogen bonds
constantly break and re-form

Moderation of Temperature

- By absorbing heat from air that is warmer and,
- Releasing the stored heat to air that is cooler.
- Water is effective as a heat bank because it can absorb or release a relatively large amount of heat with only **a slight change** in its own temperature.

Evaporative cooling of water

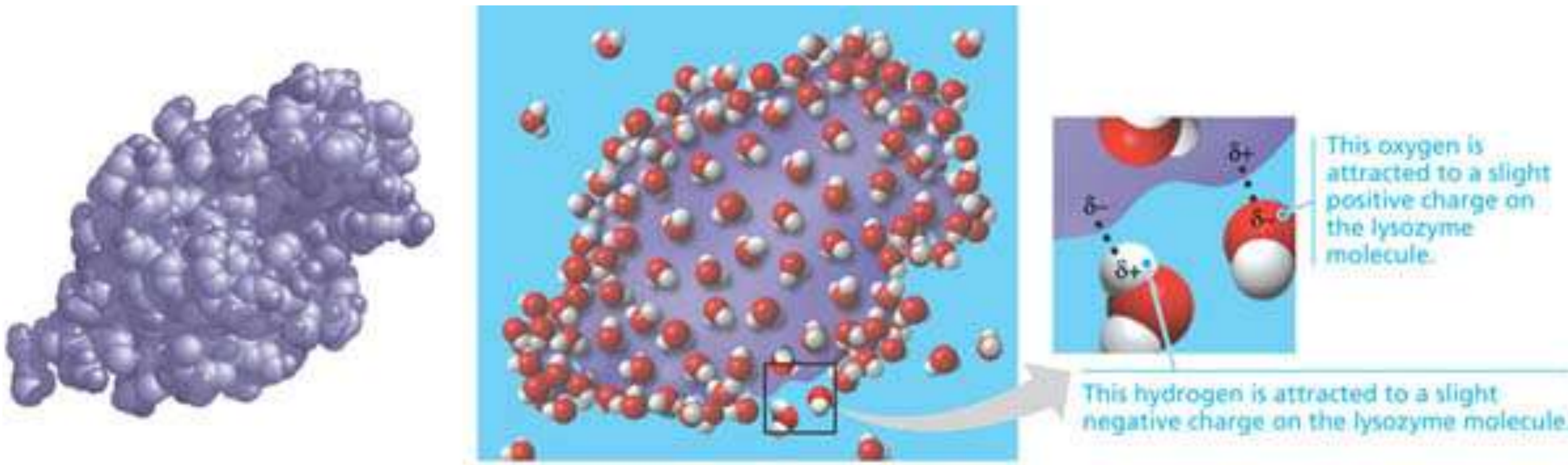
- contributes to the stability of temperature in lakes and, seas
- Water provides a mechanism that prevents organisms from overheating.
  - e.g. evaporation of water from the leaves ----- keep the tissues in the leaves from becoming too warm in the sunlight.

Water is The Universal Solvent of Life

- **Solution:** is A liquid that is a completely homogeneous mixture of two or more substances.
- **Solvent:** is the dissolving agent
- **Solute:** is the substance that is dissolved.
- An **aqueous solution** is one in which water is the solvent

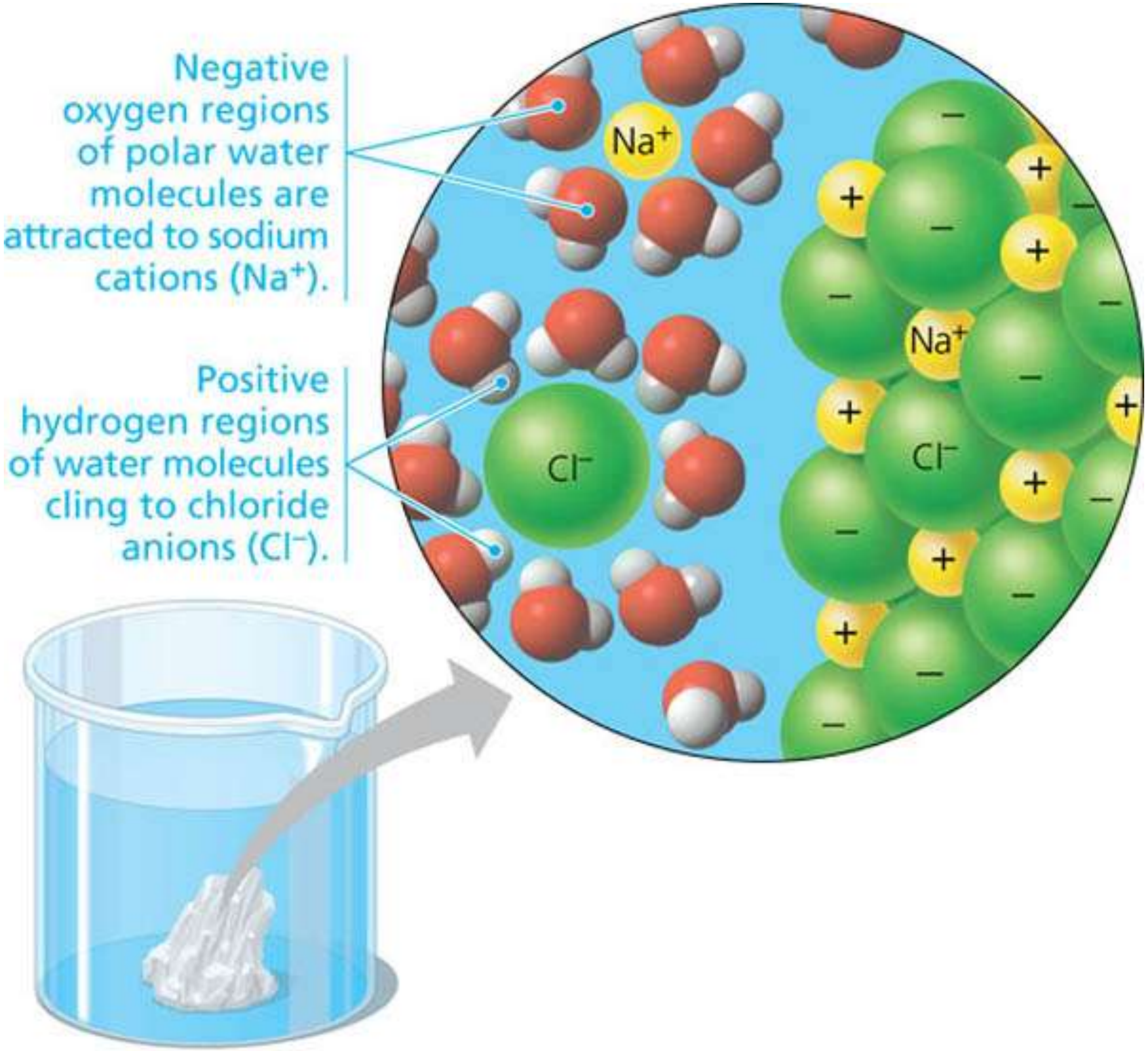
- Due to the highly polar character (has a high **dielectric constant**), water is a universal solvent. And is a very versatile solvent (table 1.2)

- a **hydration shell:** The sphere of water molecules around each dissolved ion. This encourage solvation by reducing the propabilty of ions to recombine and for crystals



(a) Lysozyme molecule in a nonaqueous environment **(b)** Lysozyme molecule (purple) in an aqueous environment such as tears or saliva **(c)** Ionic and polar regions on the protein's surface attract water molecules.

- Even molecules as large as proteins can dissolve in water if they have ionic and Polar Regions on their surface

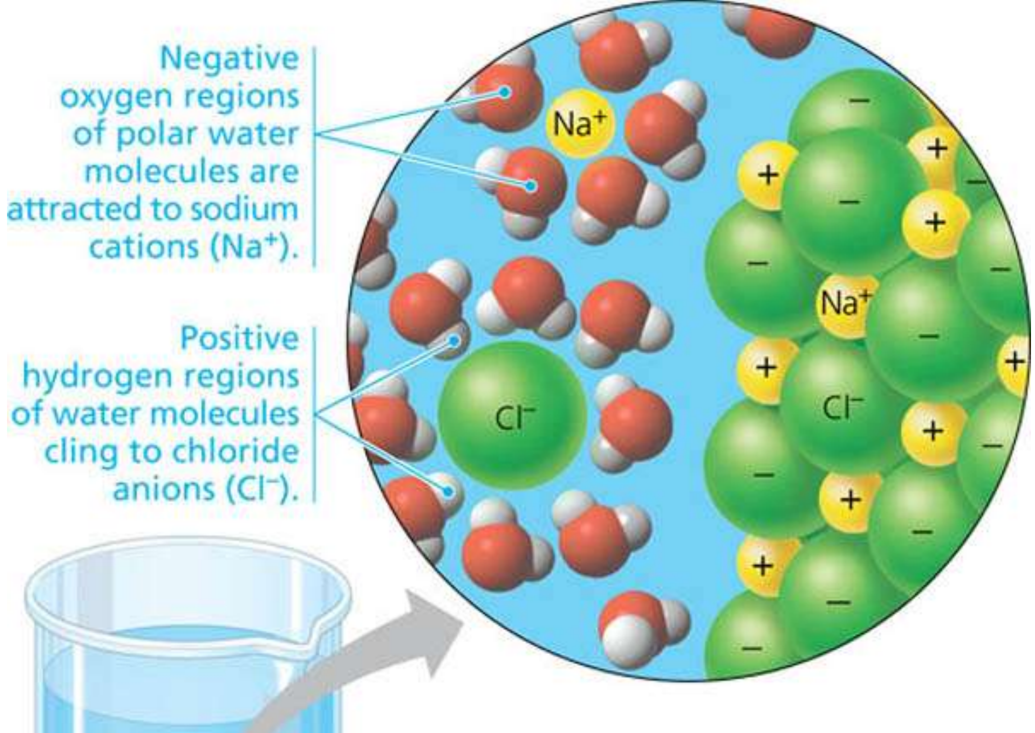


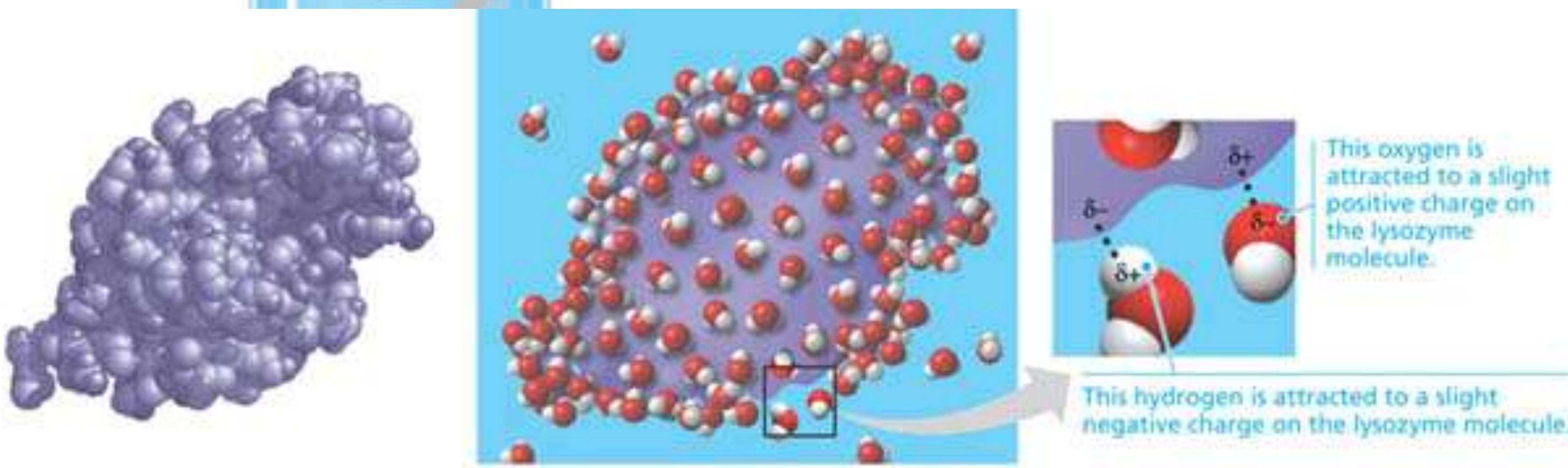
- many of solutes of important to plants are charged

Hydrophilic and Hydrophobic Substances

- **Hydrophilic:** Any substance that has an affinity for water
- In some cases, substances can be hydrophilic without actually dissolving.

- **Hydrophobic:** Substances that do not have an affinity for water (nonionic and nonpolar)





(a) Lysozyme molecule in a nonaqueous environment

(b) Lysozyme molecule (purple) in an aqueous environment such as tears or saliva

(c) Ionic and polar regions on the protein's surface attract water molecules.

Polarity of water molecules results in cohesion and adhesion

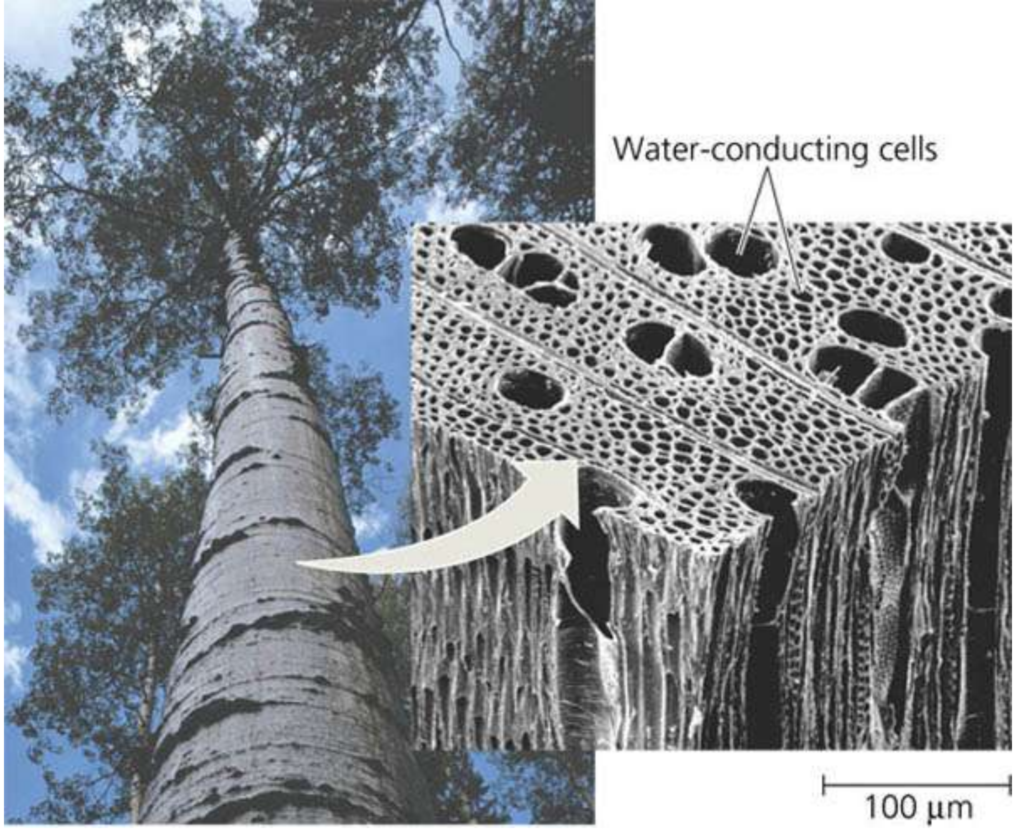
Cohesion

- Water molecules stay close to each other as a result of hydrogen bonding.
- When water is in its liquid form, its hydrogen bonds are very fragile, about 1/20 as strong as covalent bonds. They form, break, and re–form with great frequency
- The hydrogen bonds hold the substance together, a phenomenon called **cohesion**.

Adhesion,

- the sticking of one substance to another.

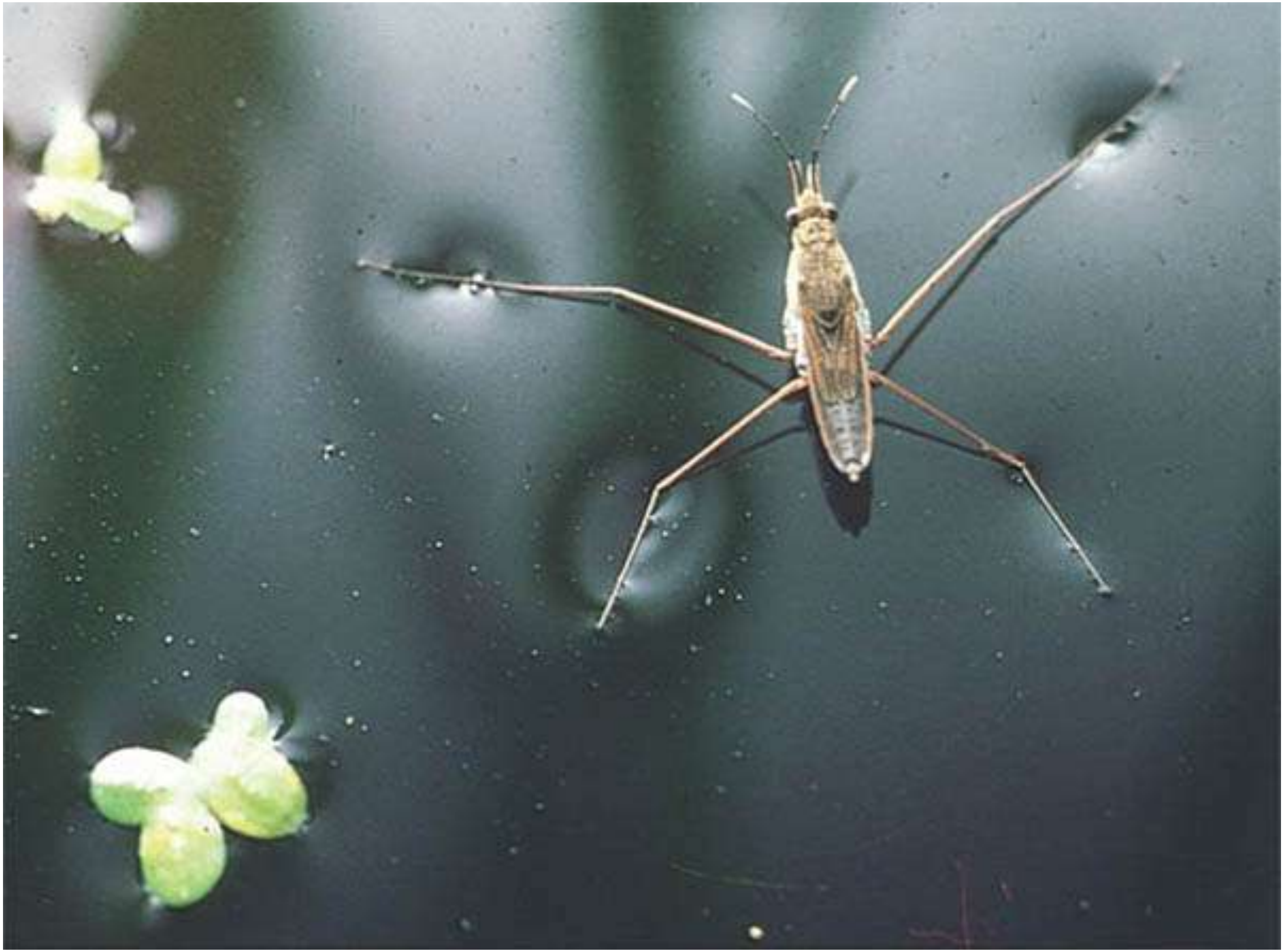
- Adhesion of water to the walls of the cells helps counter the downward pull of gravity.



- **Cohesion** due to hydrogen bonding helps hold together the column of water within the cells.

surface tension,

- A measure of how difficult it is to stretch or break the surface of a liquid. E.g. overfilling a drinking glass.
- The high surface tension of water, resulting from the collective strength of its hydrogen bonds.
- Water has a greater surface tension than most other liquids.
- At the interface between water and air is an ordered arrangement of water molecules, hydrogen–bonded to one another and to the water below



1.5 Water movement may be governed by diffusion or bulk flow

- Cohesion, adhesion and tensile strength help water to rise in the plant and maintain continuity of water column.

- Translocation of water through the plant is **passive** (no energy needed).

- Passive translocation occurred through:
  - **Bulk flow (mass flow).**
    - Substances move in a mass due to external force such as gravity or pressure. (movement of water into roots).
  - **Diffusion (osmosis):** directed movement from a region of high concentration to a region of low concentration.
    - Diffusion is important in distribution water, gasses and solutes throughout the plants. (supply CO_2 for photosynthesis and loss of water vapor from leaves).

Fick's First low describes the process of diffusion

$J = - D. A. \Delta c. l^{-1}$

J, The rate of transport, or the flux density (***J_s***), is the amount of substance *s* crossing a unit area per unit time (e.g., J_s may have units of moles per square meter per second [mol m^{-2} s^{-1}]).

D, The diffusion coefficient is a proportionality constant that measures how easily substances moves through a particular medium.

The negative sign indicates that the flux moves down a concentration gradient.

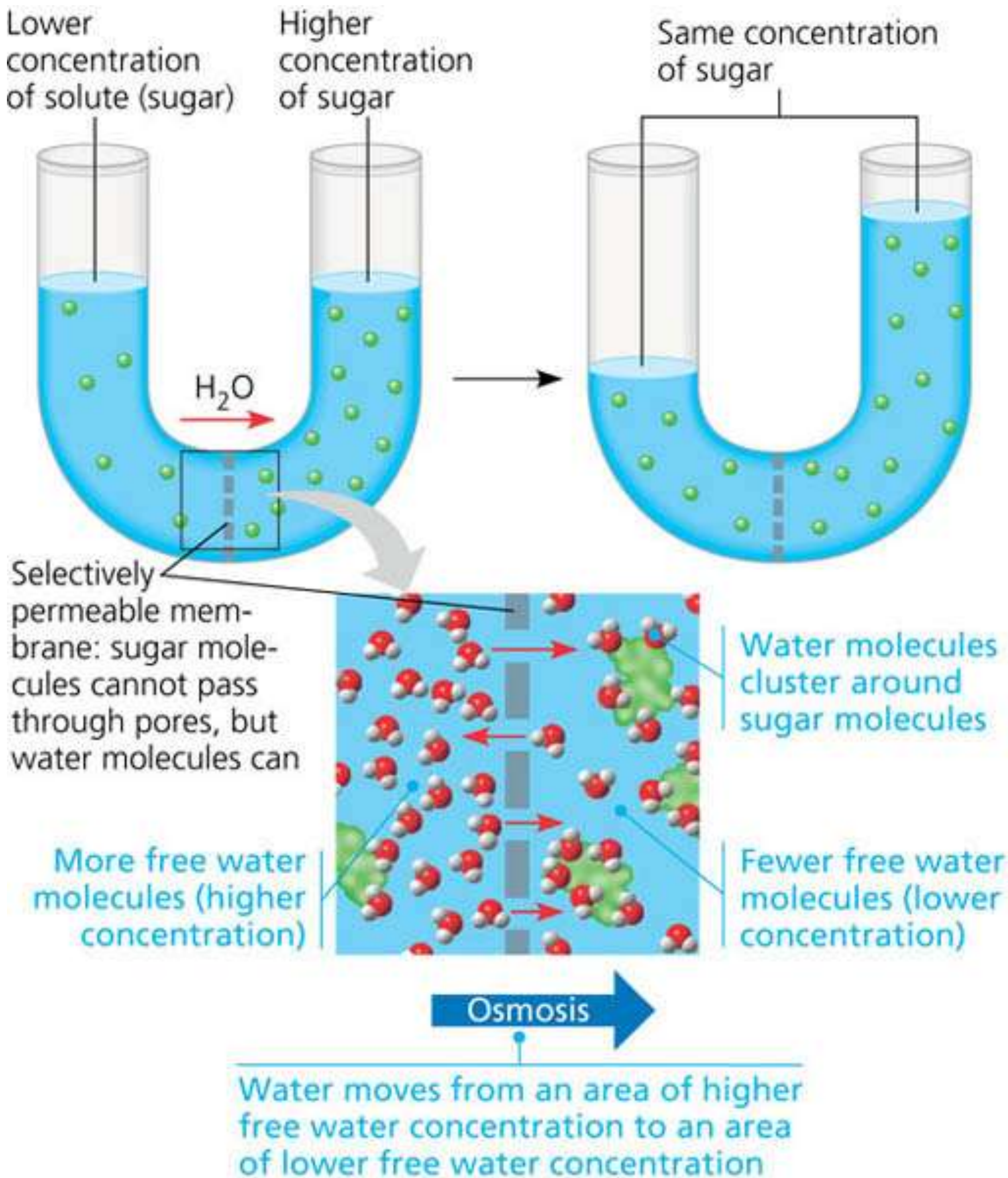
A, cross-sectional area

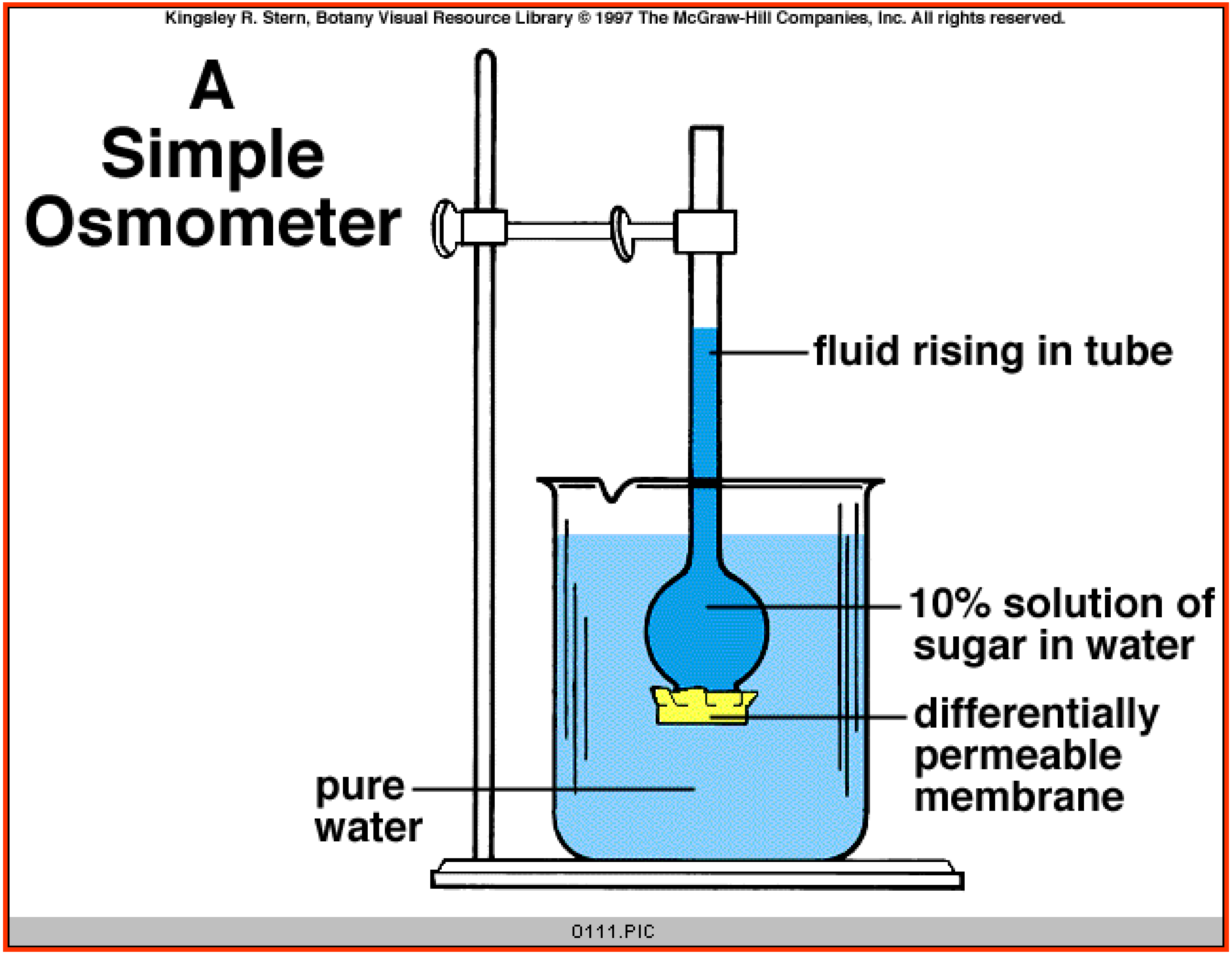
Δc, difference in concentration in two regions, **(concentration gradient)**

l, length of the diffusion path

1.6 **Osmosis** is the diffusion of water across a selectively permeable membrane

- **Osmosis** (the diffusion of water across a selectively permeable membrane).
  - Water move from the solution of high water potential to solution of low water potential.


Lower concentration of solute (sugar)
Higher concentration of sugar
Same concentration of sugar
H_2O
Selectively permeable membrane: sugar molecules cannot pass through pores, but water molecules can
Water molecules cluster around sugar molecules
More free water molecules (higher concentration)
Fewer free water molecules (lower concentration)
Osmosis
Water moves from an area of higher free water concentration to an area of lower free water concentration



Kingsley R. Stern, Botany Visual Resource Library © 1997 The McGraw-Hill Companies, Inc. All rights reserved.
A Simple Osmometer
fluid rising in tube
10% solution of sugar in water
differentially permeable membrane
pure water
0111.PIC

Water and Plant Cells

- Water plays a crucial role in the life of the plant.
- Photosynthesis requires that plants draw carbon dioxide from the atmosphere, but doing so exposes them to water loss and the threat of dehydration.
- For every gram of organic matter made by the plant, approximately 500 g of water is absorbed by the roots, transported through the plant body, and lost to the atmosphere.
- Even slight imbalances in this flow of water can cause water deficits and severe malfunctioning of many cellular processes. Thus, balancing the uptake and loss of water represents an important challenge for land plants.

- A major difference between plant and animal cells that affects their relation with water is the existence in plants of the cell wall.
- Cell walls allow plant cells to build up large internal hydrostatic pressures, called **turgor pressure.**
- Turgor pressure is essential for many physiological processes, including cell enlargement, stomatal opening, transport in the phloem, and various transport processes across membranes.
- Turgor pressure also contributes to the rigidity and mechanical stability of nonlignified plant tissues.

1.6.2 Osmosis in plant cells is indirectly energy dependent

- Pure water has greater energy than water in solutes.
- **Chemical potential (μ):** is a measure of the capacity of a substance to react or move. **(the free energy per mole of that substance)**
- Osmosis occur when there is a difference in the chemical potential of water in the two sides of selectively permeable membrane.
- Chemical potential of water affected mainly by:
  - Concentration
  - Pressure

- Osmosis occurs only when there is a difference in the chemical potential of water on two sides of selectively permeable membrane.
- Increasing solute concentration in an aqueous solution decreases the **Mole fraction** of water (X_w)
- X_w= w/w+s

W, moles of H_2O in a given volume

S , moles of solute in the same volume

- Plants control the movement of water in and out of the cell by altering the solute concentration of the cytosol relative to the solution external to the cell
- Root cells can take up nitrate ions NO^-_3 from the soil by active transport
- $\Delta\mu = (\mu_{nitrate})_{in} - (\mu_{nitrate})_{out}$

$\mu_{nitrate=}$ chemical potential of NO^-_3

1.7 Hydrostatic pressure and osmotic pressure are two component of water potential (ψ)

- Water potential (ψ) is the sum of hydrostatic pressure and osmotic pressure.

$\Psi = P - \pi$

- water moves from a region of higher **water potential** (osmotic potential and pressure potential combined) to a region of lower water potential
- (ψ is usually negative).
- Ψ for pure water = 0 at atmospheric pressure.

- **Osmotic pressure or potential is the pressure required to prevent osmosis from taking place.**

- The pressure that develops in a cell as a result of water entering it is called **turgor**.

1.8 water potential is the sum of its component potentials

- $\Psi = \psi_p + \psi_s$
  - $\Psi_{p,}$ is the pressure potential
  - Ψ_s is the osmotic potential (solute potential), Ψ_s= osmotic pressure (π) but negative.
  - main factors contribute to water potential are ψ_p and ψ_s.
- At constant pressure, water always move from the solution with the higher (less negative) osmotic potential to the solution with lower (more negative) osmotic potential)

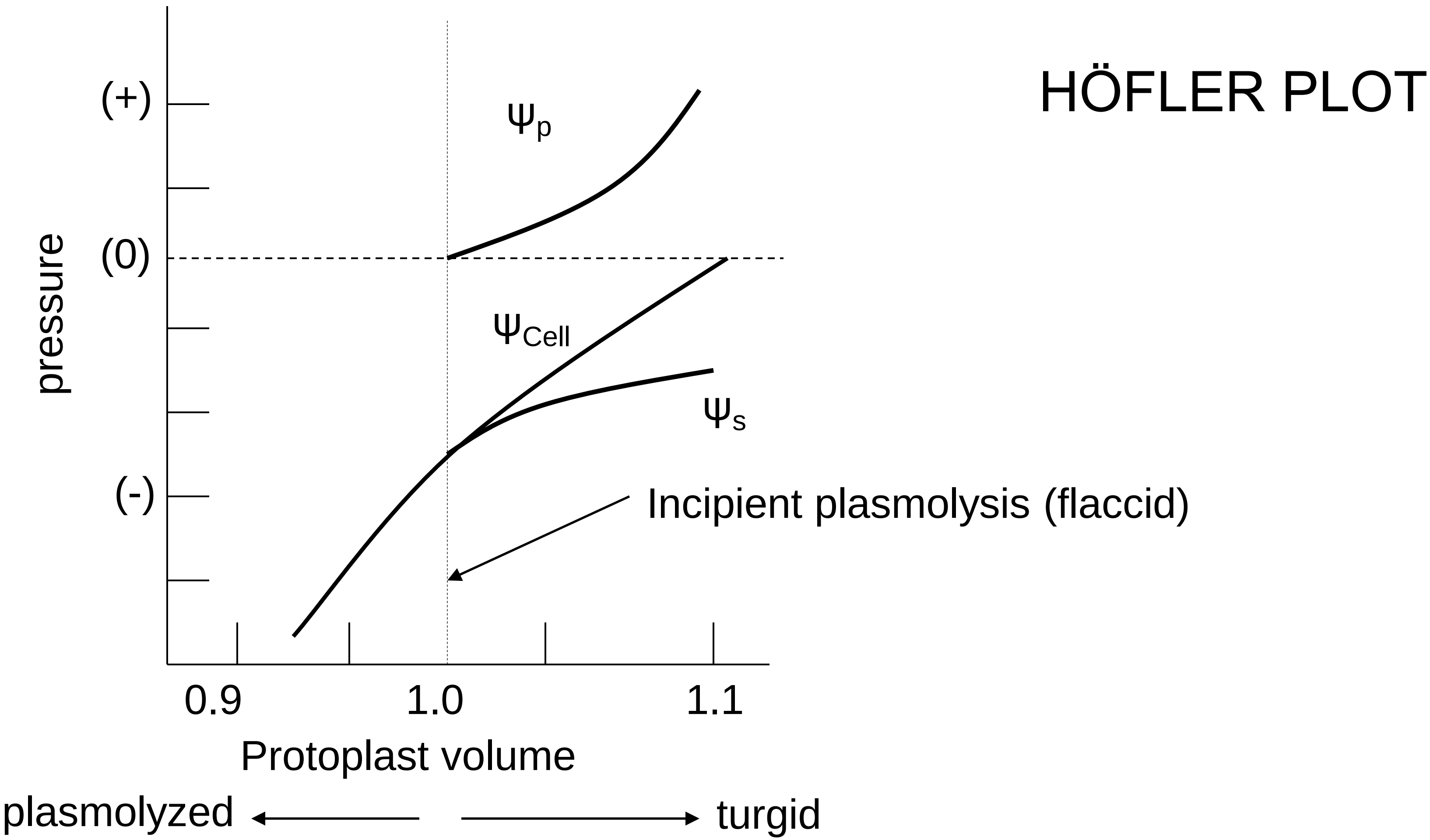
- **Osmometer** and the **osmotic pressure (π).**
- **Osmotic potential (ψ_s)** is the negative of osmotic pressure.
- $\psi_s = -\pi$
- Osmosis driven by both solute concentration and pressure differences which determine water movement in plants.

In the osmometer example:

- Dissolved sucrose generate an osmotic potential in the thistle tube ($-\psi_s$), which lowered ($\psi<0$) of the solution.
- Ψ of Pure water on the other side of the membrane =0.
- Water move into the solution.
- Hydrostatic pressure increase as the volume of the solution increase until $\Psi = 0$ on both sides.
- **Mole fraction** of water increase.

- In plant cell:
- Osmotic potential result from the vacuole contents (sugars, inorganic salts, organic acids and anthocyanin pigments).
- Pressure potential (Ψ_p) in the cell arise from the force exerted outwardly against the cell wall (**wall pressure**) due to protoplast expanding (**turgor pressure**)(cell is **turgid**).
- At turgor pressure = 0 cell is **flaccid.**
- Turgor pressure is responsible for maintaining erect habit in herbaceous plants.
- Wilting of leaves due to loss of turgor.

Water movement in cells and tissues



Water movement in cells and tissues

- At incipient plasmolysis:
  - $\Psi_p = 0$ (turgor pressure)
  - $\Psi_S = \Psi_{cell}$
  - With hypotonic solution (water) (increase Ψ_S) until turgor.
  - With hypertonic solution (more negative Ψ_S), water loss from the cell until plasmolysis.
  - The water potential of welted cells becomes more negative as it is sum of two negative components:
- $\Psi = \psi_p + \psi_s$

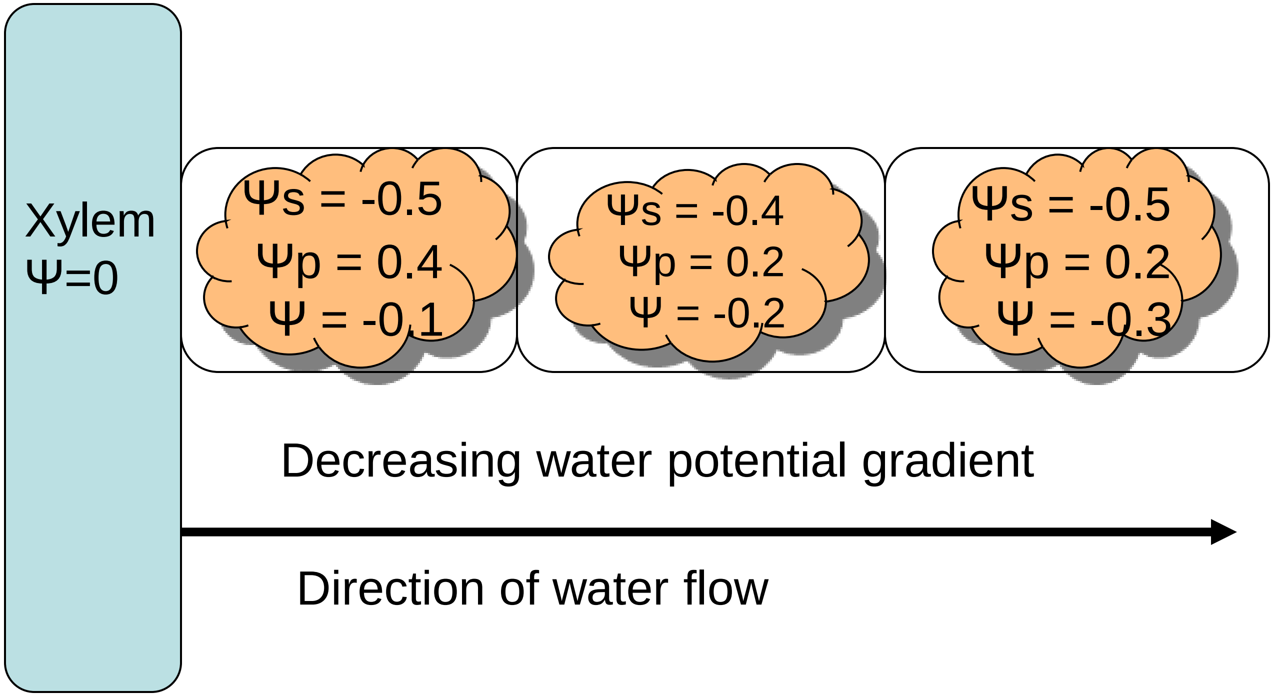

Xylem
Ψ=0
Ψs = -0.5
Ψp = 0.4
Ψ = -0.1
Ψs = -0.4
Ψp = 0.2
Ψ = -0.2
Ψs = -0.5
Ψp = 0.2
Ψ = -0.3
Decreasing water potential gradient
Direction of water flow

TABLE 3.1
Comparison of units of pressure

1 atmosphere	= 14.7 pounds per square inch
	= 760 mm Hg (at sea level, 45° latitude)
	= 1.013 bar
	= 0.1013 MPa
	= 1.013×10^5 Pa

A car tire is typically inflated to about 0.2 MPa.

The water pressure in home plumbing is typically 0.2–0.3 MPa.

The water pressure under 15 feet (5 m) of water is about 0.05 MPa.

Osmosis and chemical potential

- Pure water has greater energy than water in solutes.
- Chemical potential is a measure of the capacity of a substance to react or move.
- Osmosis occur when there is a difference in the chemical potential of water in the two sides of selectively permeable membrane.
- Chemical potential of water affected mainly by:
  - Concentration
  - Pressure

- **Osmosis** (the diffusion of water).
  - Need selectively permeable membrane (i.e cellular membranes).
  - Water move from the solution of high water potential to solution of low water potential.
  - **Osmometer** and the **osmotic pressure (π).**
  - **Osmotic potential (ψ_s)** is the negative of osmotic pressure.
  - $\psi_s = -\pi$
  - Osmosis driven by both solute concentration and pressure differences which determine water movement in plants.

Water potential (ψ)

- Water potential (ψ) is the sum of hydrostatic pressure and osmotic pressure. $\Psi = P - \pi$

- Water moves from a region of high water potential to a region of low water potential.
- (ψ is usually negative).
- Ψ for pure water = 0 at atmospheric pressure.

The component of ψ

- $\Psi = \psi_p + \psi_s$
  - $\Psi_{p,}$ is the pressure potential
  - Ψ_s is the osmotic potential (solute potential), Ψ_s= osmotic pressure (π) but negative.
  - main factors contribute to water potential are ψ_p and ψ_s.
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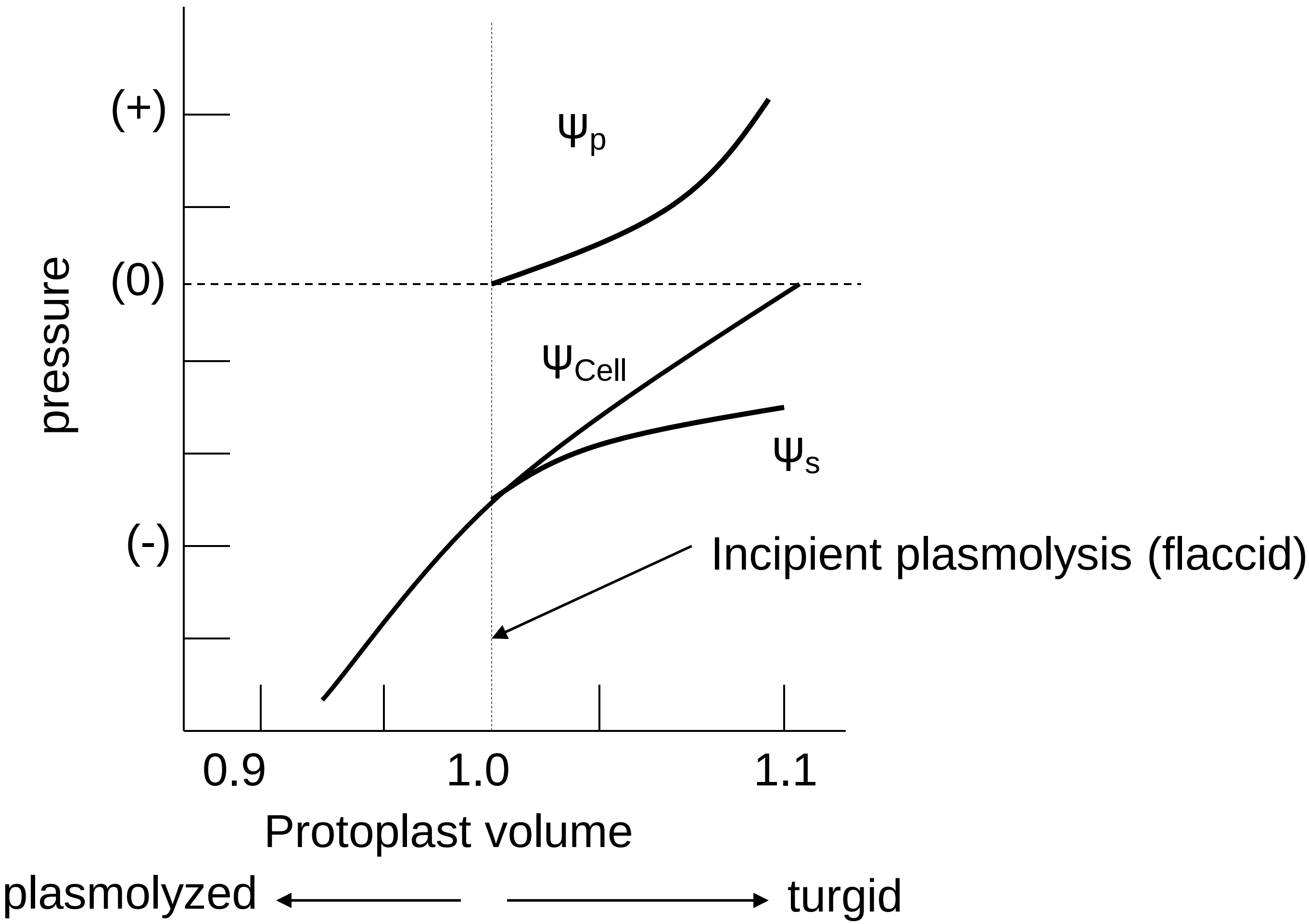
Water movement in cells and tissues



Water movement in cells and tissues

- At incipient plasmolysis:
  - $\Psi_p = 0$ (turgor pressure)
  - $\Psi_S = \Psi_{cell}$
  - With hypotonic solution (water) (increase Ψ_S) until turgor.
  - With hypertonic solution (more negative Ψ_S), water loss from the cell until plasmolysis.
  - The water potential of welted cells becomes more negative as it is sum of two negative components:
- $\Psi = \psi_p + \psi_s$

- Three major factors contribute to cell water potential:
    - **Concentration, pressure and gravity**

$$\Psi_w = \Psi_s + \Psi_p + \Psi_g$$

- SOLUTES
- **Ψ_s** (solute potential or the osmotic potential), represents the effect of dissolved solutes on water potential.
- Solutes reduce the free energy of water by diluting the water.
- For dilute solutions such as sucrose, the **osmotic potential** may be estimated by the van't Hoff equation:

$$\boldsymbol{\Psi_s = -RTc_s}$$

$$\Psi_s = - RTc_s$$

- where R is the gas constant (8.32 j mol^{-1} K^{-1}), T is the absolute temperature (in degrees Kelvin, or K), and c_s is the solute concentration of the solution, expressed as osmolality (moles of total dissolved solutes per liter of water) mol L^{-1}
- The minus sign indicates that dissolved solutes reduce the water potential of a solution relative to the reference state of pure water.

TABLE 3.2
Values of RT and osmotic potential of solutions at various temperatures

Temperature (°C)	RT^a (L MPa mol–1)	Osmotic potential (MPa) of solution with solute concentration in mol L^{-1} water: 0.01	0.10	1.00	Osmotic potential of seawater (MPa)
0	2.271	-0.0227	-0.227	-2.27	-2.6
20	2.436	-0.0244	-0.244	-2.44	-2.8
25	2.478	-0.0248	-0.248	-2.48	-2.8
30	2.519	-0.0252	-0.252	-2.52	-2.9

[a] $R = 0.0083143$ L MPa mol^{-1} K^{-1}.

PRESSURE (Ψ_p)

- The term (Ψ_p) is the hydrostatic pressure of the solution.
- Positive pressures raise the water potential; negative pressures reduce it.
- Sometimes $\boldsymbol{\Psi_p}$ is called ***pressure potential.***
- The positive hydrostatic pressure within cells is the pressure referred to as *turgor pressure.*
- The value of **Ψp** can also be negative, as is the case in the xylem and in the walls between cells, where a *tension,* or *negative hydrostatic pressure,* can develop.
- As we will see, negative pressures are important in moving water long distances through the plant.

- Hydrostatic pressure is measured as the deviation from ambient pressure.
- Remember that water in the reference state is at ambient pressure, so by this definition $(\Psi_p) = 0$ MPa at standard state

- GRAVITY **(Ψg)**
- Gravity causes water to move downward unless the force of gravity is opposed by an equal and opposite
- where $\mathbf{\Psi g} =$ 0.01 MPa m^{-1}.
- Thus a vertical distance of 10 m translates into a 0.1 MPa change in water potential. (negligible).
- Thus, $\mathbf{\Psi_w = \Psi_s + \Psi_p + \Psi_g}$ could be

simplified to $\mathbf{\Psi_w = \Psi_s + \Psi_p}$

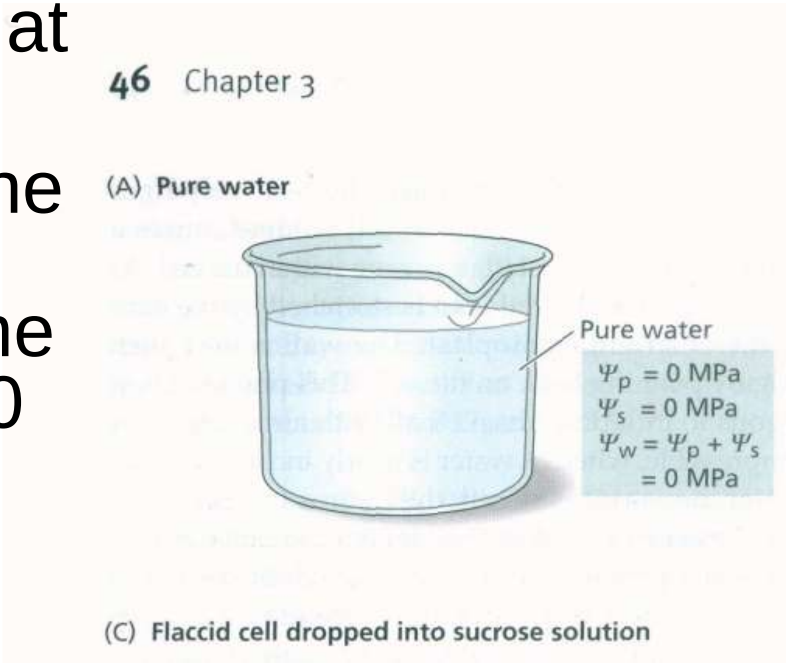
WATER POTENTIAL IN THE PLANT

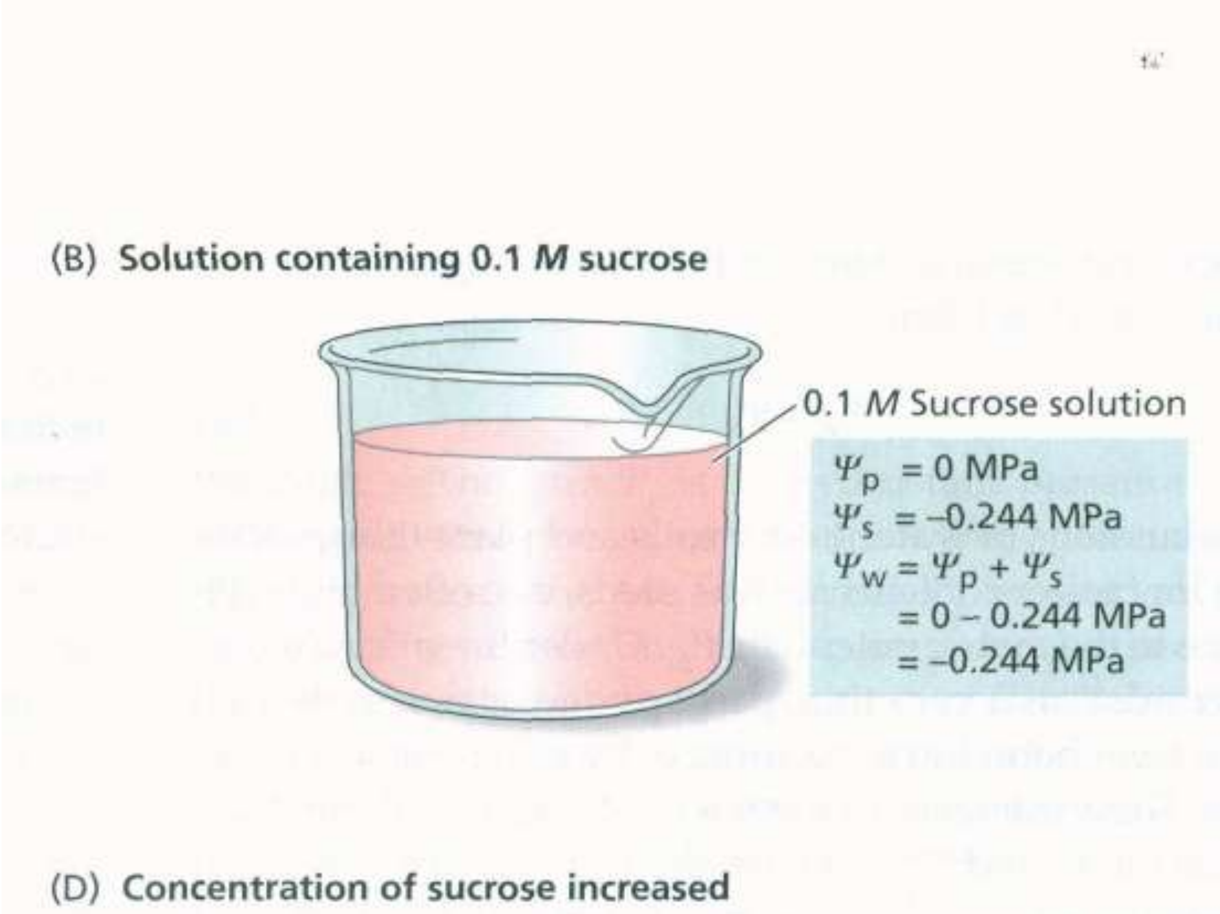
- Cell growth, photosynthesis, and crop productivity are all strongly influenced by water potential and its components.
- water potential is a good overall indicator of plant health and accurate and reliable methods for evaluating the water status of plants.

Water enters the cell along a water potential gradient

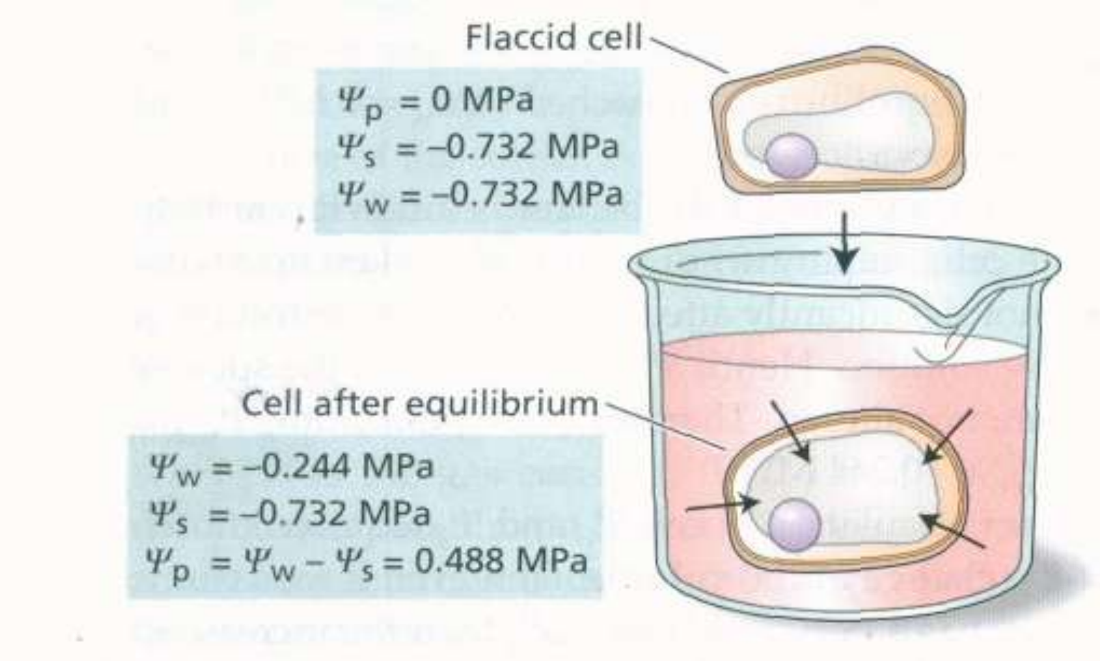
- the osmotic behavior of plant cells with some numerical examples.

- open beaker full of pure water at 20°C .
- Because the water is open to the atmosphere, the hydrostatic pressure of the water is the same as atmospheric pressure ($\Psi_p = 0$ MPa).
- There are no solutes in the water, so $\Psi_s = 0$ MPa; therefore the water potential is 0 MPa (**$\Psi w = \Psi s + \Psi p$**).

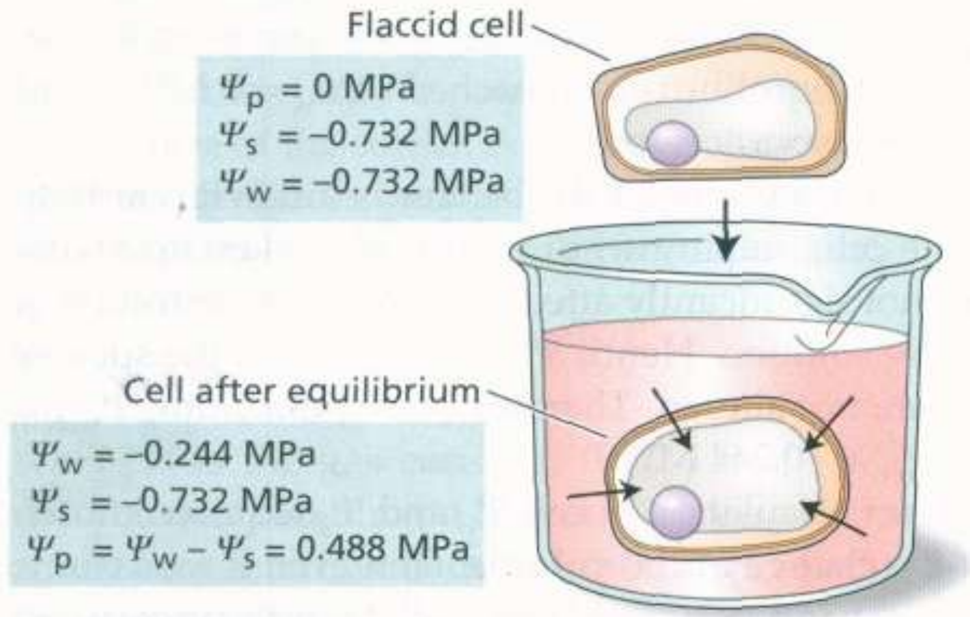




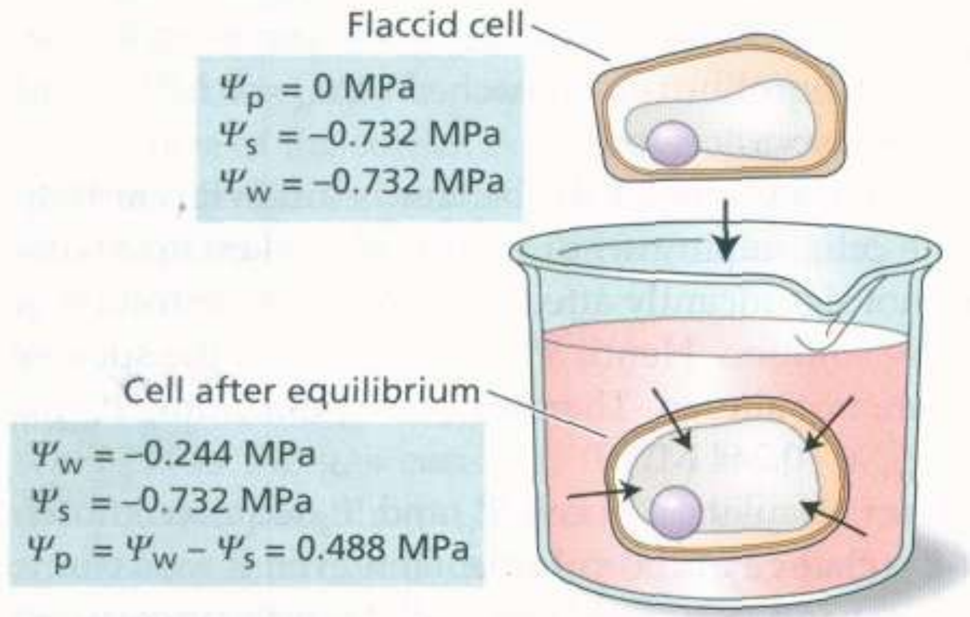
- Now imagine dissolving sucrose in the water to a concentration of 0.1 *M*
- This addition lowers the osmotic potential (**Ψs**) to -0.244 MPa (see Table 3.2) and decreases the water potential (**Ψw**) to -0.244 MPa.



- Next consider a "wilted" plant cell (i.e., a cell with no turgor pressure) that has a total internal solute concentration of 0.3 *M*. This solute concentration gives an osmotic potential (**Ψs**) of -0.732 MPa.
- Because the cell is flaccid, the internal pressure is the same as ambient pressure, so the hydrostatic pressure (**Ψp**) is 0 MPa and the water potential of the cell is -0.732 MPa.



- What happens if this cell is placed in the beaker containing 0.1 M sucrose.
- Because the water potential of the sucrose solution (**Ψw** = -0.244 MPa; see Figure 3.9B) is greater than the water potential of the cell (**Ψw** = -0.732 MPa), water will move from the sucrose solution to the cell (from high to low water potential).
- Because plant cells are surrounded by relatively rigid cell walls, even a slight increase in cell volume causes a large increase in the hydrostatic pressure within the cell. As water enters the cell, the cell wall is stretched by the contents of the enlarging protoplast. The wall resists such stretching by pushing back on the cell.

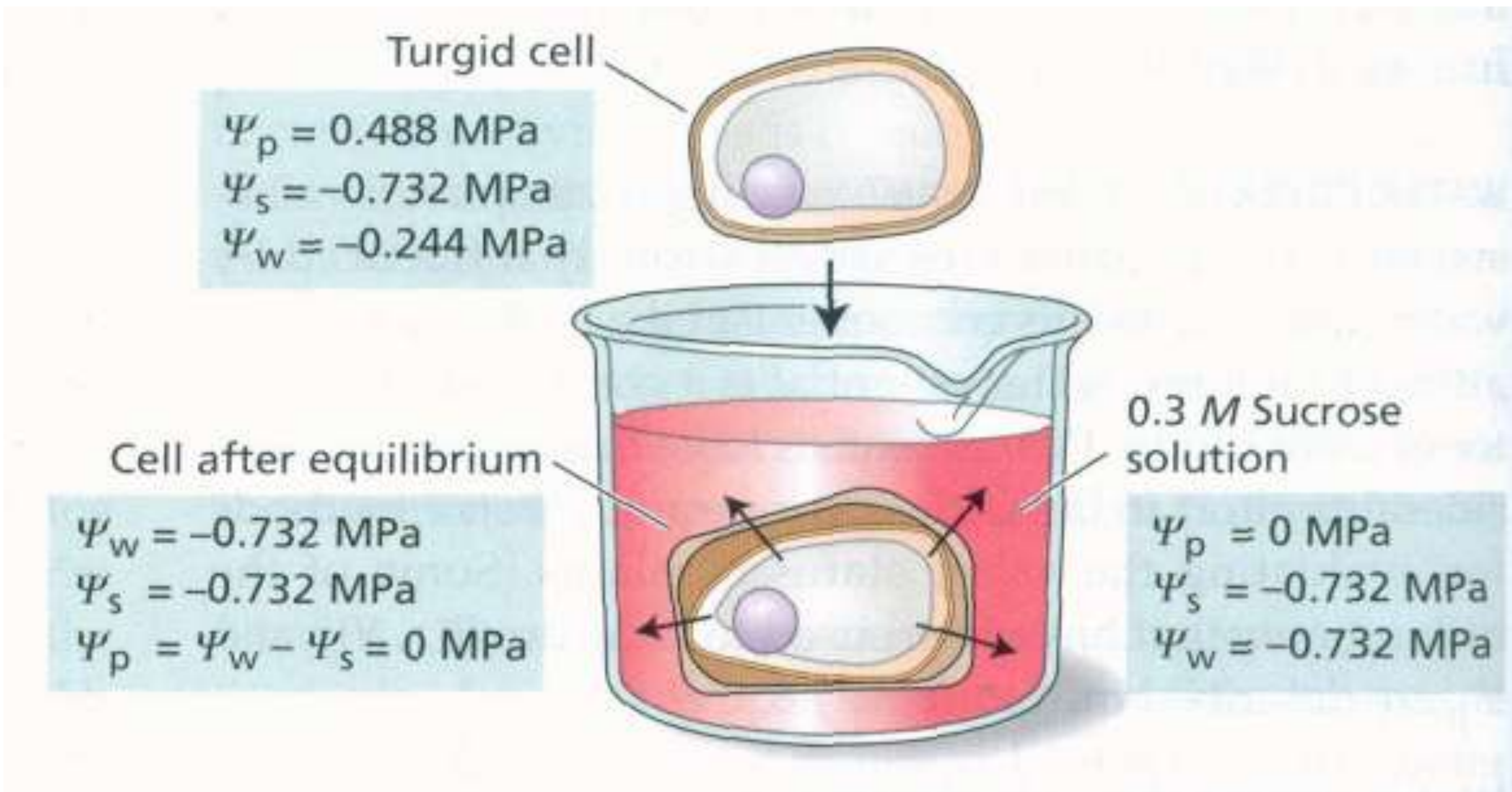


- As water moves into the cell, the hydrostatic pressure, or turgor pressure (**Ψp**), of the cell increases. Consequently, the cell water potential (**Ψw**) increases, and the difference between inside and outside water potentials (Δ**Ψw**) is reduced.
- Eventually, cell **Ψp** increases enough to raise the cell **Ψw** to the same value as the **Ψw** of the sucrose solution. At this point, equilibrium is reached (Δ**Ψw** = 0 MPa), and net water transport ceases.

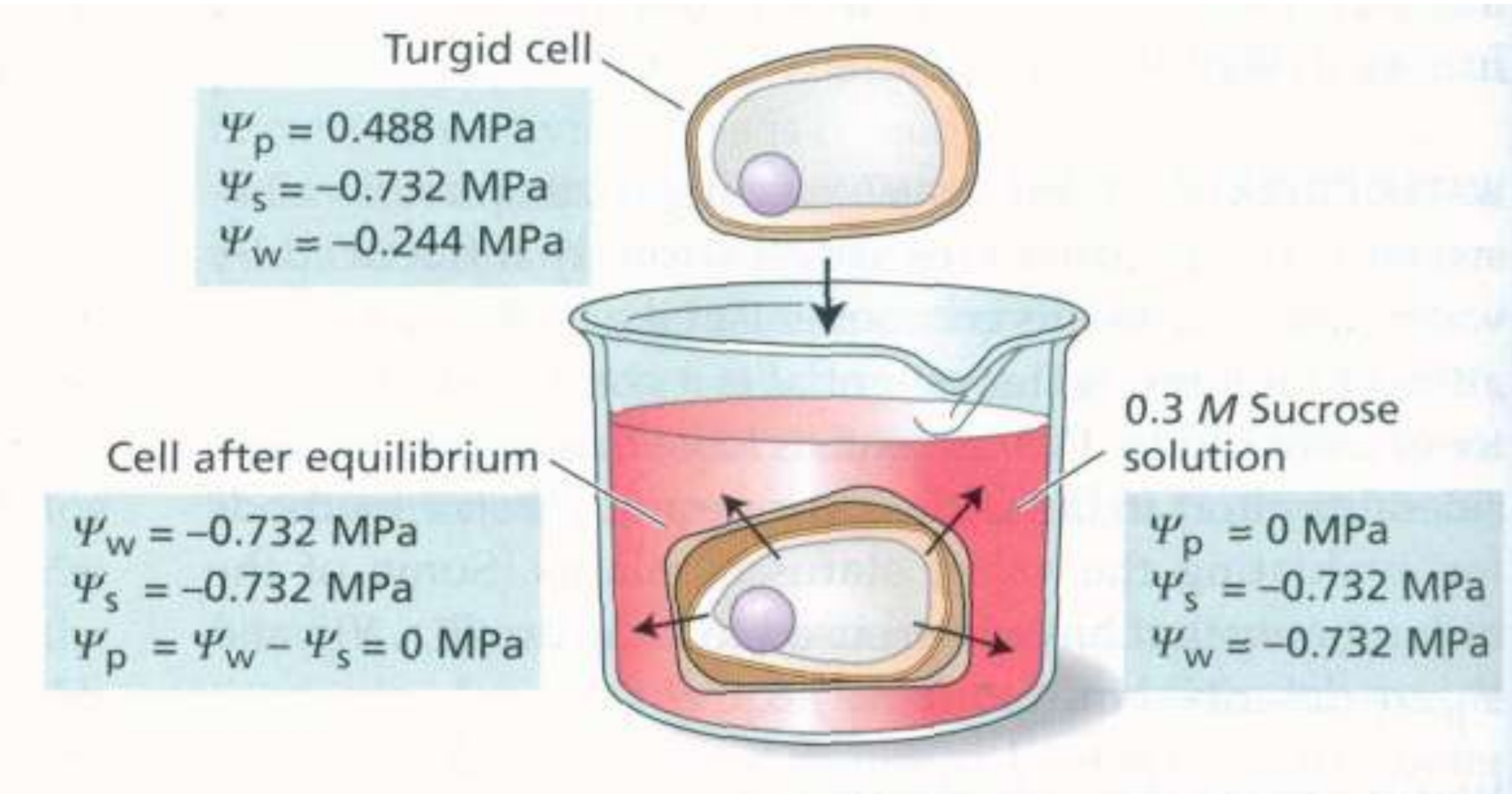
- Because the volume of the beaker is much larger than that of the cell, the tiny amount of water taken up by the cell does not significantly affect the solute concentration of the sucrose solution.
- Hence $\boldsymbol{\Psi s + \Psi p}$ and $\boldsymbol{\Psi w}$ of the sucrose solution are not altered. Therefore, at equilibrium, $\boldsymbol{\Psi w_{(Cell)}} = \boldsymbol{\Psi w_{(solution)}} = -244$ MPa.

Water can also leave the cell in response to a water potential gradient

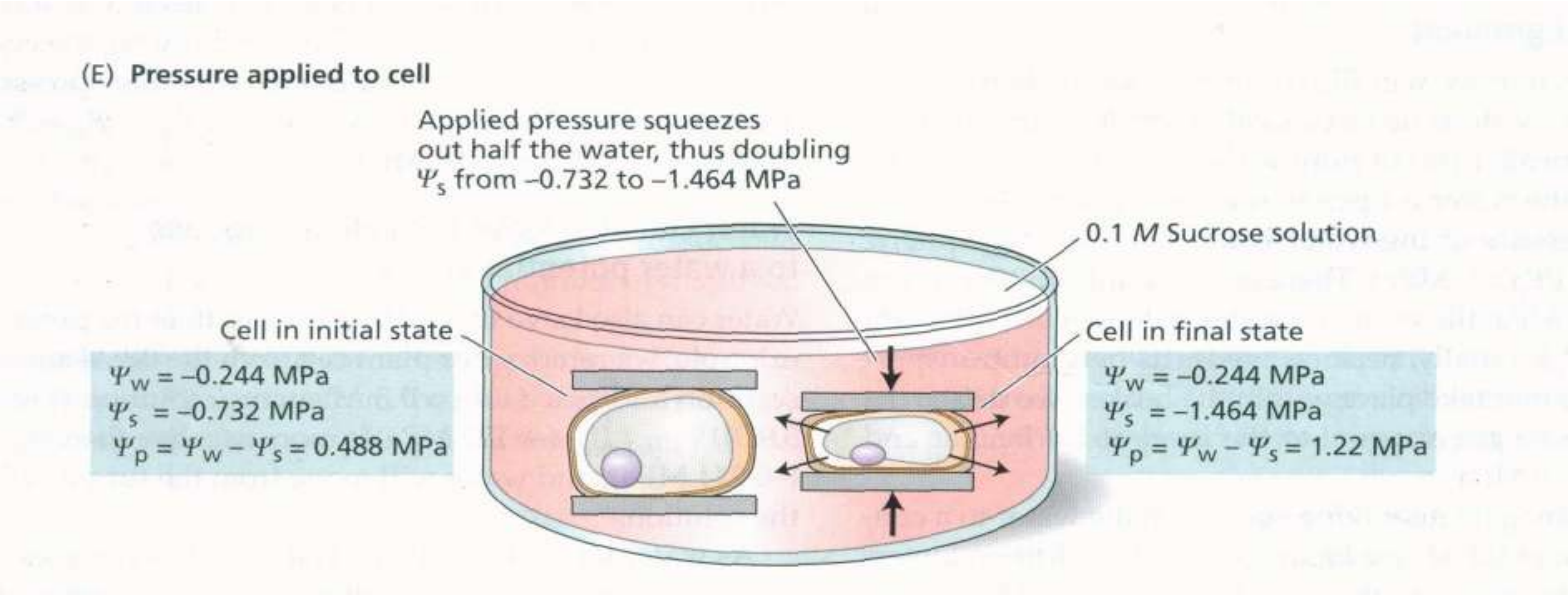
- Water can also leave the cell by osmosis.
- If we remove our plant cell from the 0.1 M and place it in a 0.3 M sucrose solution (Figure 3.9D), **Ψw** $_{(solution)}$ (-0.732 MPa) is more negative than **Ψw** $_{\textbf{(Cell)}}$ (-0.244 MPa), and water will move from the turgid cell to the solution.



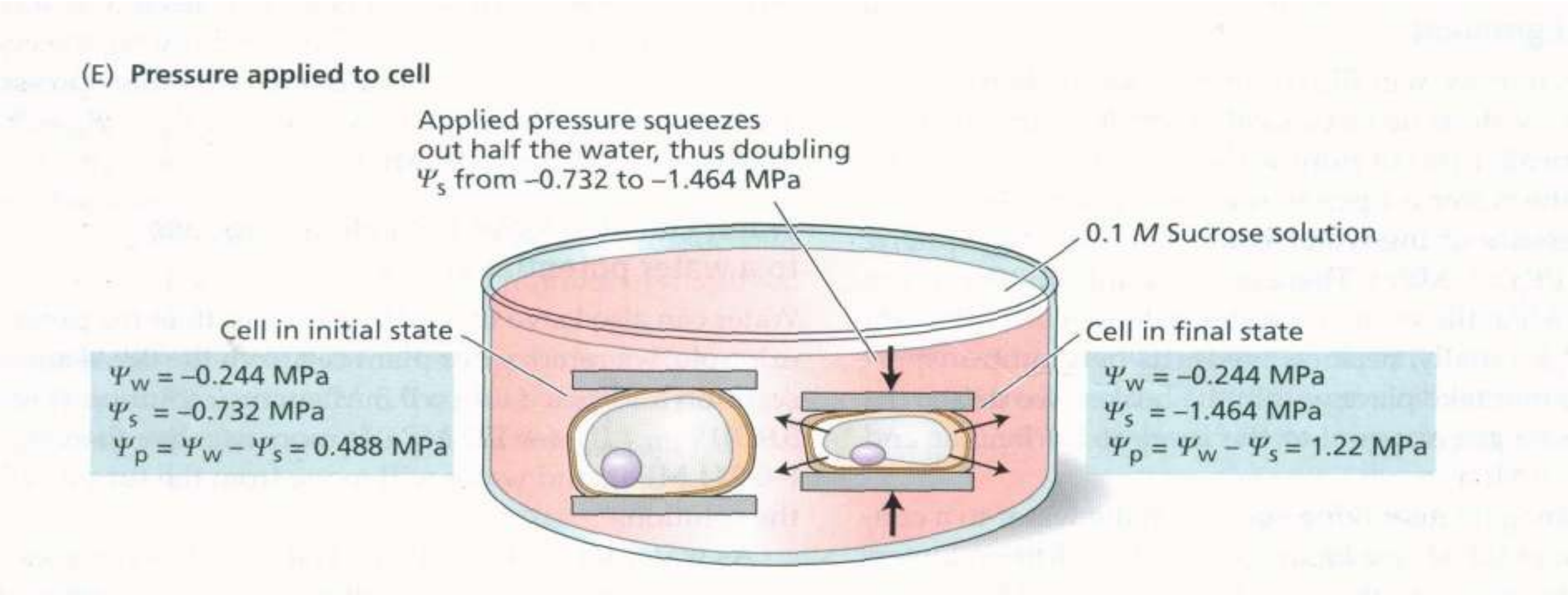
- As water leaves the cell, the cell volume decreases. As the cell volume decreases, cell **Ψp** and **Ψw** decrease also until **Ψw** (cell) = **Ψw** (solution) = (-0.732 MPa
- *From* the water potential equation $\mathbf{\Psi_w = \Psi_s + \Psi_p}$ we can calculate that at equilibrium $\mathbf{\Psi_p}$ = 0 MPa. As before, we assume that the change in cell volume is small, so we can ignore the change in **Ψs** due to the net outflow of water from the cell.

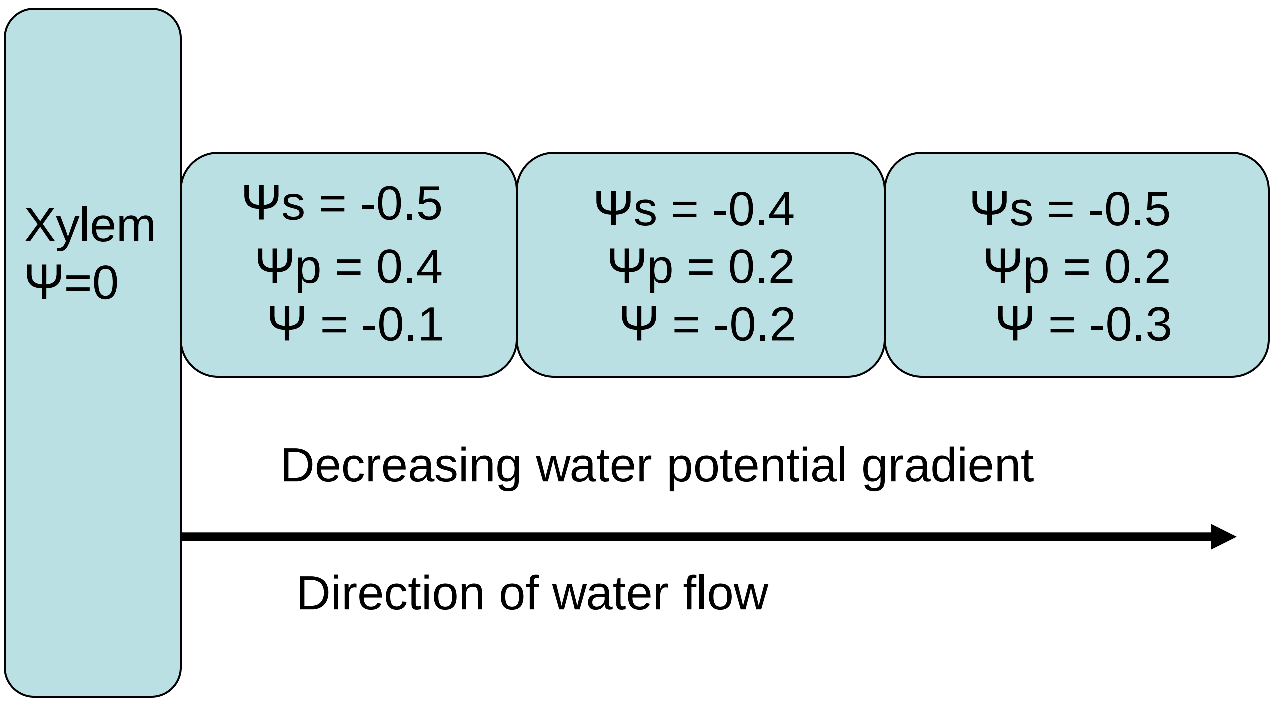


- If we then slowly squeeze the turgid cell by pressing it between two plates (Figure 3.9E), we effectively raise the cell $\mathbf{\Psi_p}$, consequently raising the cell $\mathbf{\Psi}_w$ and creating a $\Delta\mathbf{\Psi_w}$ such that water now flows *out* of the cell.
- If we continue squeezing until half the cell water is removed and then hold the cell in this condition, the cell will reach a new equilibrium.



- Because half of the water was squeezed out of the cell while the solutes remained inside the cell (the plasma membrane is selectively permeable), the cell solution is concentrated twofold, and thus **Ψs** is lower (-0.732 x 2 = -1.464 MPa).
- Knowing the final values for *fw* and *fs,* we can calculate the turgor pressure, using Equation $\mathbf{\Psi_w = \Psi_s + \Psi_p}$ as $\mathbf{\Psi_p}$ = $\mathbf{\Psi_w}$ - $\mathbf{\Psi_s}$ = (-0.244) - (-1.464) = 1.22 MPa. In our example we used

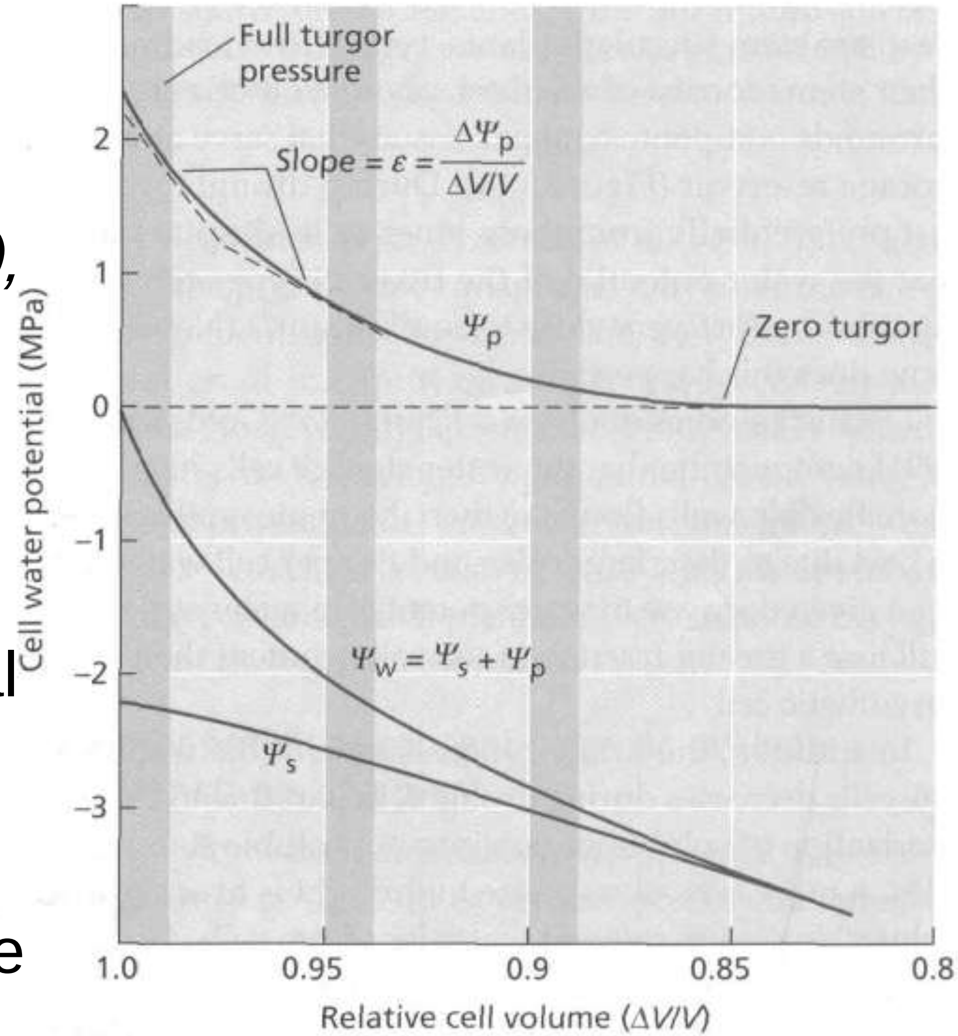



Xylem
Ψ=0
Ψs = -0.5
Ψp = 0.4
Ψ = -0.1
Ψs = -0.4
Ψp = 0.2
Ψ = -0.2
Ψs = -0.5
Ψp = 0.2
Ψ = -0.3
Decreasing water potential gradient
Direction of water flow

- One point common to all these examples *Water flow across membranes is a passive process.*
- *That is, water moves in response to physical forces, toward regions of low water potential or low free energy.*
- There are no metabolic "pumps" (reactions driven by ATP hydrolysis) that can be used to drive water across a semipermeable membrane against its gradient in free energy.

- **Small changes in plant cell volume cause large changes in turgor pressure**
- Cell walls provide plant cells with a substantial degree of volume homeostasis relative to the large changes in water potential that they experience as the everyday consequence of the transpirational water losses associated with photosynthesis
- Because plant cells have fairly rigid walls, a change in cell Ψ_w is generally accompanied by a large change in Ψ_p, with relatively little change in cell (protoplast) volume.
-

- cell water potential (Ψ_w) and its components (**Ψp** and **Ψs** *),* and relative cell volume *(ΔV/V).* Note that turgor pressure (**Ψp**) decreases steeply with the initial 5% decrease in cell volume. In comparison, osmotic potential (**Ψs**) changes very little. As cell volume decreases below 0.9 in this example, the situation reverses: Most of the change in water potential is due to a drop in cell **Ψs** accompanied by relatively little change in turgor pressure.



Aquaporins facilitate the movement of water across cell membranes

The water potential concept helps us evaluate the water status of a plant

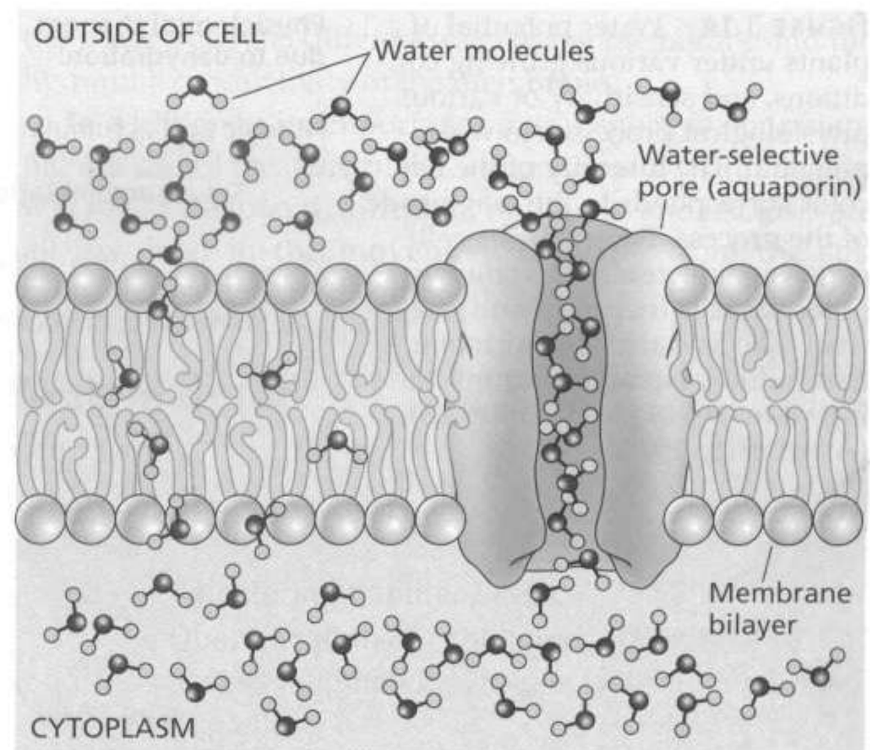


FIGURE 3.13 Water can cross plant membranes by diffusion of individual water molecules through the membrane bilayer, as shown on the left, and by the linear diffusion of water molecules through a water-selective pore formed by integral membrane proteins such as aquaporins.

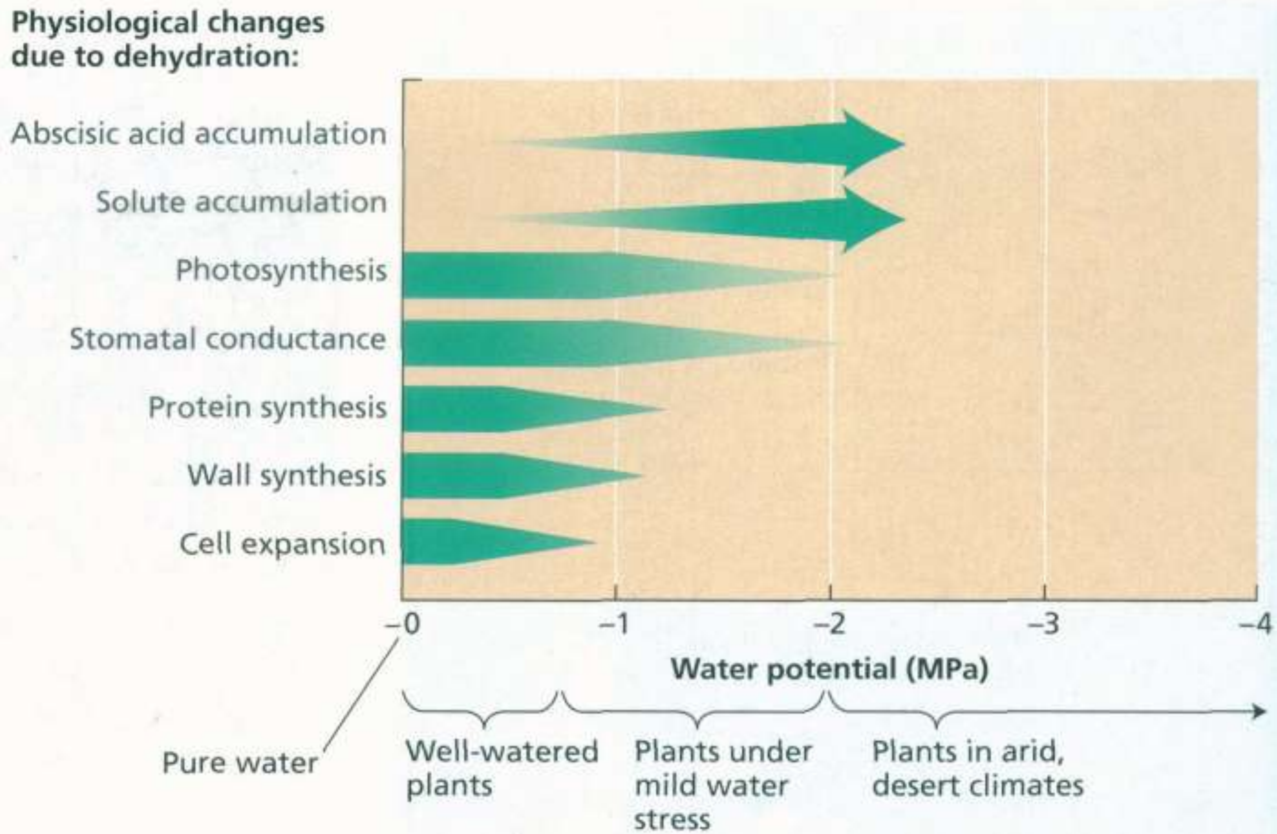
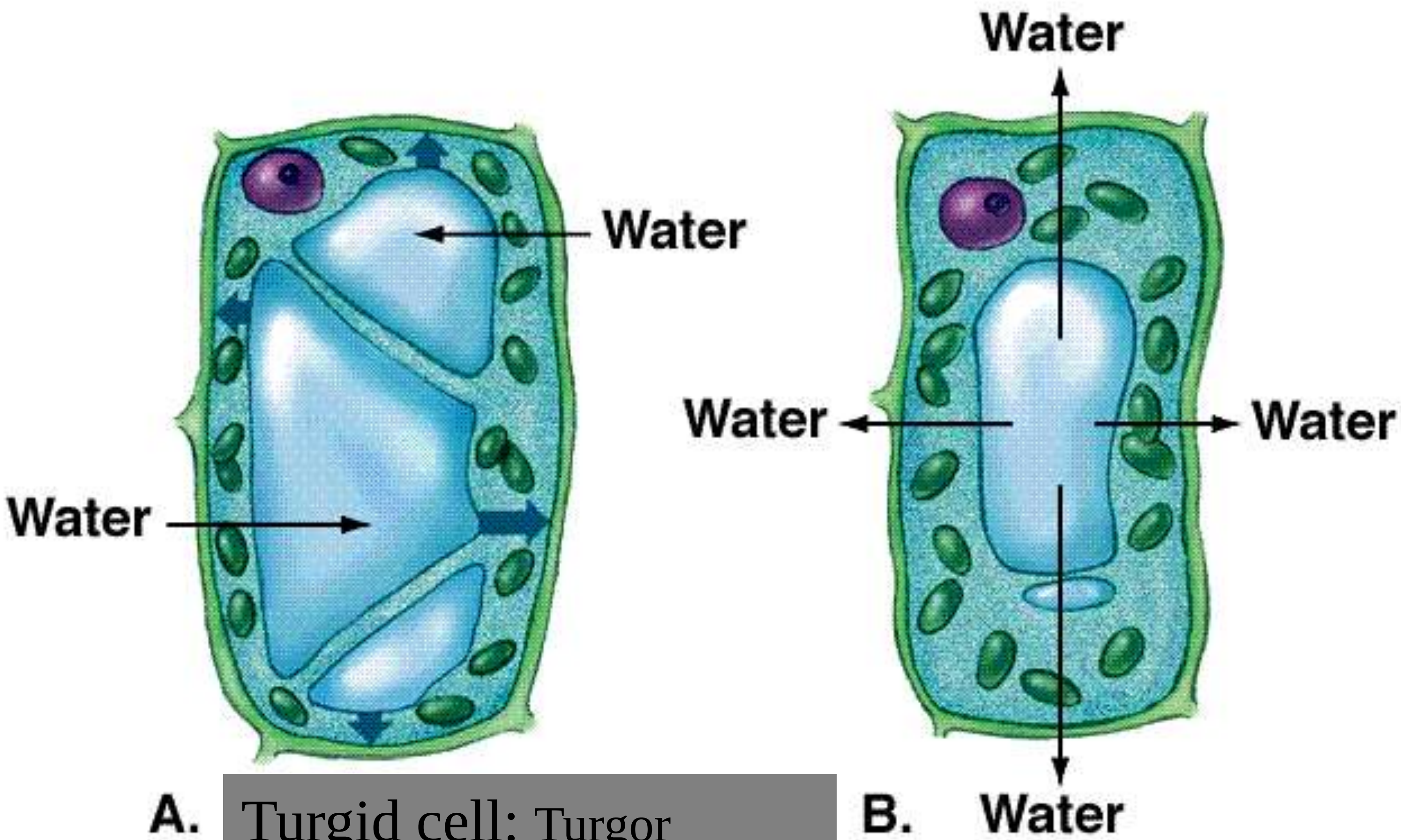


FIGURE 3.14 Water potential of plants under various growing conditions, and sensitivity of various physiological processes to water potential. The intensity of the bar color corresponds to the magnitude of the process. For example, cell expansion decreases as water potential falls (becomes more negative). Abscisic acid is a hormone that induces stomatal closure during water stress (see Chapter 23). (After Hsiao 1979.)

- **The components of water potential vary with growth conditions and location within the plant**

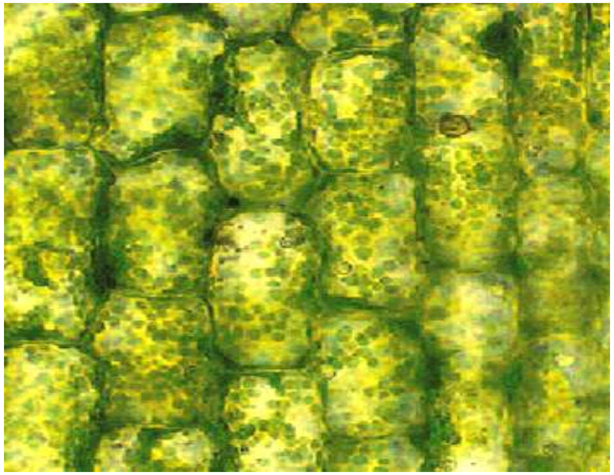
Turgor Pressure in a Cell



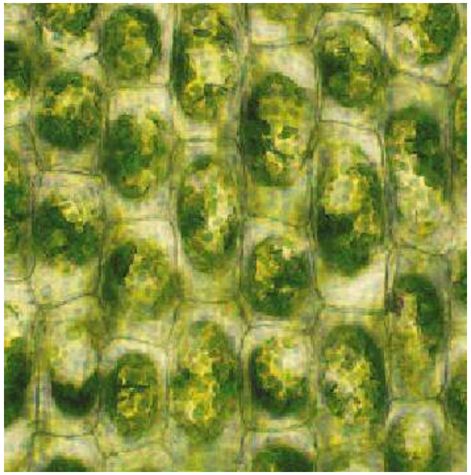
Turgid cell: Turgor pressure is pushing the cell content against the wall

Water has left the cell and turgor pressure has dropped

Plasmolysis is the shrinkage of the cytoplasm away from the cell wall as a result of osmosis taking place when the water potential inside the cell is greater than outside.



Normal cells

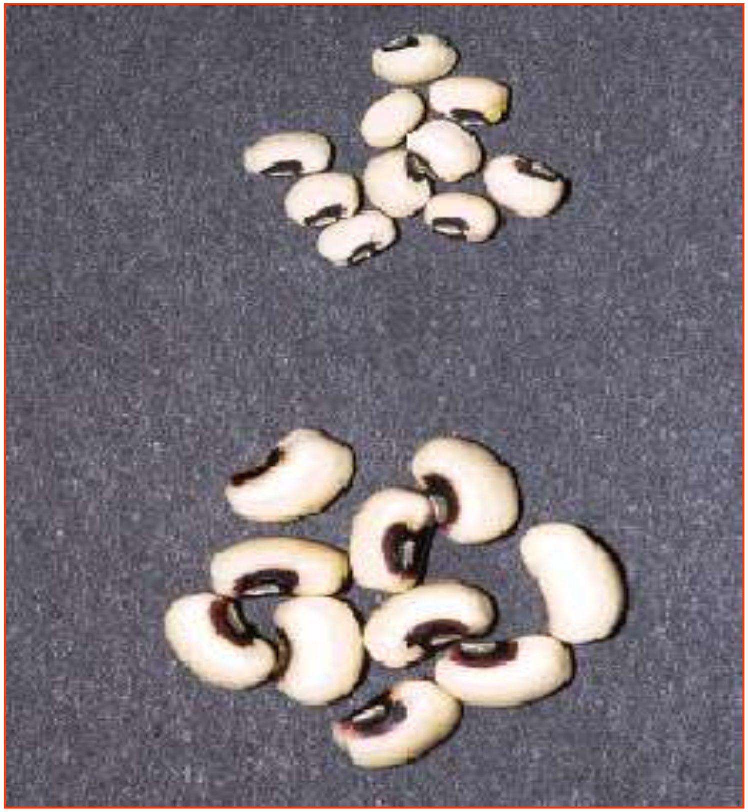


Plasmolyzed

Leaf of water weed *Elodea*

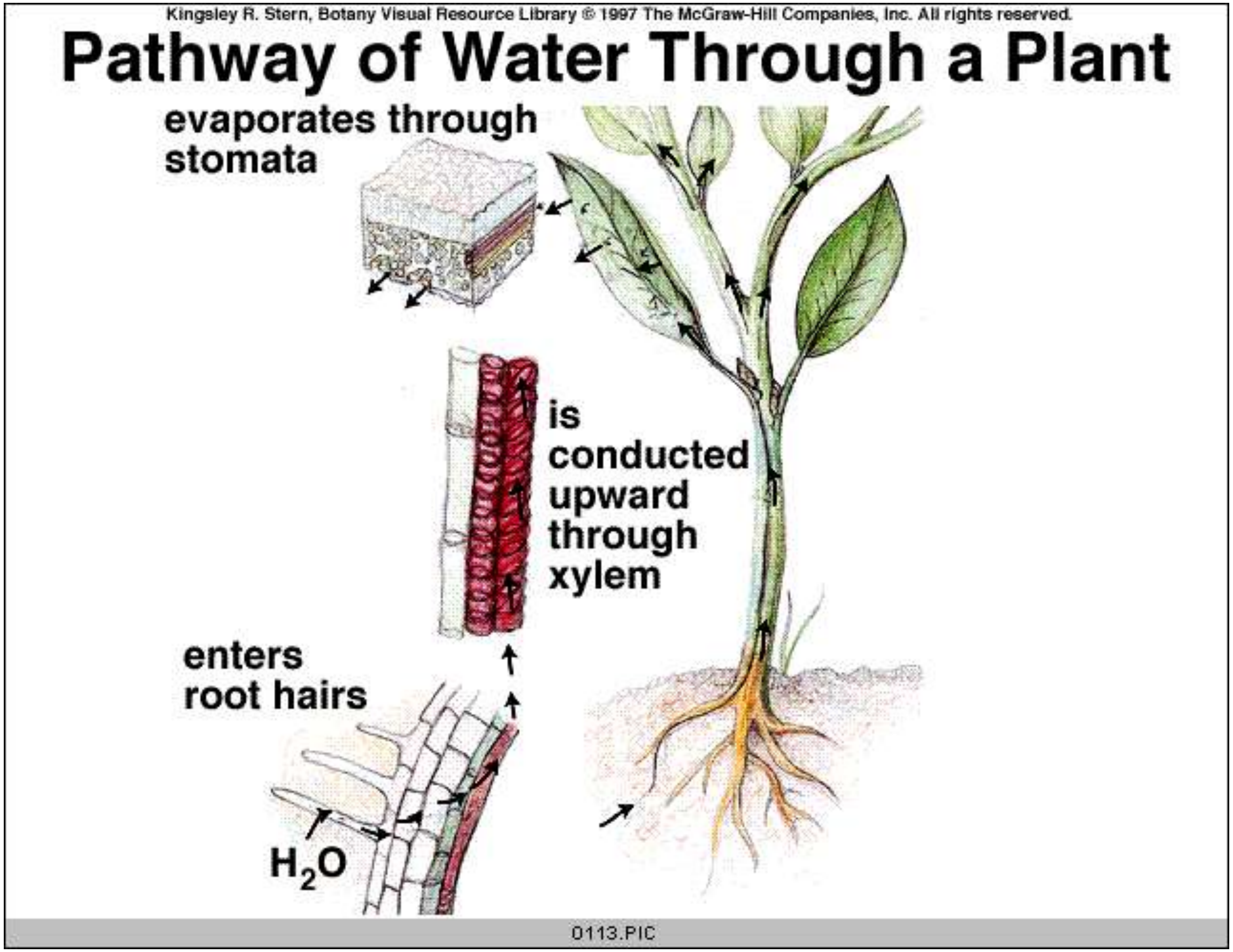
Imbibition is the attraction and adhesion of water molecules to the internal surfaces of materials; it results in swelling and it is the initial step in the germination of seeds.

* Water molecules are polar so they become adhesive to large organic molecules such as cellulose and cohesive with one another.



Before imbibition

After imbibition



* The exposed surface of the mesophyll cells within the leaf have to be moist at all time. Wilting occurs if the transpiration is more than water taken by the root.

Water moves in the root via the apoplast, symplast, and transmembrane pathways

- In the soil, water is transported to the root surface predominantly by bulk flow.
- From the epidermis to the endodermis of the root, there are three pathways through which water can flow: the **apoplast, symplast, and transmembrane** pathways.

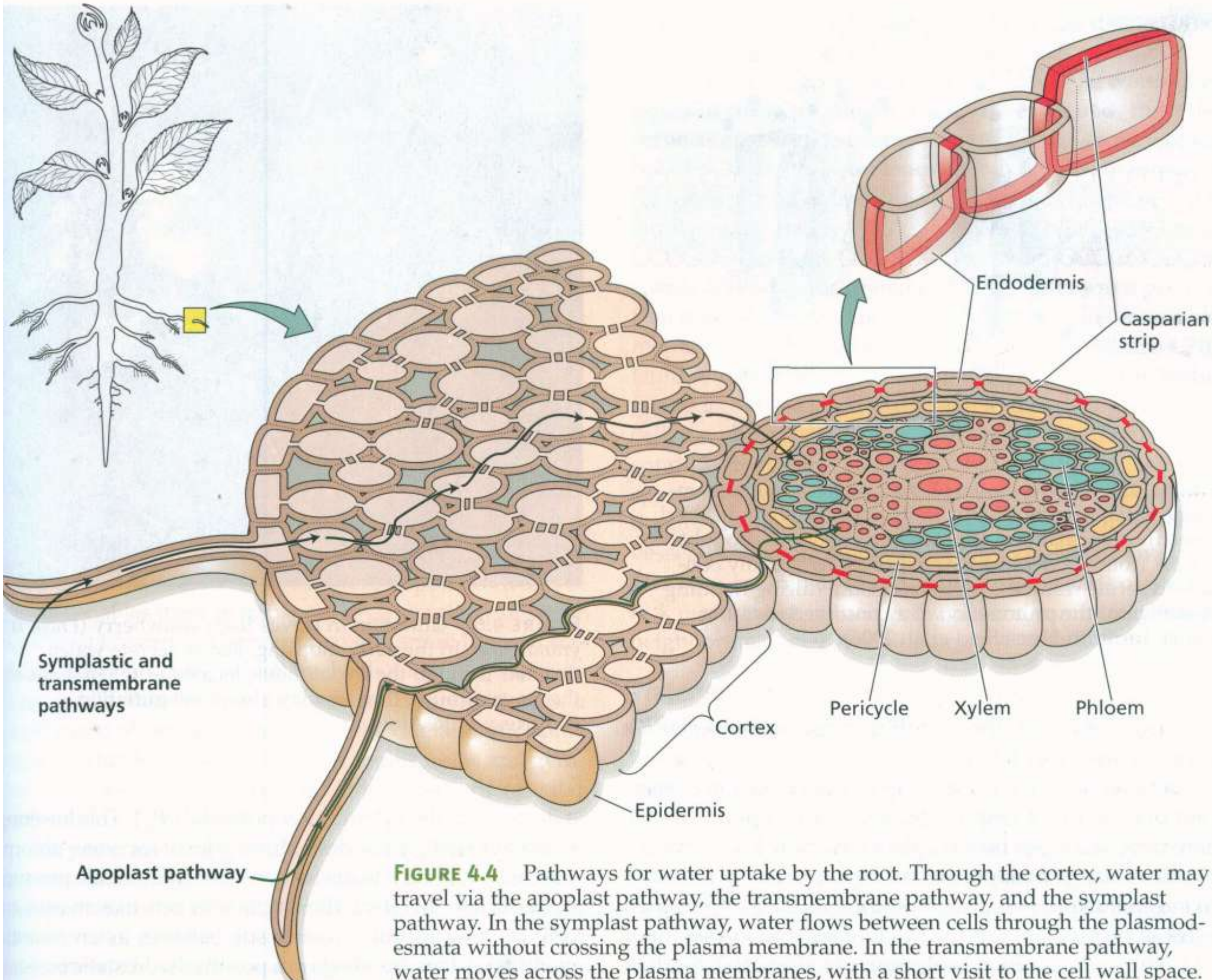


FIGURE 4.4 Pathways for water uptake by the root. Through the cortex, water may travel via the apoplast pathway, the transmembrane pathway, and the symplast pathway. In the symplast pathway, water flows between cells through the plasmodesmata without crossing the plasma membrane. In the transmembrane pathway, water moves across the plasma membranes, with a short visit to the cell wall space. At the endodermis, the apoplast pathway is blocked by the Casparian strip.

1. **The apoplast** is the continuous system of cell walls, intercellular air spaces, and lumen of cells that have lost their cytoplasm (e.g., xylem conduits and fibers).

- In the apoplast pathway, water moves through cell walls and any water-filled extracellular spaces (i.e, without crossing any membranes) as it travels across the root cortex.

2. The symplast consists of the entire network of cell cytoplasm interconnected by plasmodesmata.

- In the symplast pathway, water travels across the root cortex by passing from one cell to the next via the plasmodesmata.
- Because water movement in both the apoplast and symplast pathways does not have to cross any semipermeable membranes, the relevant driving force for mass flow is the gradient in hydrostatic pressure.

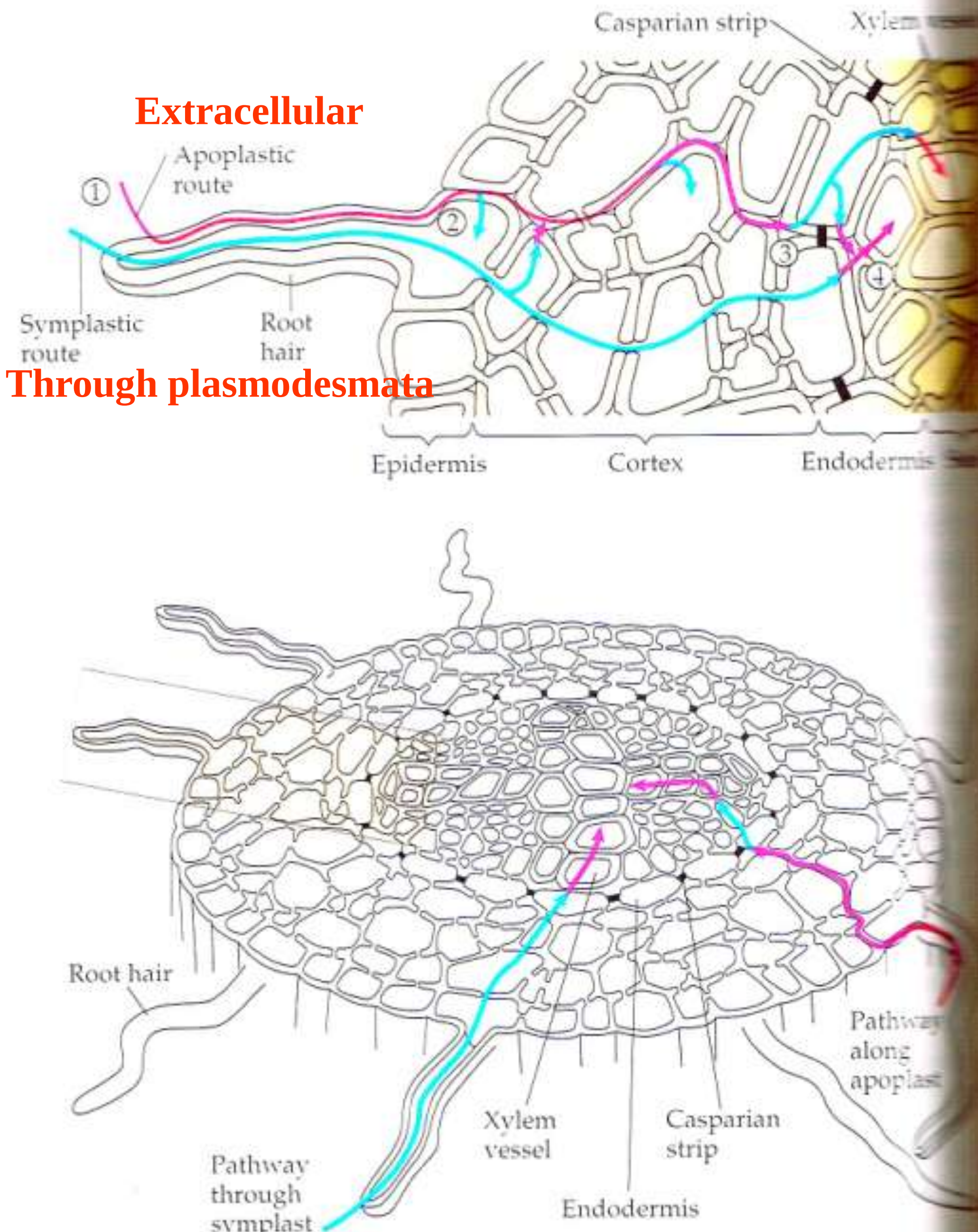
3. The transmembrane pathway is the route followed by water that sequentially enters a cell on one side, exits the cell on the other side, enters the next in the series, and so on.

- In this pathway, water crosses at least two membranes for each cell in its path .
- In the transmembrane pathway, the presence of semipermeable membranes means that the relevant driving force is the total water potential gradient.

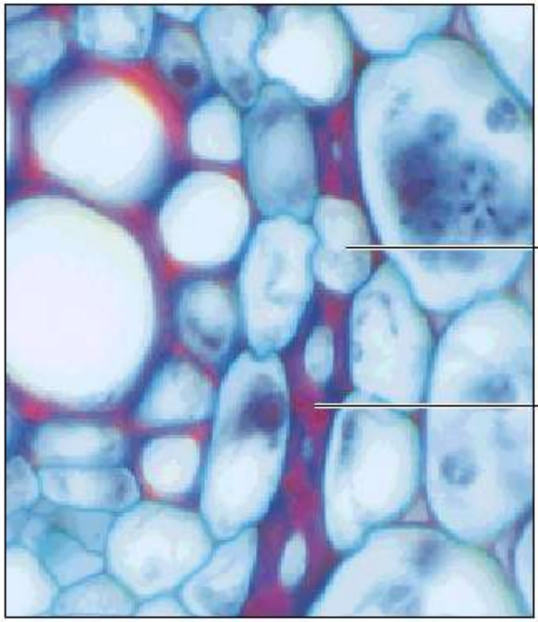
- At the endodermis, water movement through the apoplast pathway is obstructed by the Casparian strip
- The **Casparian strip** is a band of radial cell walls in the endodermis that is impregnated with the wax-like, hydrophobic substance **suberin.**
- Suberin acts as a barrier to water and solute movement.
- The Casparian strip breaks the continuity of the apoplast pathway, forcing water and solutes to cross the endodermis by passing through the plasma membrane

FIGURE 32.6

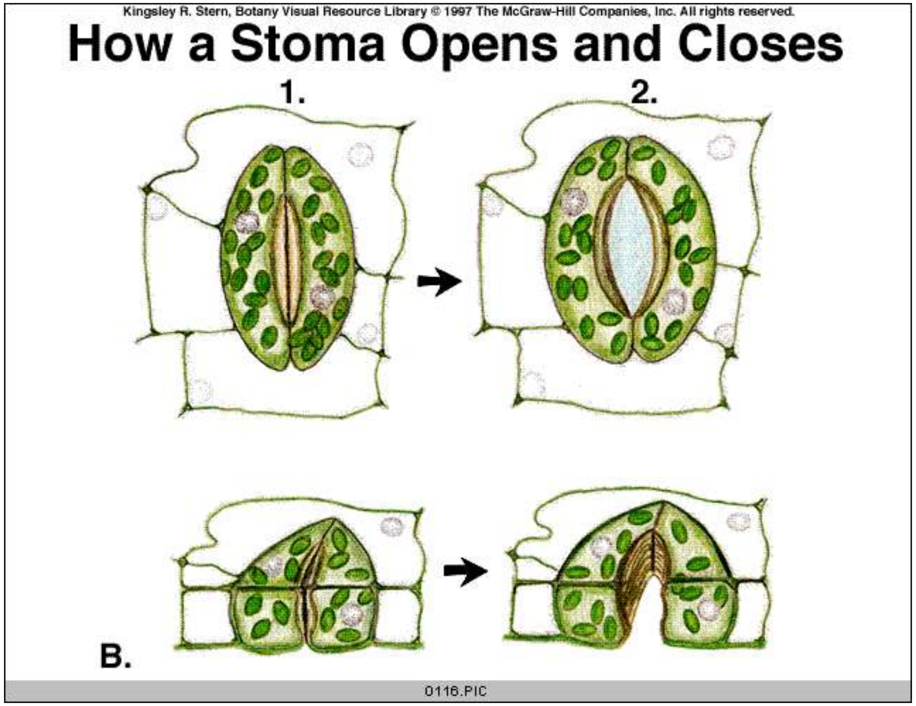
Lateral transport of minerals and water in roots. Minerals are absorbed with the soil solution by the root surface, especially by root hairs. The water and minerals then move across the root cortex to the vascular cylinder by a combination of the apoplastic and symplastic routes (see FIGURE 32.5). ① The uptake of soil solution by the hydrophilic walls of the epidermis provides access to the apoplast, and water and minerals can soak into the cortex along this matrix of cell walls. Minerals and water that cross the plasma membranes of root hairs enter the symplast. ② As soil solution moves along the apoplast, some water and minerals are transported into cells of the epidermis and cortex and then move inward via the symplast. ③ Water and minerals that move all the way to the endodermis along cell walls cannot continue into the stele via the apoplastic route. Within the wall of each endodermal cell is a belt of waxy material (black band) that blocks the passage of water and dissolved minerals. This barrier to apoplastic transport is called the Casparian strip. Only minerals that are already in the symplast or enter that pathway by crossing the plasma membrane of an endodermal cell can detour around the Casparian strip and pass into the stele. Thus, the transport of minerals into the stele is selective; only those minerals that are admitted into cells by membranes gain access to the vascular tissue. ④ Endodermal cells, and parenchyma cells within the stele, discharge water and minerals into their walls, which, as part of the apoplast, are continuous with the xylem vessels. Water and minerals absorbed from soil are now ready for upward transport into the shoot system.



The water and solutes can travel across the epidermis and cortex via the cell walls until they reach the endodermis. There the water and solutes are forced by ***Casparian strips*** to cross the cytoplasm of the endodermal cells on their way to the vessels and tracheids of the xylem.



* The stomatal apparatus regulate transpiration and gas exchange. Its closed when turger pressure is low and open when turgor pressure is high. During photosynthesis, guard cells expend energy to acquire potassium ions from adjacent cells, this lowered water potential in guard cells leading to the opening of the stomatal pores. When photosynthesis is not occurring the potassium ions leave, guard cells are less turgid and the stomatal pores close



When turgor pressure in the guard cells increases, they swell, the thinner outer walls stretch more than the thicker inner walls causing the stomatal pore to open.

•**Transpiration is regulated by temperature, humidity (water vapor in the atmosphere) and the stomatal pores**, which open and close through changes in turgor pressure of the guard cells. These changes, which involve potassium ions, result from osmosis and active transport between the guard cells and the adjacent epidermal cells. High humidity reduces transpiration, while high temperature increases transpiration.

Chapter 2

Whole plant water relations

2.1 Transpiration is driven by differences in vapor pressure

- **Transpiration:** Loss of water from plants through stomata (or lenticels) in the form of water vapor.
- Plant leaves are covered with multilayered waxy layer called **cuticle.**
- **Cuticle** restrict evaporation of water directly from the outer surfaces of leaf epidermal cells and protects both the epidermal and mesophyll cells from desiccation.

- **Stomata:** small pores surrounded by pair of guard cells that control their size.
- Stomata provide a rout for exchange of gasses mainly carbon dioxide, oxygen and water vapor) between the internal air space and the surrounding atmosphere.
- Diffusion of water vapor can occur through:
  - **Stomatal transpiration (90% -95%)**
  - **Cuticular transpiration (5% -10%)**(species dependent), important for leaves with thin cuticle, under dry conditions and stomata closed.

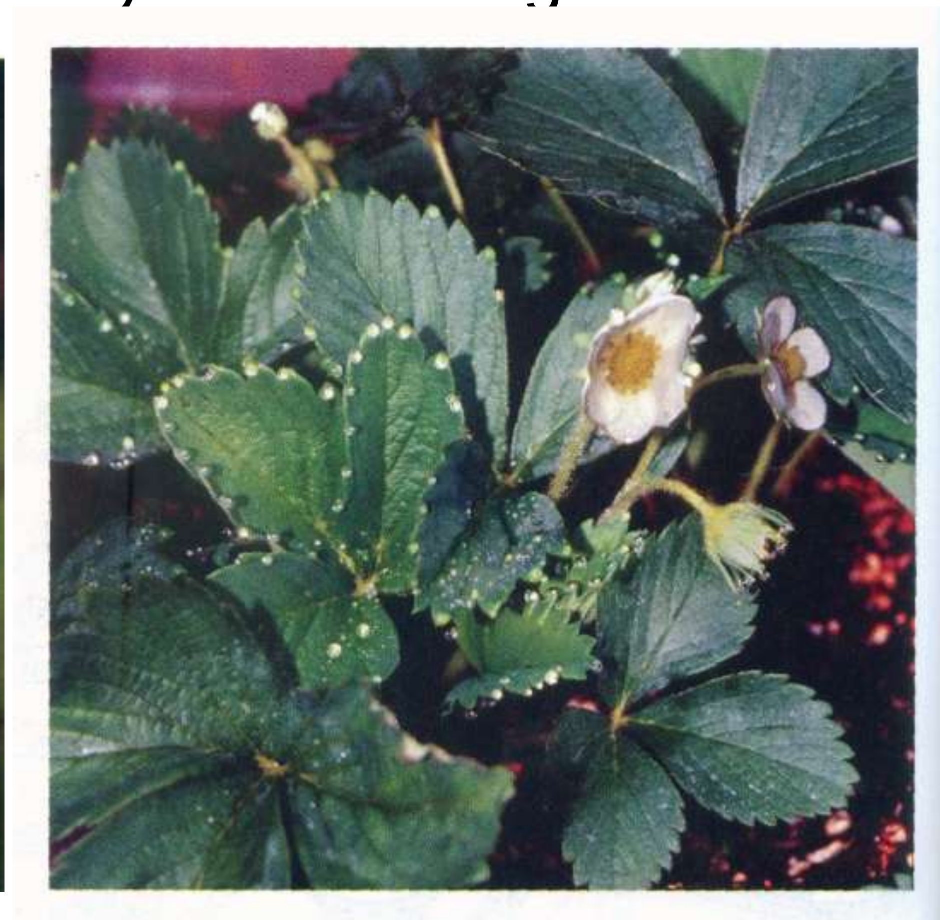
Water that enters a plant passes through it and mostly (90%) transpires into the atmosphere via stomatal pores. About 5% of the water escaping through the cuticle. Water retained by the plant is used in photosynthesis (~ 1%) and other metabolic activities.

E. g. A corn plant transpire about 15 L/week

Guttation is the loss of water at night (cool night after a warm humid day) in liquid form through **hydathodes** at the tips of leaf veins.

Droplets of guttation water at the tips of young barley leaves.

- Guttation in leaves from strawberry In the early morning, leaves secrete water droplets through the **hydathodes**, located at the margins of the leaves. Young flowers may also show guttation.



2.2 The driving force of transpiration is differences in vapor pressure

- Transpiration can be measured by:
  - Weight loss
  - gas exchange

The driving force of transpiration

- Water movement determined by differences in water potential.
- **Vapor density** (g/m^3).
- **Vapor pressure (Pa),** influenced by solute concentration (mole fraction) and temperature (water kinetic energy).
- Water vapor diffuse from a region of high vapor pressure to a region of low vapor pressure.

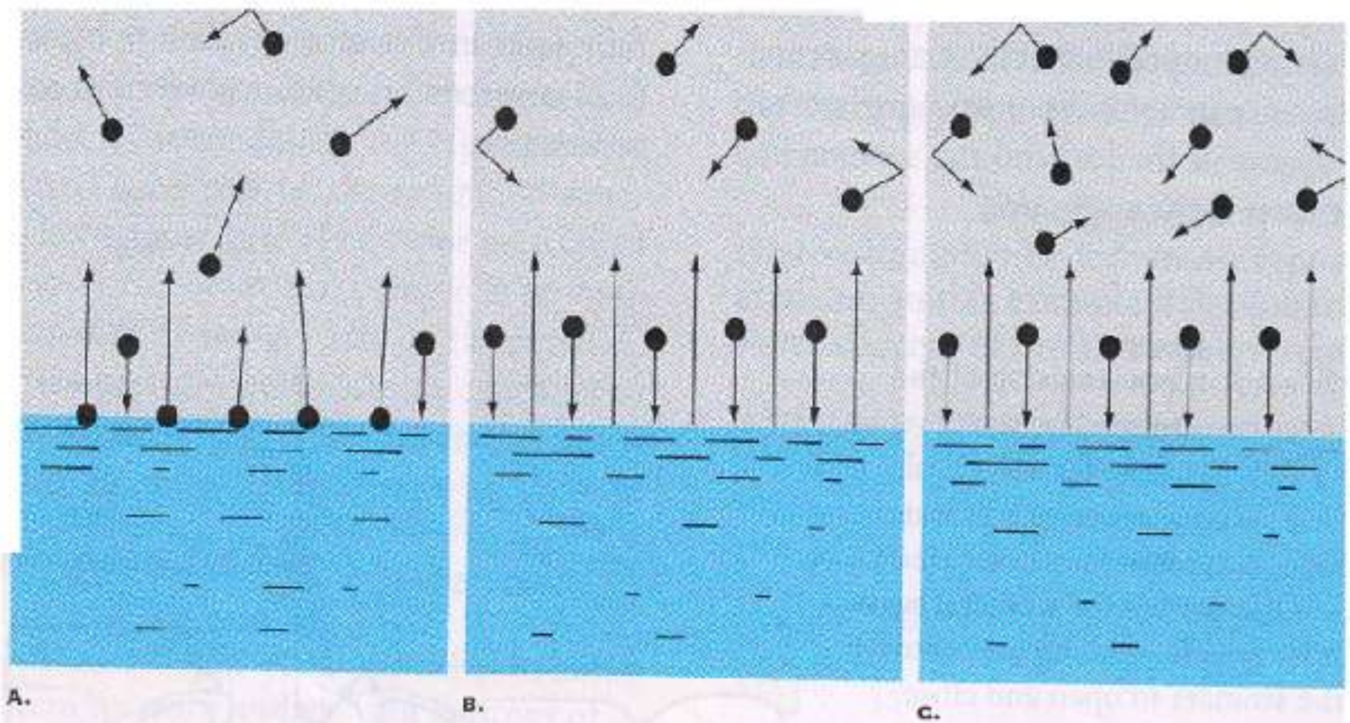


FIGURE 2.2 Vapor pressure in a closed container. Initially (*A*), more molecules escape from the water surface than condense, filling the air space with water vapor molecules. The vaporous water molecules exert pressure—vapor pressure—against the walls of the chamber and the water surface. At equilibrium (*B*) the rate of condensation equals evaporation and the air is saturated with water vapor. The vapor pressure when the air is saturated is known as the saturation vapor pressure. At higher temperature (*C*), a higher proportion of water molecules have sufficient energy to escape. Both the concentration of water molecules in the vapor phase and the saturation vapor pressure are correspondingly higher.

2.3 the rate of transpiration is influenced by environmental factors

- Substomatal air space of a leaf is normally saturated or nearly saturated with water vapor.
- This create a gradient between the high water vapor pressure interior of the leaf and lower water vapor pressure of the external atmosphere.
- The difference is the driving force for transpiration

- Transpiration rate naturally influenced by:
  - Humidity
  - Temperature
  - Wind speed

$T \propto e_{leaf} - e_{air}$

$$T = \frac{e_{leaf} - e_{air}}{r_{air} + r_{leaf}}$$

e = vapor pressure
r = resistance

Boundry layer: a layer of undisturbed air on the surface of the leaf

2.3.1 Effect of humidity

- **Humidity**: the actual water content of air expressed as vapor density (g m^{-3}). Or vapor pressure kPa.
- **Relative humidity**: ratio of the actual water content of air to the maximum amount of water can be held by air at that temperature. (ratio of actual vapor pressure to the saturation vapor pressure). Expressed as RH X 100
- how humidity affects transpiration in plants?

Effect of humidity and temperature on the vapor pressure

Table 2.1 Water vapor pressure (kPa) in air

	Relative Humidity				
Temp.	100%	80%	50%	20%	10%
30	4.24	3.40	2.21	0.85	0.42
20	2.34	1.87	1.17	0.47	0.23
10	1.23	0.98	0.61	0.24	0.12

Relative humidity and temperature have significant effect on the water potential of air

Table 2.2 Water potential (ψ) as a function of RH at 20 ^{o}C

RH (%)	Ψ (MPa)
100	0
95	-6.9
90	-14.2
50	-93.5
20	-217.1

2.3.2 what is the effects of temperature

- TABLE 2.3. The effect of temperature and relative humidity On leaf-to-air vapor pressure gradient.

Leaf	Atmosphere	$e_{leaf} - e_{air}$
(A) T= 10 ^oC e= 1.2 kPa RH = 100%	T= 10 ^oC e= 0.61 kPa RH = 50%	0.61
(B) T= 20 ^oC e= 2.34 kPa RH = 100%	T= 20 ^oC e= 0.61 kPa RH = 26%	1.73
(C) T= 30 ^oC e= 4.24 kPa RH = 100%	T= 20 ^oC e= 0.61 kPa RH = 26%	3.63

As long as the stomata remain open and the vapor pressure gradient exists between the leaf and atmosphere, water vapor will diffuse out of the leaf.

2.3.3 what is the effect of wind

- Wind speed modifies the effective length of the diffusion path of water molecules and the boundary layer.
- Thickness of the boundary layer is a function of:
  – leaf size and shape,
  – the presence of trichomes
  – and wind speed.
- Wind speed cool the leaf and cause sufficient desiccation to close the stomata (wind have less effect on transpiration rate than expected depending on the boundary layer.)

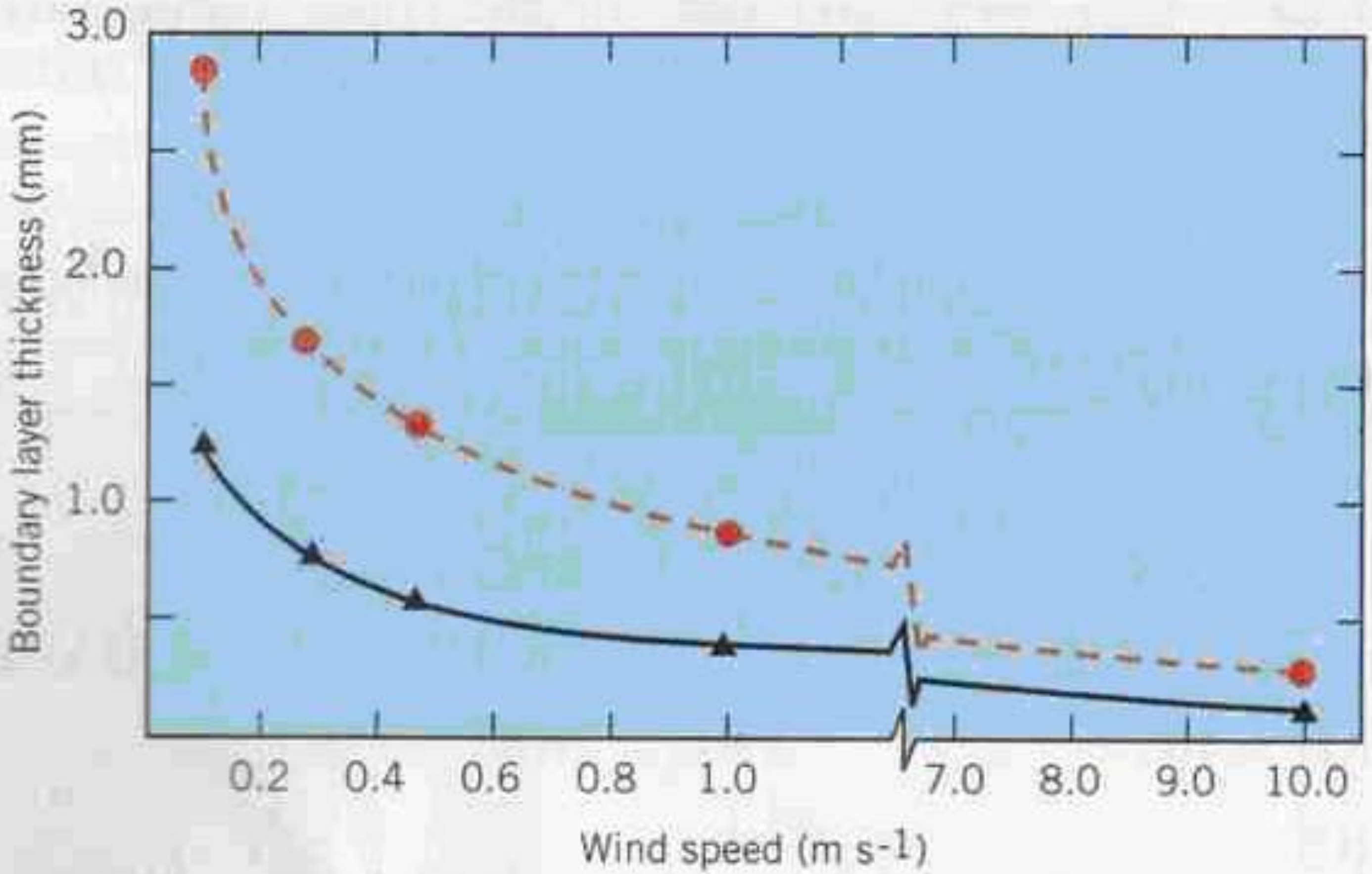


FIGURE 2.4 The impact of wind speed on calculated boundary layer thickness for leaves 1.0 cm (triangles) or 5.0 cm (circles) wide. A wind speed of 0.28 m s^{-1} = 1 km hr^{-1}. (Plotted from the data of Nobel, 1991.)

Ch 10

Photosynthesis

Tracking Atoms Through Photosynthesis: *Scientific Inquiry*

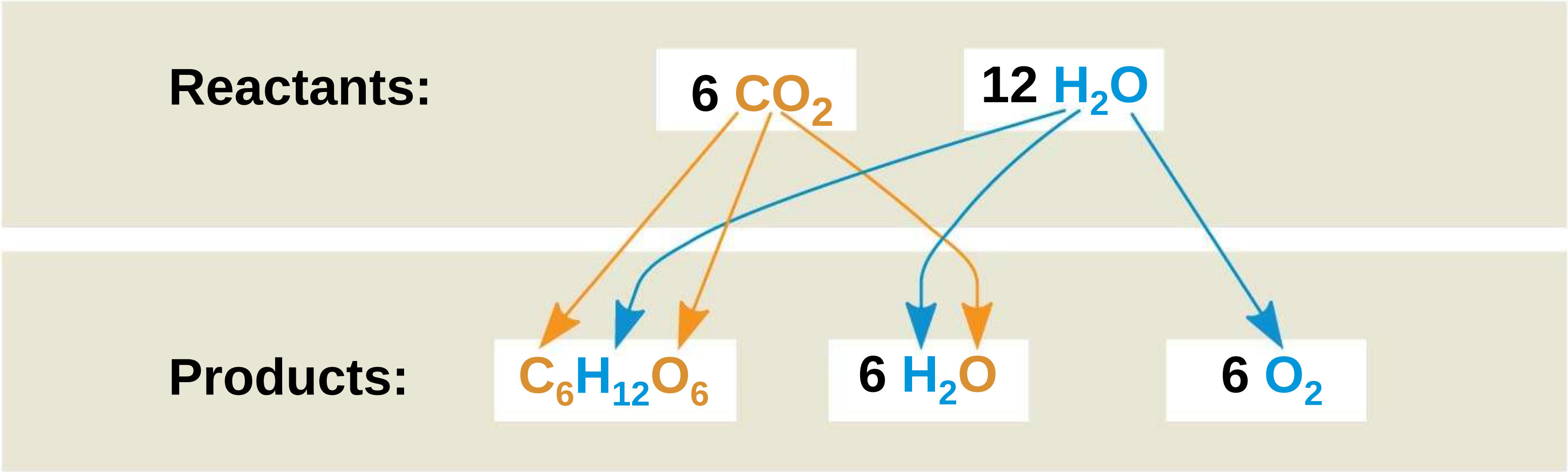
- Photosynthesis can be summarized as the following equation:

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

The Splitting of Water

- Chloroplasts split H_2O into hydrogen and oxygen, incorporating the electrons of hydrogen into sugar molecules

Fig. 10-4



Photosynthesis as a Redox Process

- Photosynthesis is a redox process in which H_2O is oxidized and CO_2 is reduced

The Two Stages of Photosynthesis: *A Preview*

- Photosynthesis consists of the **light reactions** (the *photo* part) and **Calvin cycle** (the *synthesis* part)
- The light reactions (in the thylakoids):
  - Split H_2O
  - Release O_2
  - Reduce **NADP⁺** to NADPH
  - Generate ATP from ADP by **photophosphorylation**

- The Calvin cycle (in the stroma) forms sugar from CO_2, using ATP and NADPH
- The Calvin cycle begins with **carbon fixation**, incorporating CO_2 into organic molecules

Fig. 10-5-1

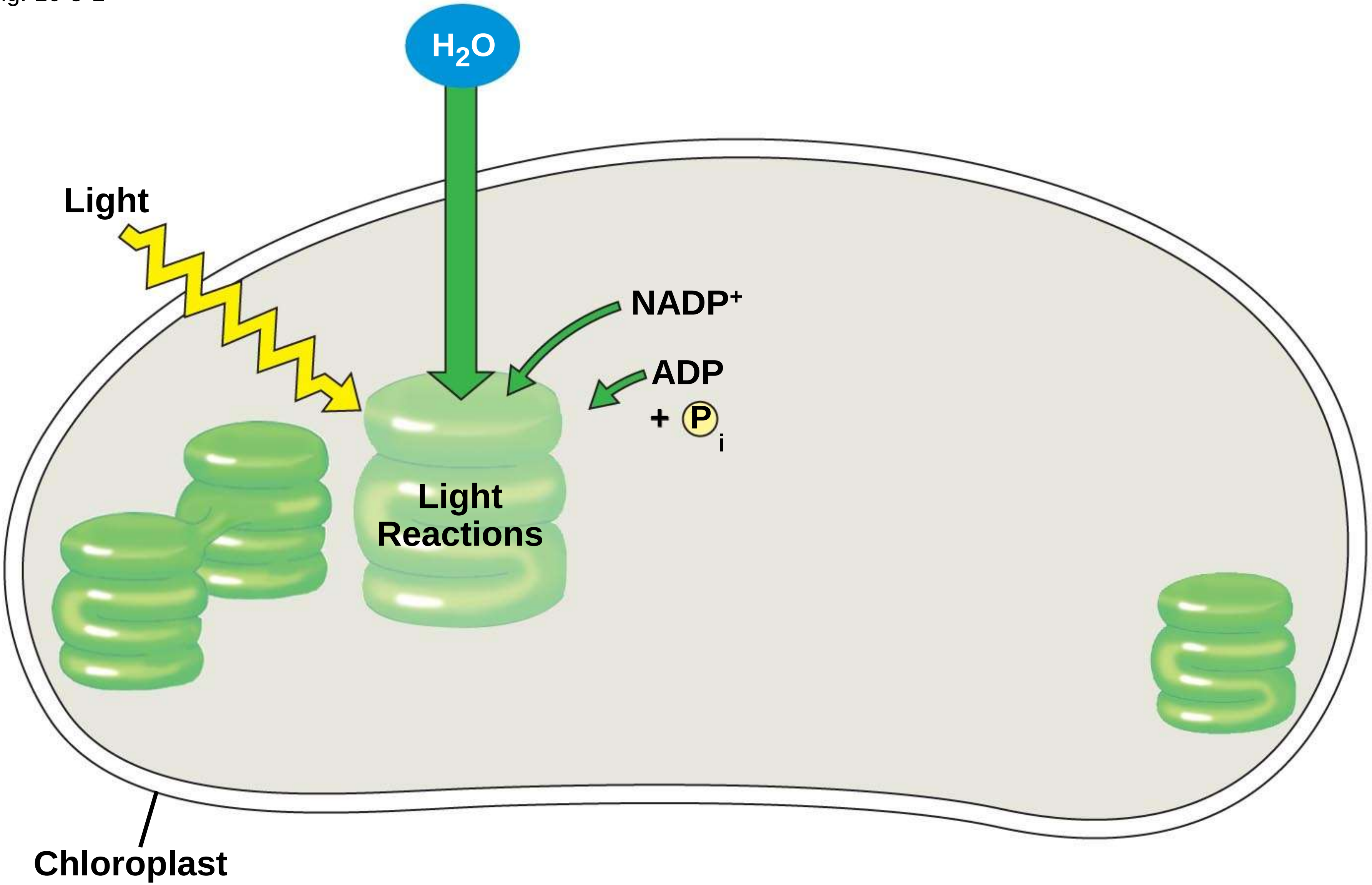


Fig. 10-5-2

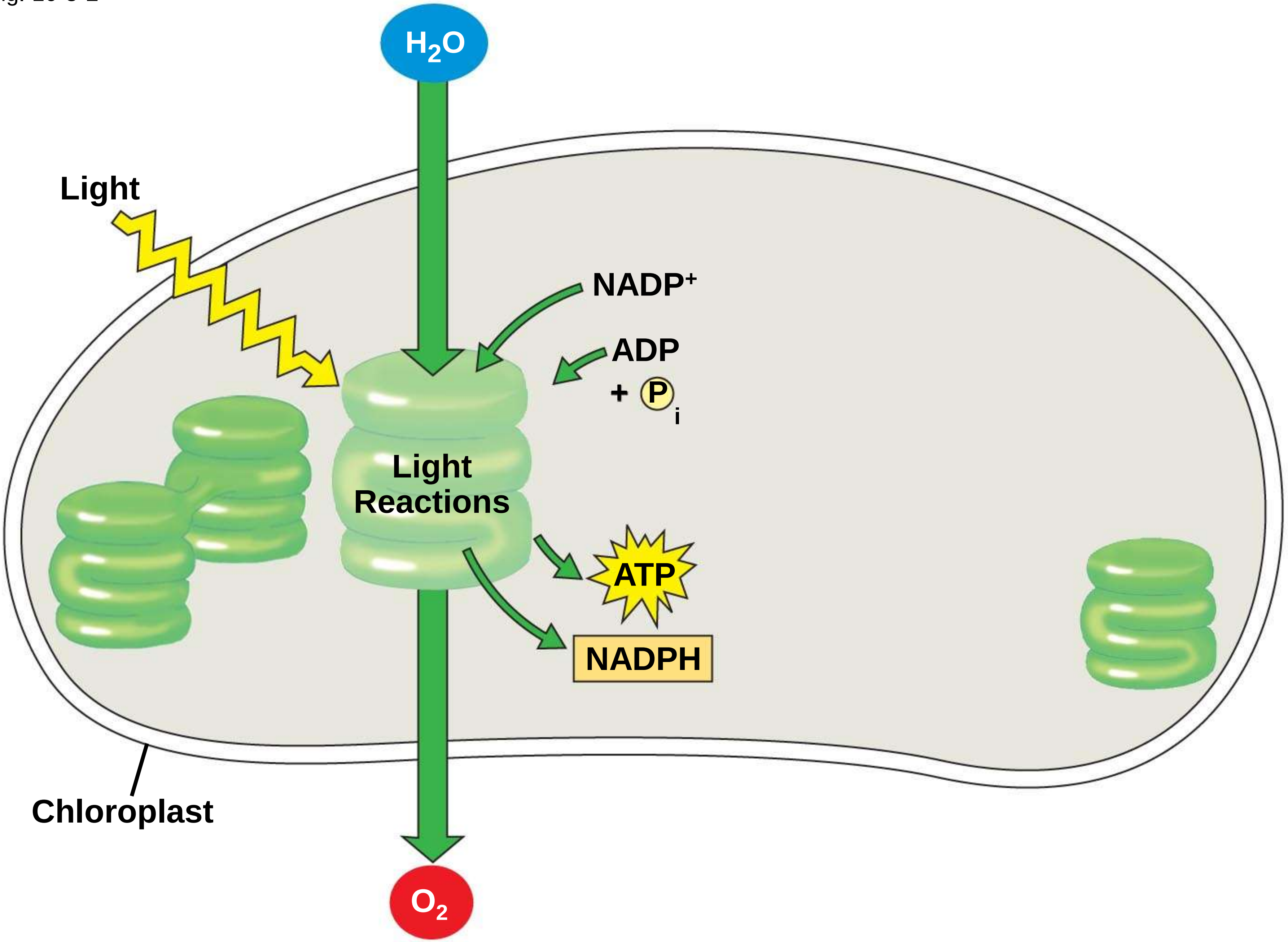
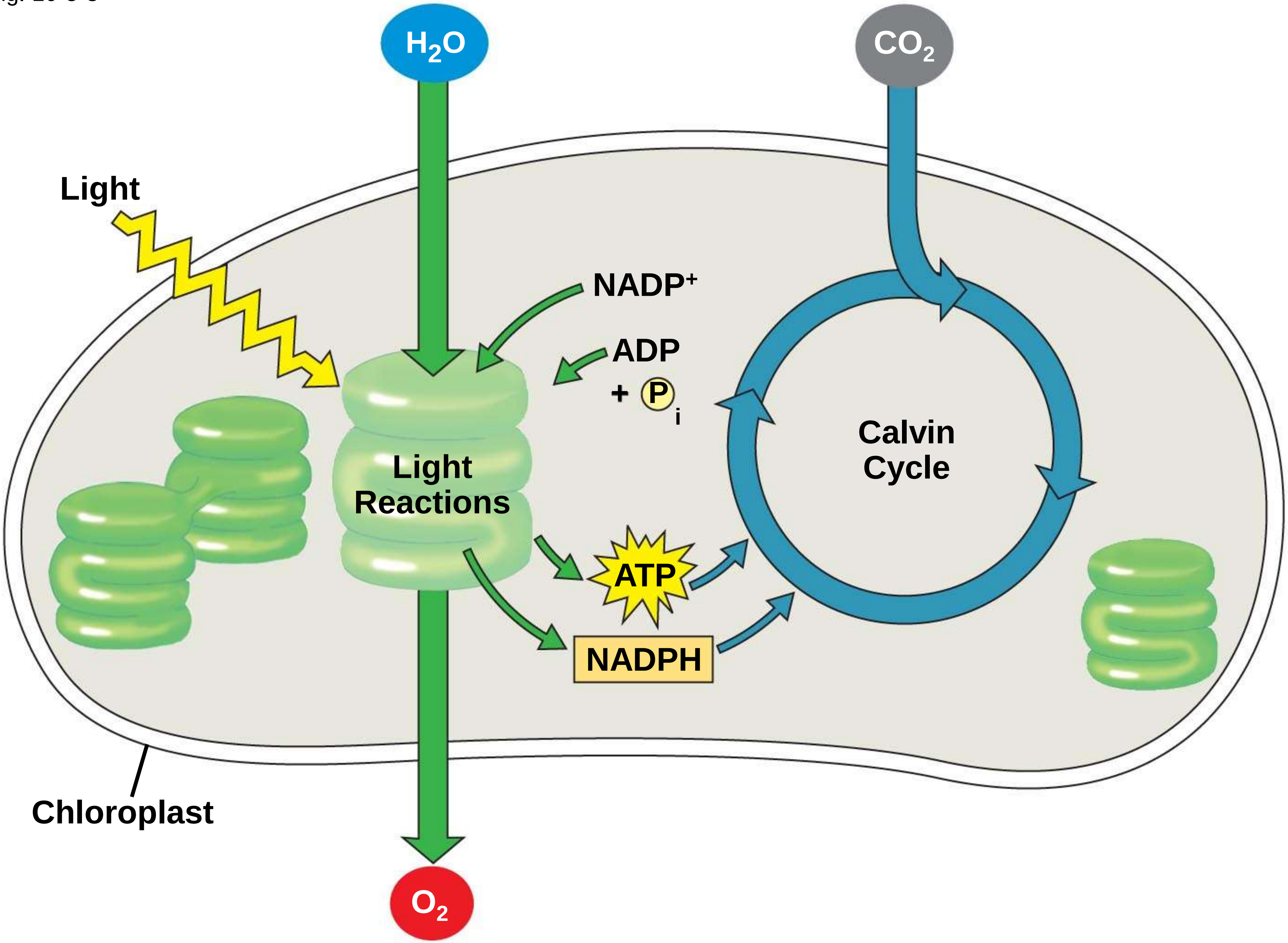
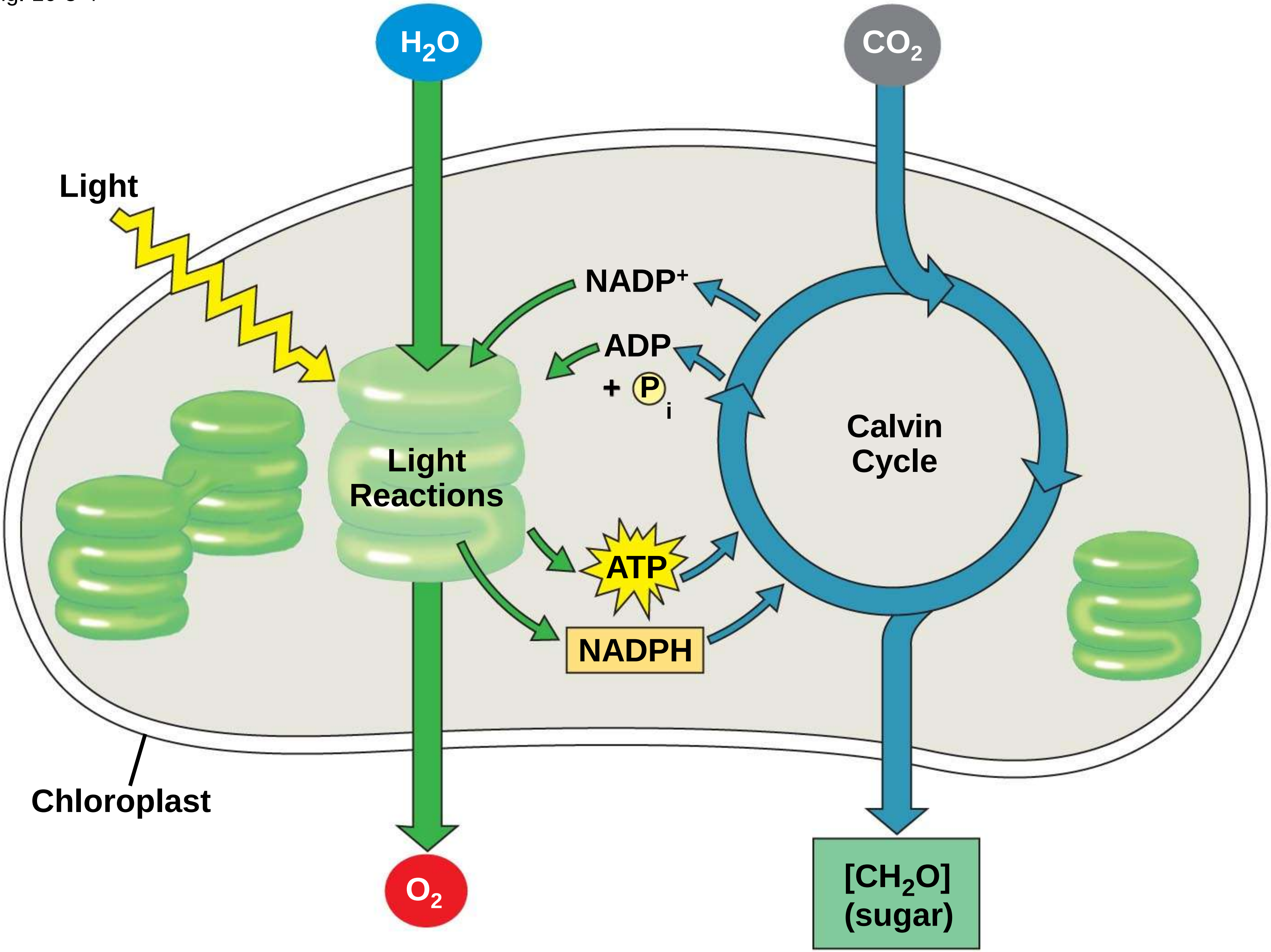

H_2O
Light
$NADP^+$
ADP
+ P_i
Light Reactions
ATP
NADPH
Chloroplast
O_2

Fig. 10-5-3



H_2O
CO_2
Light
$NADP^+$
ADP
+ P i
Light Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2

Fig. 10-5-4



H_2O
CO_2
Light
NADP+
ADP
+ P i
Light Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2
$[CH_2O]$ (sugar)

Concept 10.2: The light reactions convert solar energy to the chemical energy of ATP and NADPH

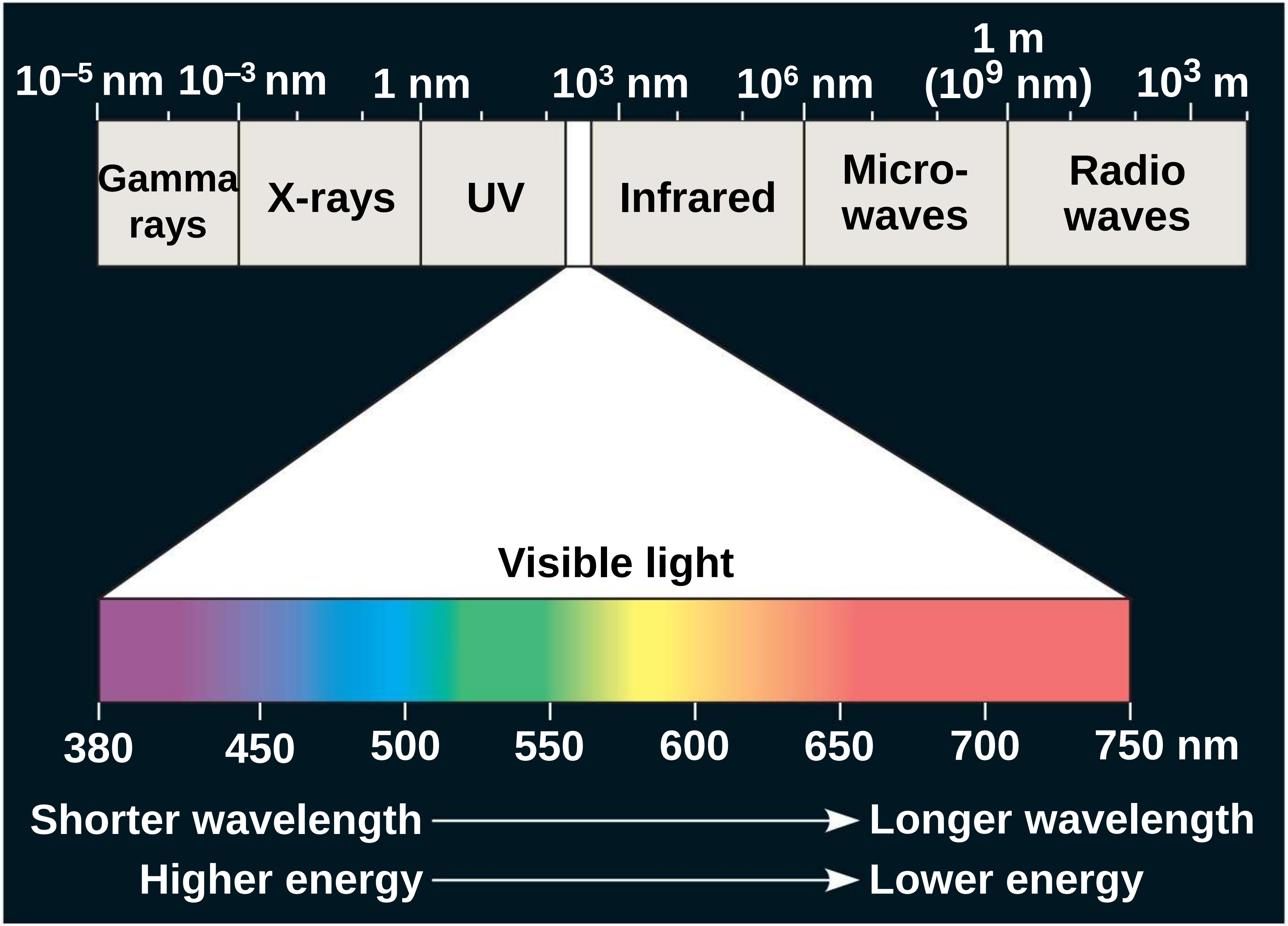
- Chloroplasts are solar-powered chemical factories
- Their thylakoids transform light energy into the chemical energy of ATP and NADPH

The Nature of Sunlight

- Light is a form of electromagnetic energy, also called electromagnetic radiation
- Like other electromagnetic energy, light travels in rhythmic waves
- **Wavelength** is the distance between crests of waves
- Wavelength determines the type of electromagnetic energy

- The **electromagnetic spectrum** is the entire range of electromagnetic energy, or radiation
- **Visible light** consists of wavelengths (including those that drive photosynthesis) that produce colors we can see
- Light also behaves as though it consists of discrete particles, called **photons**

Fig. 10-6

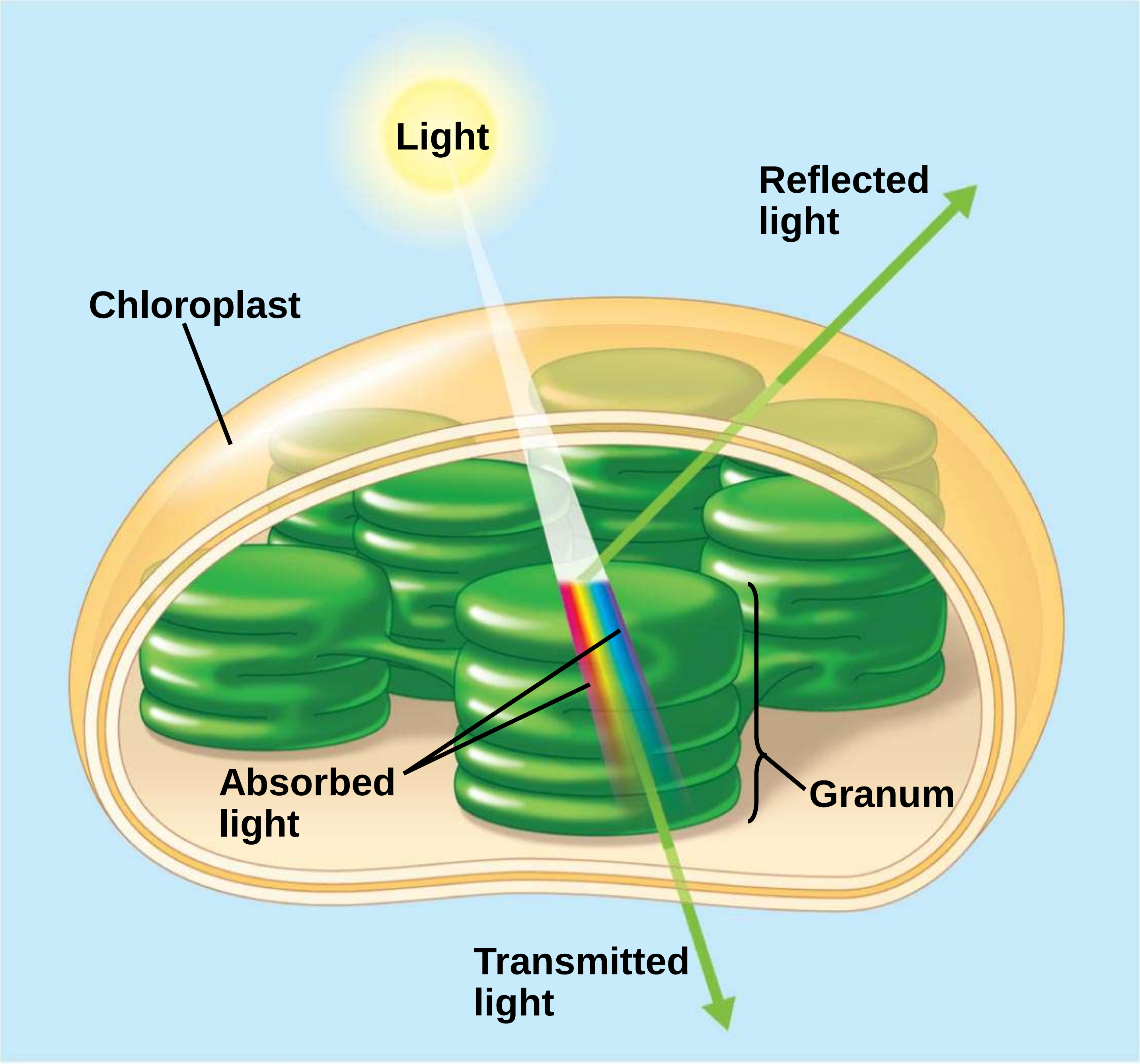


10^{-5} nm
10^{-3} nm
1 nm
10^{3} nm
10^{6} nm
1 m (10^{9} nm)
10^{3} m
Gamma rays
X-rays
UV
Infrared
Micro-waves
Radio waves
Visible light
380
450
500
550
600
650
700
750 nm
Shorter wavelength
Longer wavelength
Higher energy
Lower energy

Photosynthetic Pigments: The Light Receptors

- Pigments are substances that absorb visible light
- Different pigments absorb different wavelengths
- Wavelengths that are not absorbed are reflected or transmitted
- Leaves appear green because chlorophyll reflects and transmits green light

Fig. 10-7

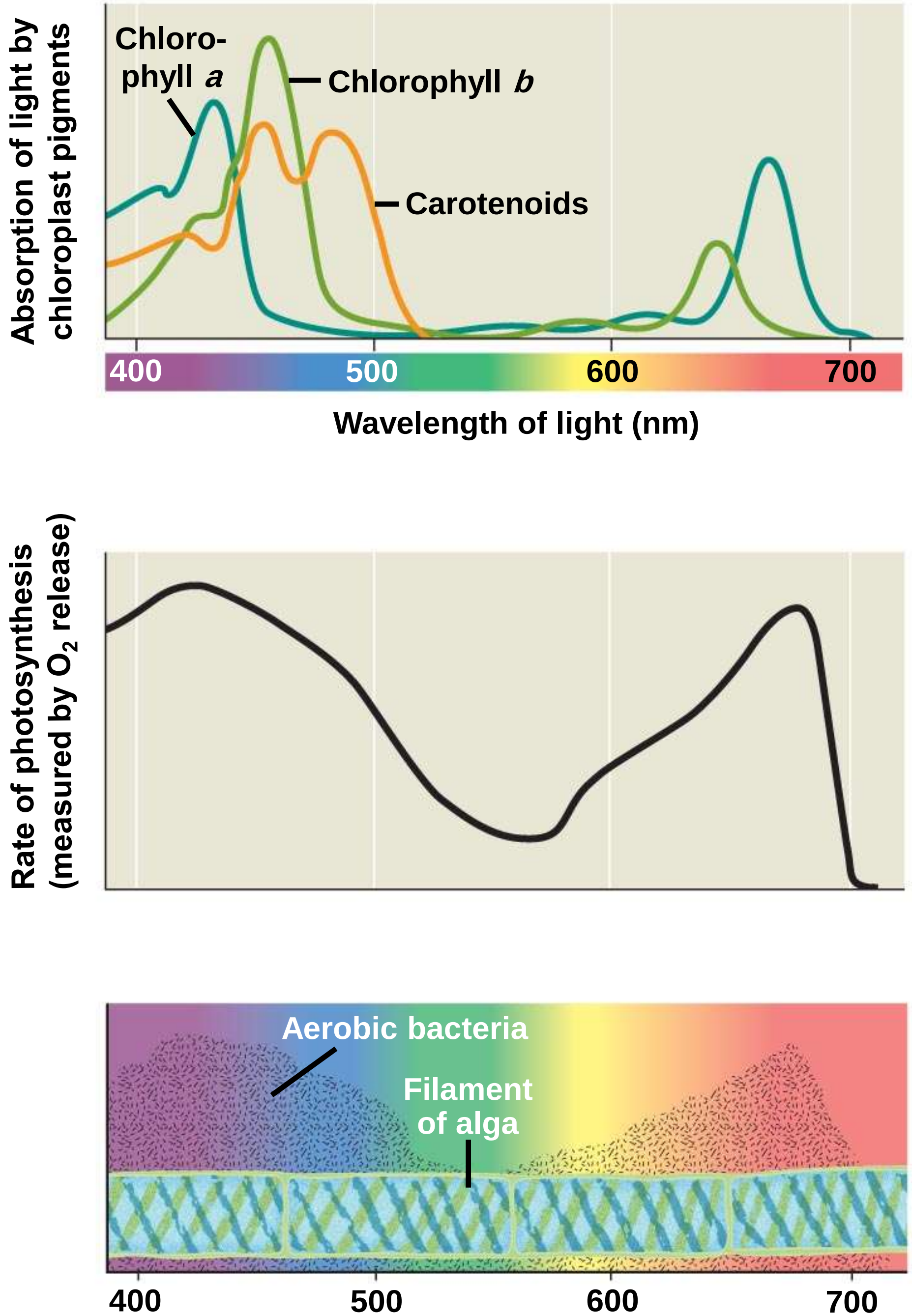


Light
Reflected light
Chloroplast
Absorbed light
Granum
Transmitted light

- An **absorption spectrum** is a graph plotting a pigment's light absorption versus wavelength
- The absorption spectrum of **chlorophyll *a*** suggests that violet-blue and red light work best for photosynthesis
- An **action spectrum** profiles the relative effectiveness of different wavelengths of radiation in driving a process

Fig. 10-9

RESULTS



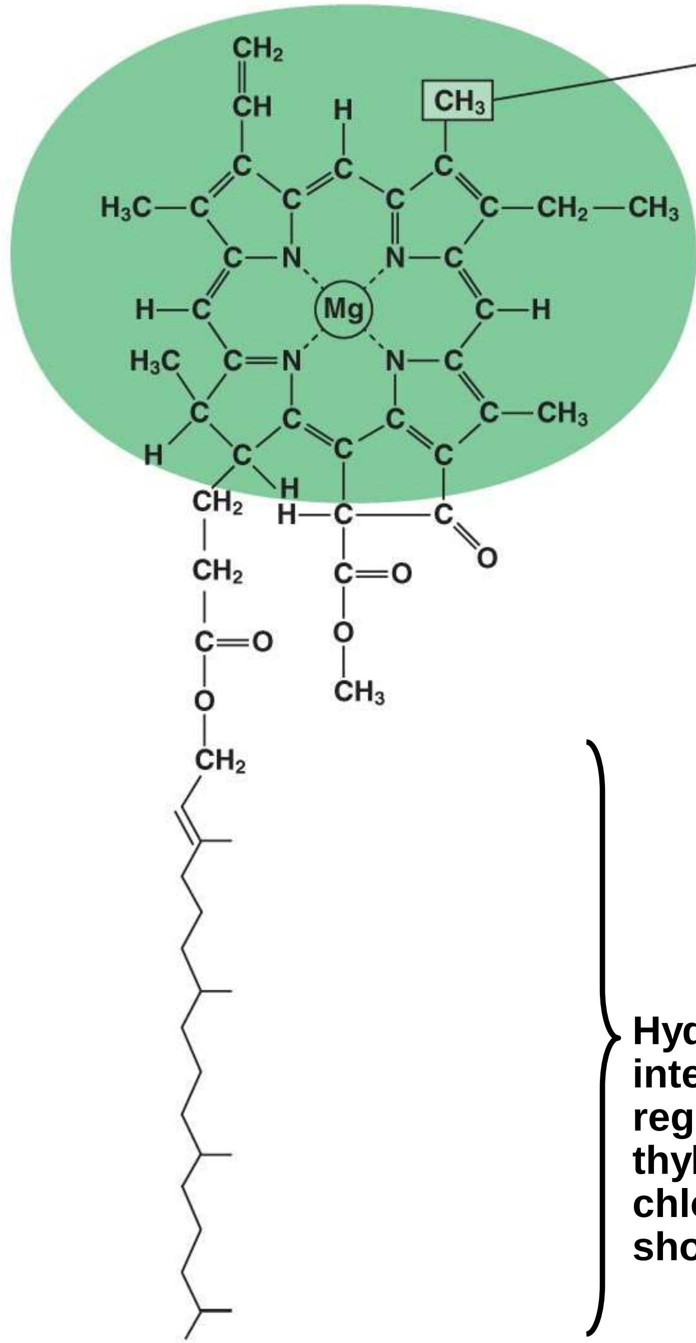
(a) Absorption spectra

(b) Action spectrum

(c) Engelmann’s experiment

- Chlorophyll *a* is the main photosynthetic pigment
- Accessory pigments, such as **chlorophyll *b***, broaden the spectrum used for photosynthesis
- Accessory pigments called **carotenoids** absorb excessive light that would damage chlorophyll (Photoprotection)
- carotenoids absorb and dissipate excessive light energy that would otherwise damage chlorophyll or interact with oxygen, forming reactive oxidative molecules that are dangerous to the cell.

Fig. 10-10



- chlorophyll a is blue–green
- chlorophyll b is yellow–green

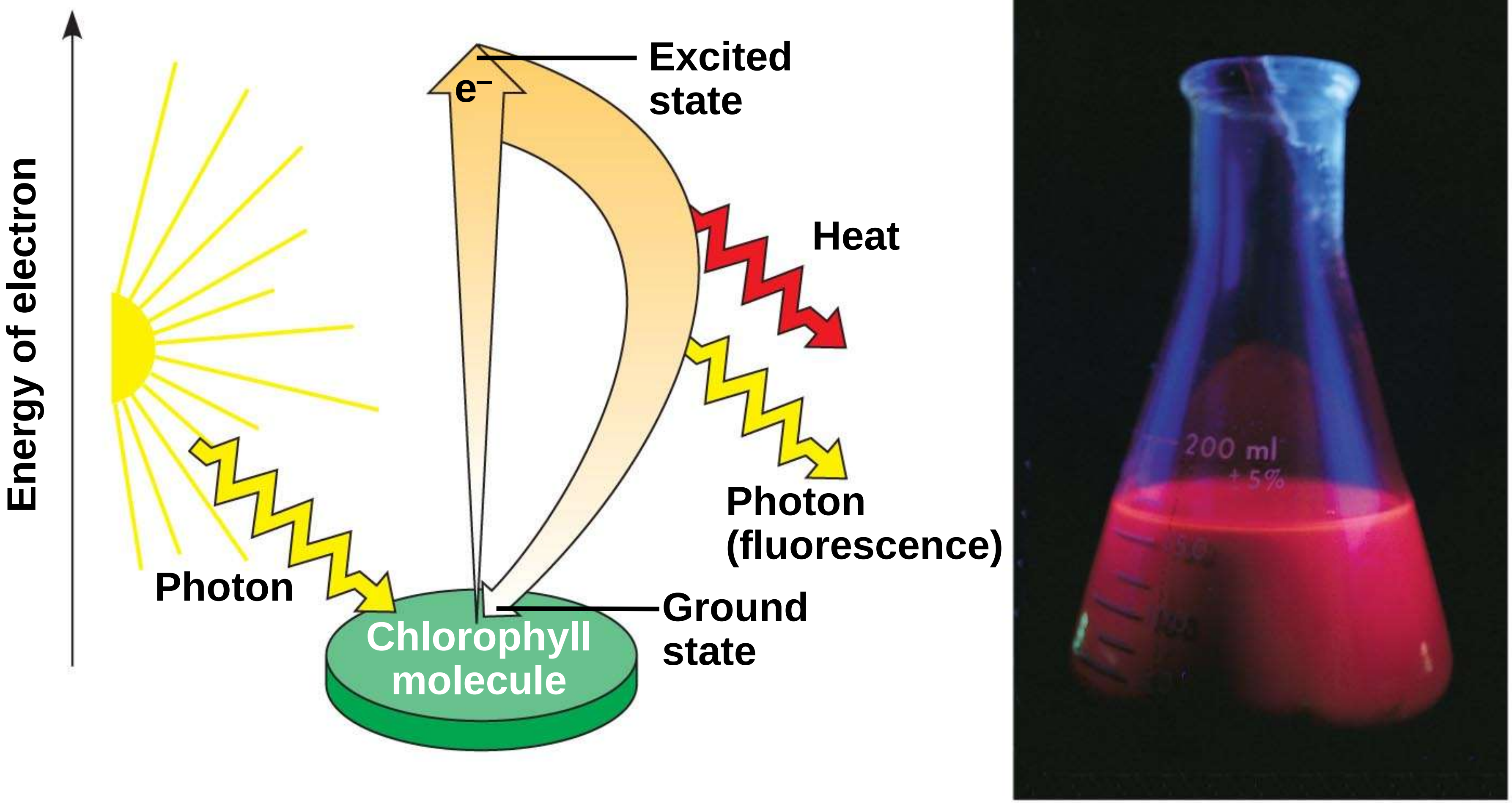
Excitation of Chlorophyll by Light

- When a pigment absorbs light, it goes from a ground state to an excited state, which is unstable
- When excited electrons fall back to the ground state, photons are given off, an afterglow called fluorescence
- If illuminated, an isolated solution of chlorophyll will fluoresce, giving off light and heat

Excitation of Chlorophyll by Light

- **ground state:** When the electron is in its normal orbital
- excited state: Absorption of a photon boosts an electron to an orbital of higher energy
- a particular compound absorbs only photons corresponding to specific wavelengths.
- The excited state, like all high–energy states, is unstable
- excited electron immediately drops back down to the ground–state orbital, and its excess energy is given off as heat and fluorescence (light).

Fig. 10-11



(a) Excitation of isolated chlorophyll molecule

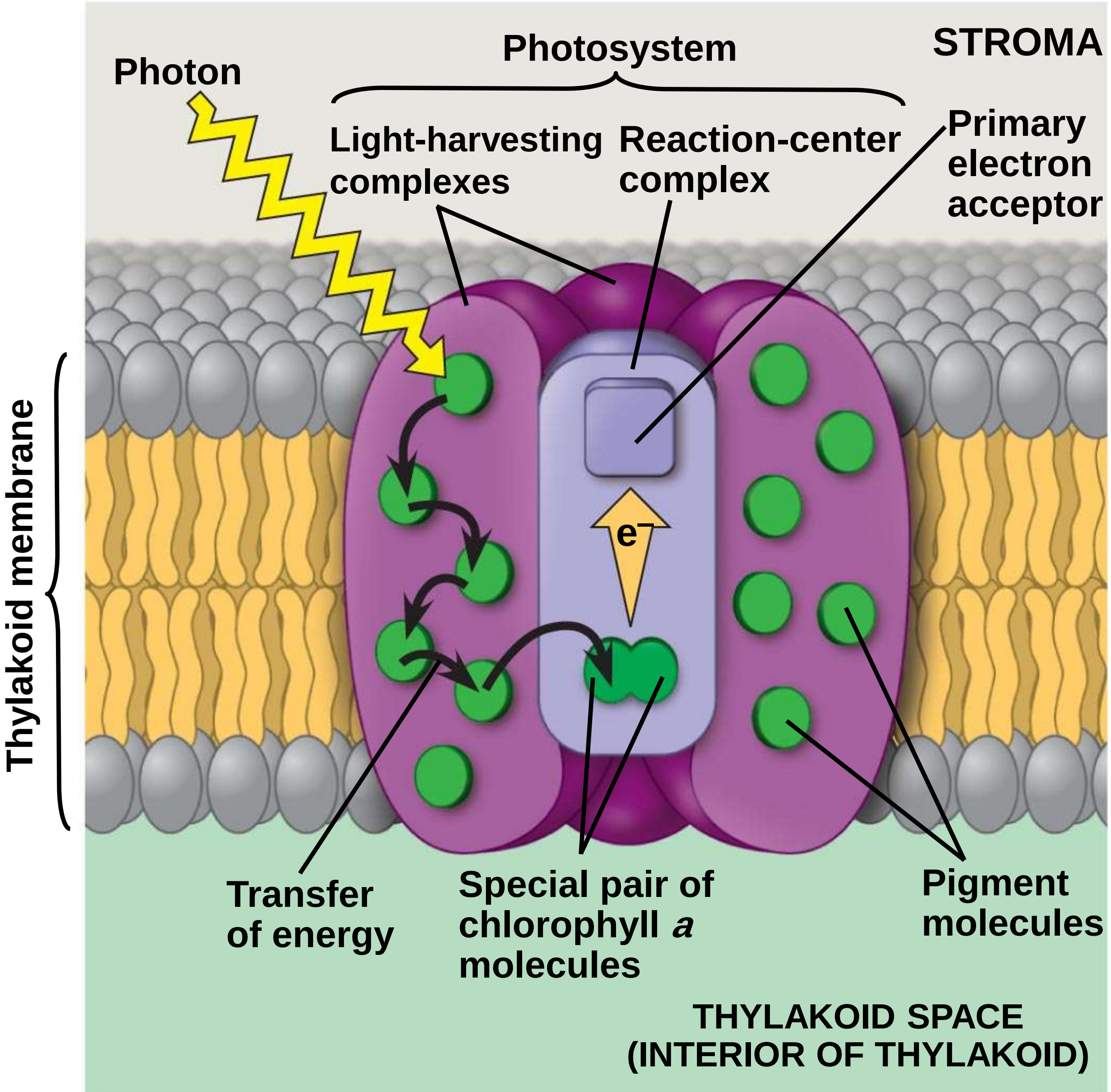
(b) Fluorescence

A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes

- A **photosystem** consists of a **reaction-center complex** (a type of protein complex) surrounded by light-harvesting complexes
- The **light-harvesting complexes** (pigment molecules bound to proteins) funnel the energy of photons to the reaction center

- A **primary electron acceptor** in the reaction center accepts an excited electron from chlorophyll *a*
- Solar-powered transfer of an electron from a chlorophyll *a* molecule to the primary electron acceptor is the first step of the light reactions

Fig. 10-12



Photon
Photosystem
STROMA
Light-harvesting complexes
Reaction-center complex
Primary electron acceptor
Thylakoid membrane
e⁻
Transfer of energy
Special pair of chlorophyll *a* molecules
Pigment molecules
THYLAKOID SPACE (INTERIOR OF THYLAKOID)

- There are two types of photosystems in the thylakoid membrane
- **Photosystem II (PS II)** functions first (the numbers reflect order of discovery) and is best at absorbing a wavelength of 680 nm
- The reaction-center chlorophyll *a* of PS II is called P680

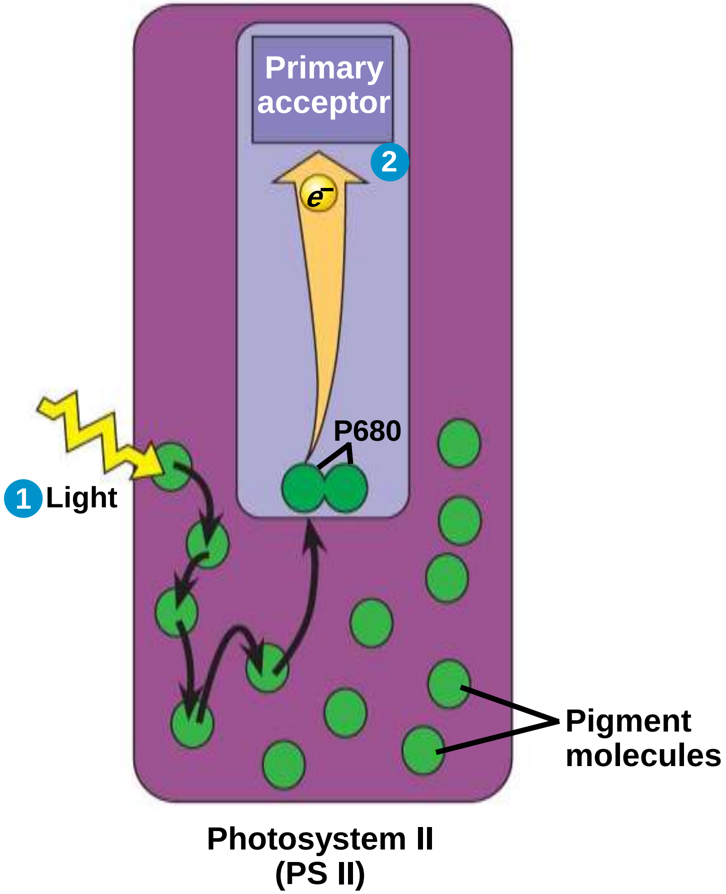
- **Photosystem I (PS I)** is best at absorbing a wavelength of 700 nm
- The reaction-center chlorophyll *a* of PS I is called P700

Linear Electron Flow

- During the light reactions, there are two possible routes for electron flow: cyclic and linear
- **Linear electron flow**, the primary pathway, involves both photosystems and produces ATP and NADPH using light energy

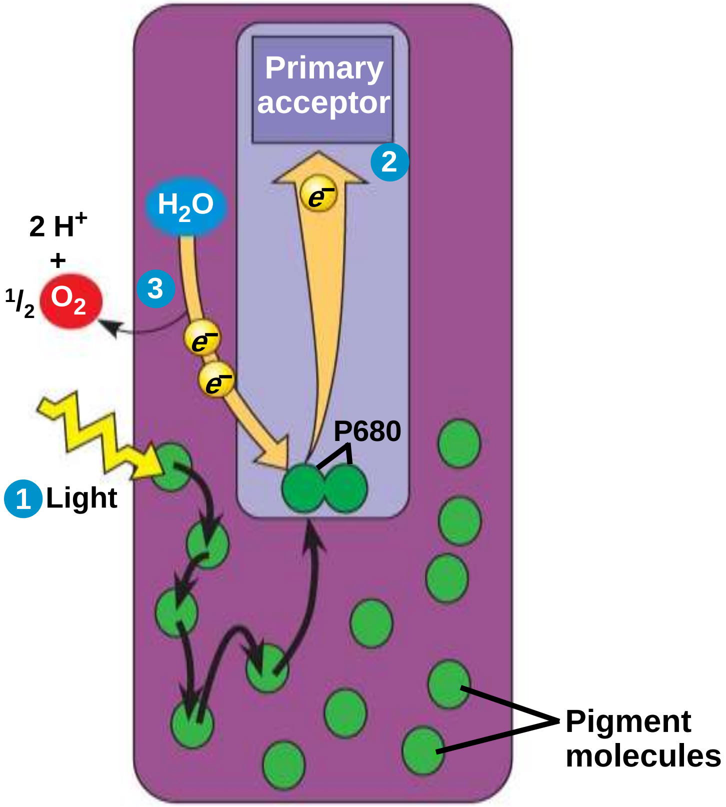
- A photon hits a pigment and its energy is passed among pigment molecules until it excites P680
- An excited electron from P680 is transferred to the primary electron acceptor

Fig. 10-13-1


Primary acceptor
2
e⁻
P680
1
Light
Pigment molecules
Photosystem II
(PS II)

- $P680^+$ (P680 that is missing an electron) is a very strong oxidizing agent
- H_2O is split by enzymes, and the electrons are transferred from the hydrogen atoms to $P680^+$, thus reducing it to P680
- O_2 is released as a by-product of this reaction

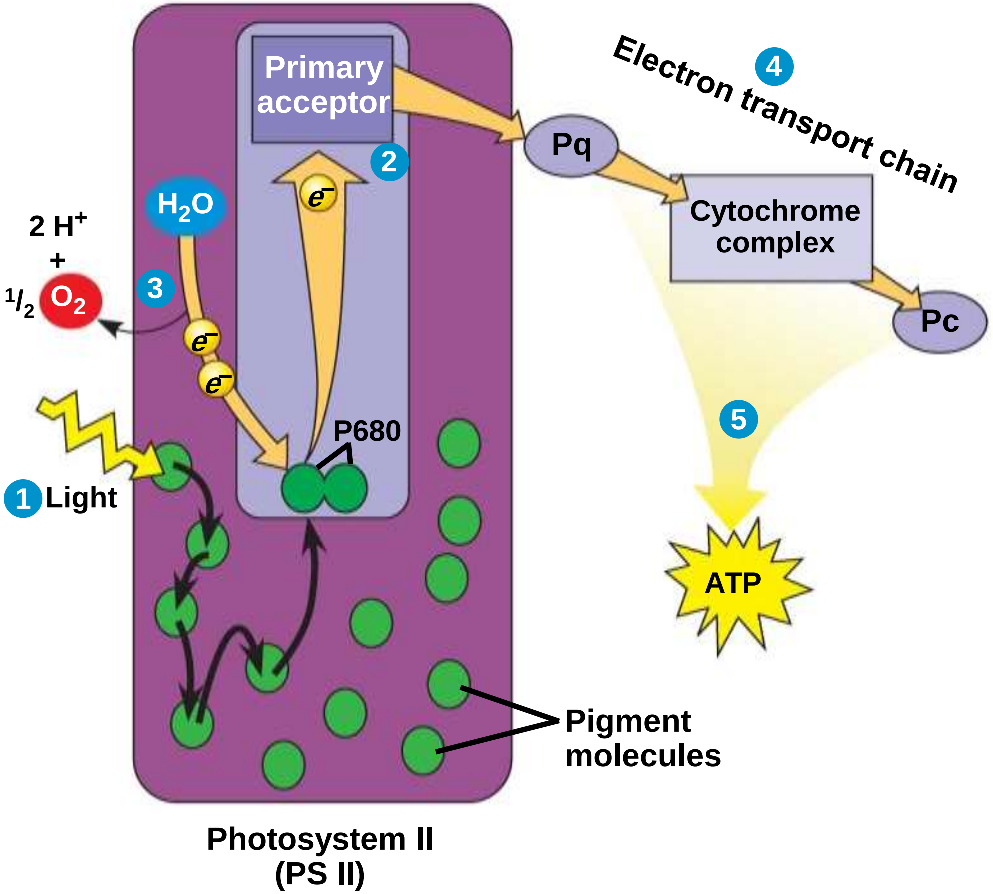
Fig. 10-13-2



Photosystem II
(PS II)

- Each electron “falls” down an electron transport chain from the primary electron acceptor of PS II to PS I
- Energy released by the fall drives the creation of a proton gradient across the thylakoid membrane
- Diffusion of H^+ (protons) across the membrane drives ATP synthesis

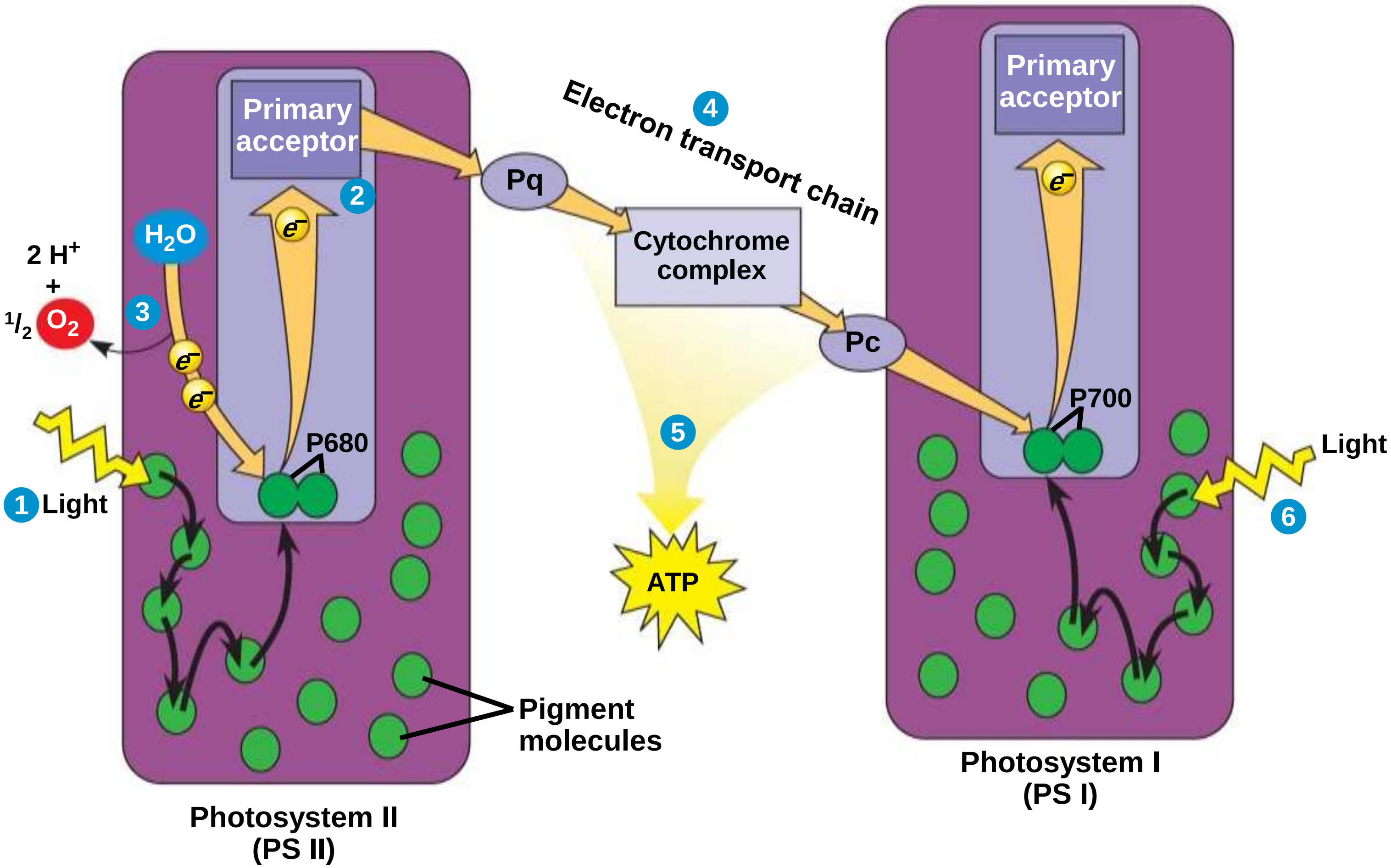
Fig. 10-13-3



Primary acceptor
4
Electron transport chain
2
Pq
e^-
H_2O
Cytochrome complex
2 H^+
+
3
$^1/_2$ O_2
Pc
e^-
e^-
5
P680
1 Light
ATP
Pigment molecules
Photosystem II (PS II)

- In PS I (like PS II), transferred light energy excites P700, which loses an electron to an electron acceptor
- P700$^+$ (P700 that is missing an electron) accepts an electron passed down from PS II via the electron transport chain

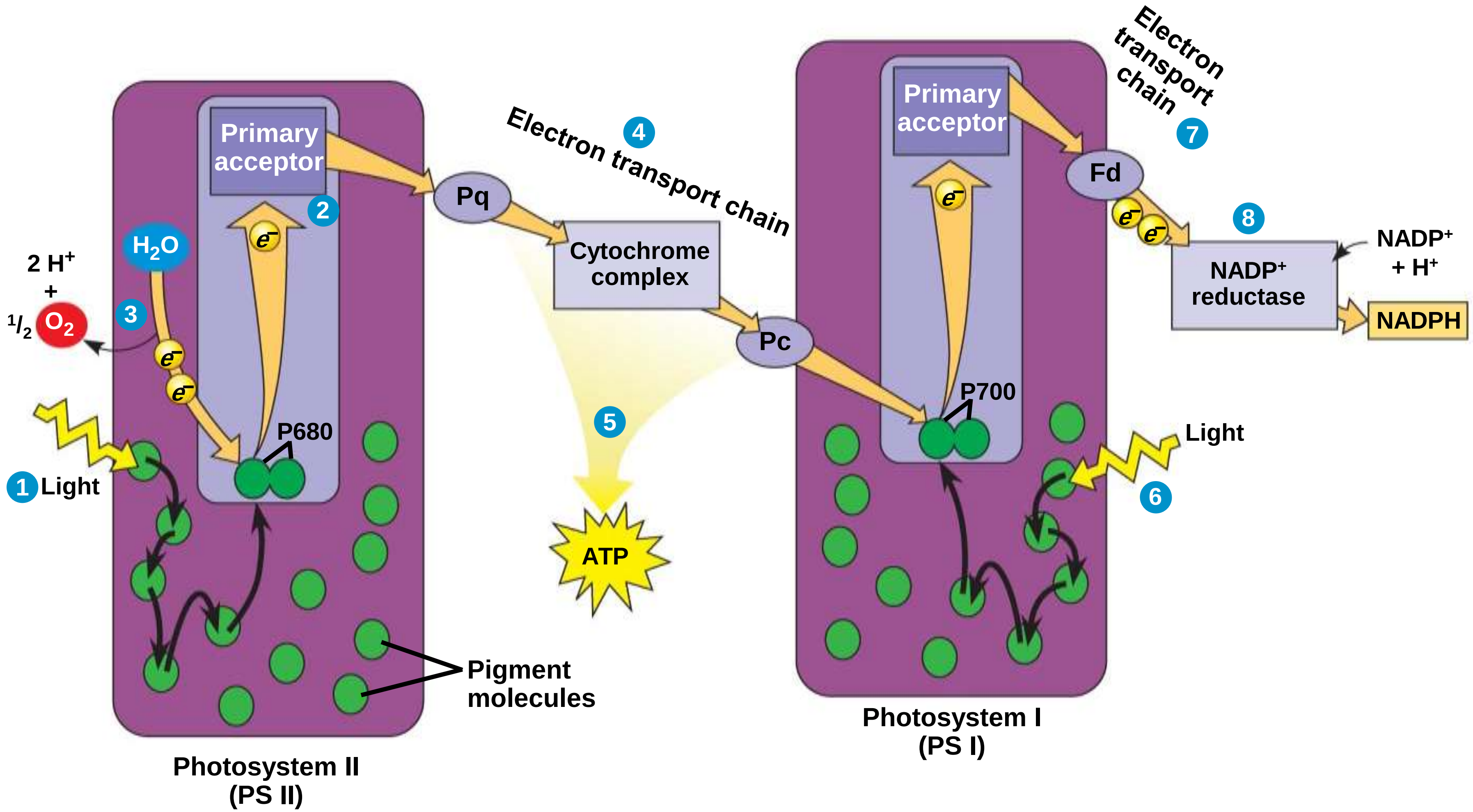
Fig. 10-13-4



Primary acceptor
Pq
Electron transport chain
4
Primary acceptor
2
H_2O
2 H^+
+
$^1/_2$ O_2
3
e
e
e
Cytochrome complex
Pc
e
P700
Light
6
5
P680
1 Light
ATP
Pigment molecules
Photosystem I (PS I)
Photosystem II (PS II)

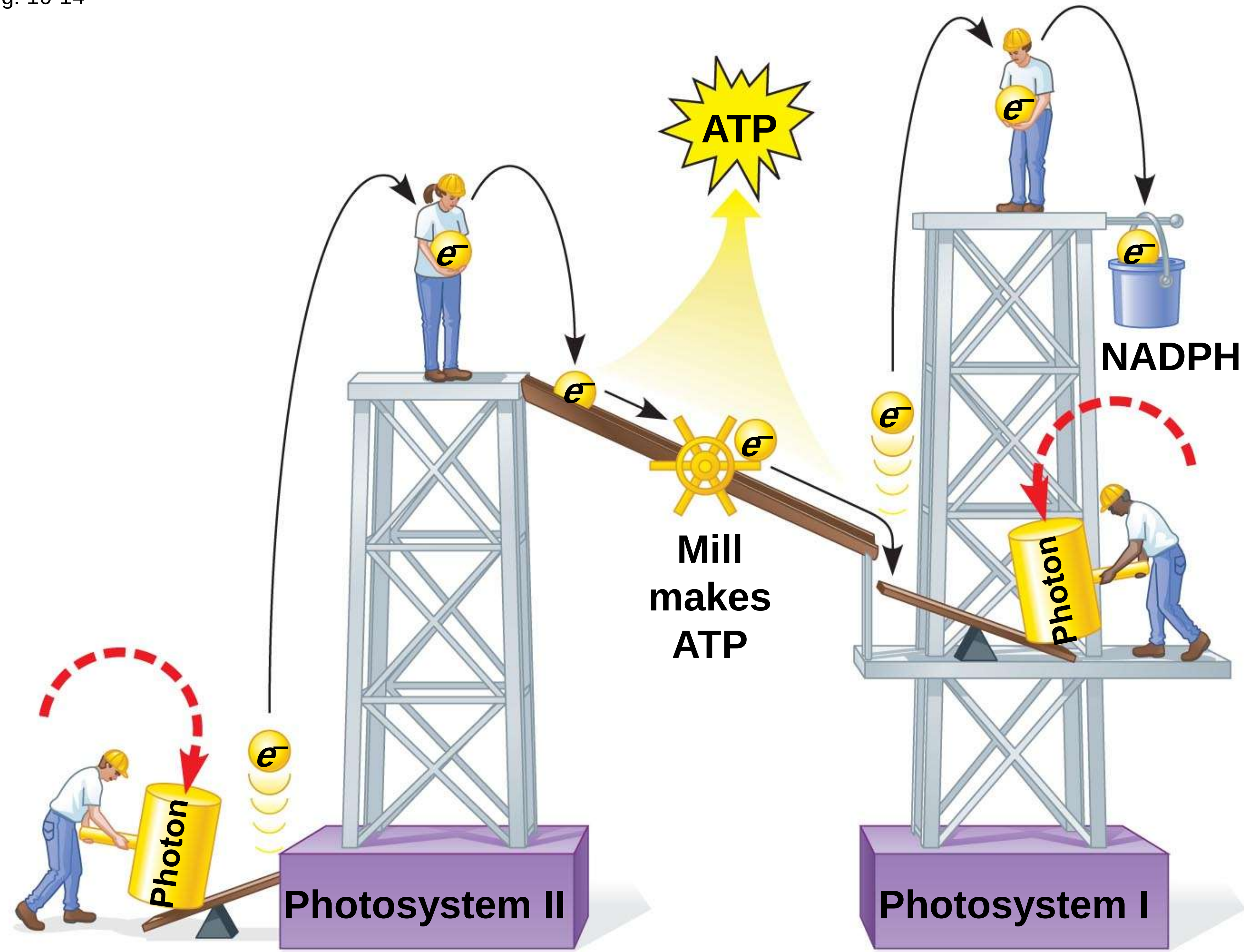
- Each electron “falls” down an electron transport chain from the primary electron acceptor of PS I to the protein ferredoxin (Fd)
- The electrons are then transferred to $NADP^+$ and reduce it to NADPH
- The electrons of NADPH are available for the reactions of the Calvin cycle

Fig. 10-13-5



Primary acceptor
Pq
Electron transport chain
4
2
H_2O
2 H^+
+
$^1/_2$ O_2
3
e^-
e^-
e^-
P680
1 Light
Cytochrome complex
Pc
5
ATP
Pigment molecules
Photosystem II (PS II)
Primary acceptor
e^-
P700
Electron transport chain
7
Fd
e^-
e^-
8
NADP$^+$ reductase
NADP$^+$ + H$^+$
NADPH
Light
6
Photosystem I (PS I)

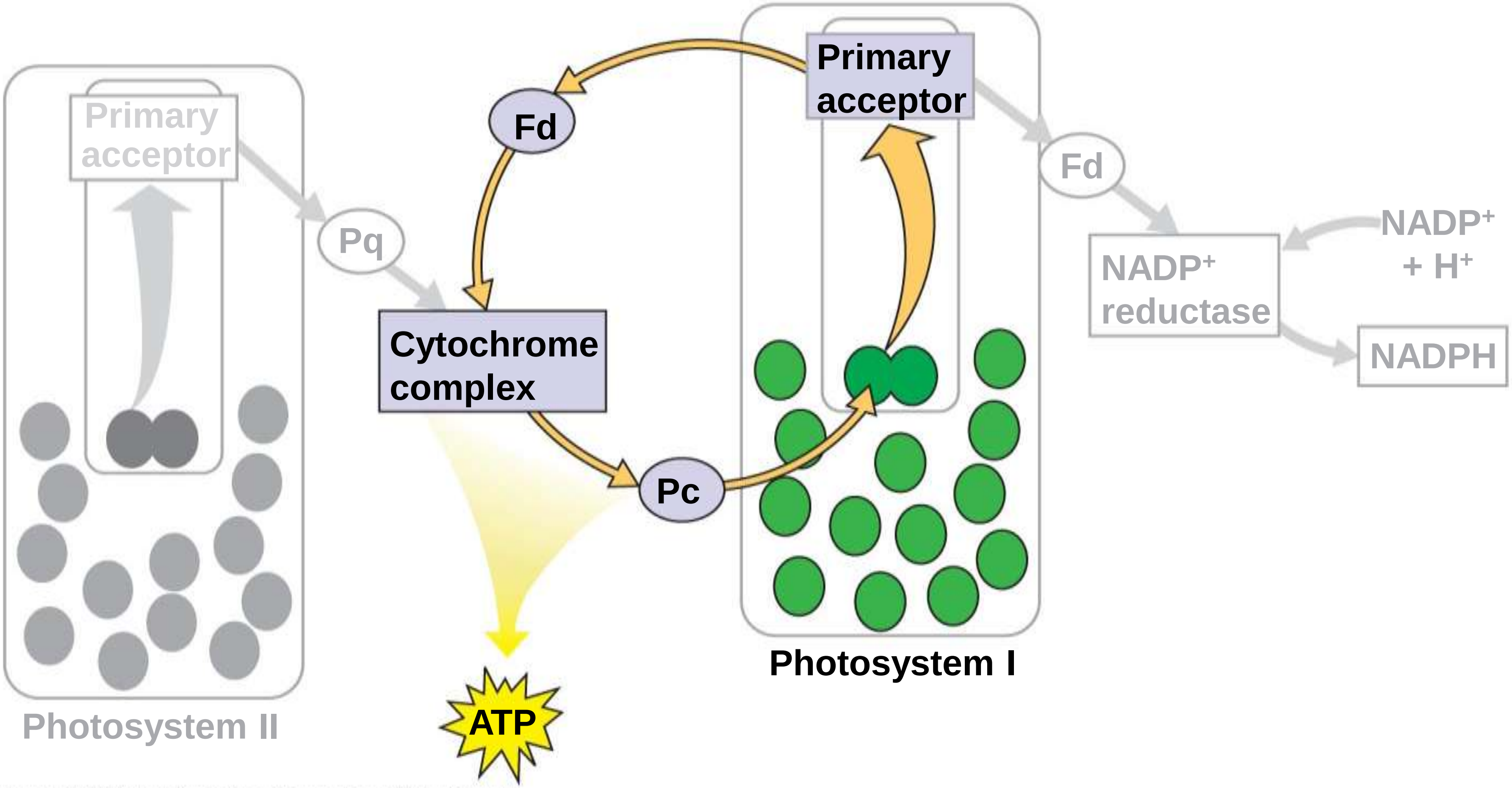
Fig. 10-14


ATP
NADPH
e⁻
Mill makes ATP
Photon
Photon
Photosystem II
Photosystem I

Cyclic Electron Flow

- **Cyclic electron flow** uses only photosystem I and produces ATP, but not NADPH
- Cyclic electron flow generates surplus ATP, satisfying the higher demand in the Calvin cycle

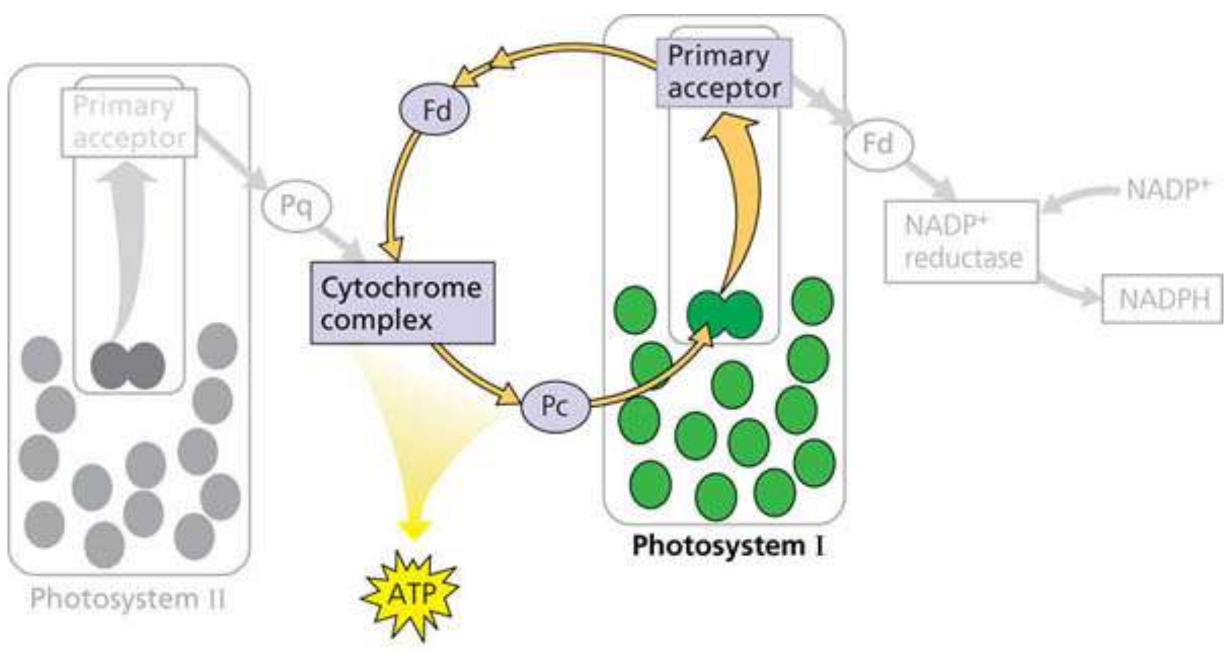
Fig. 10-15



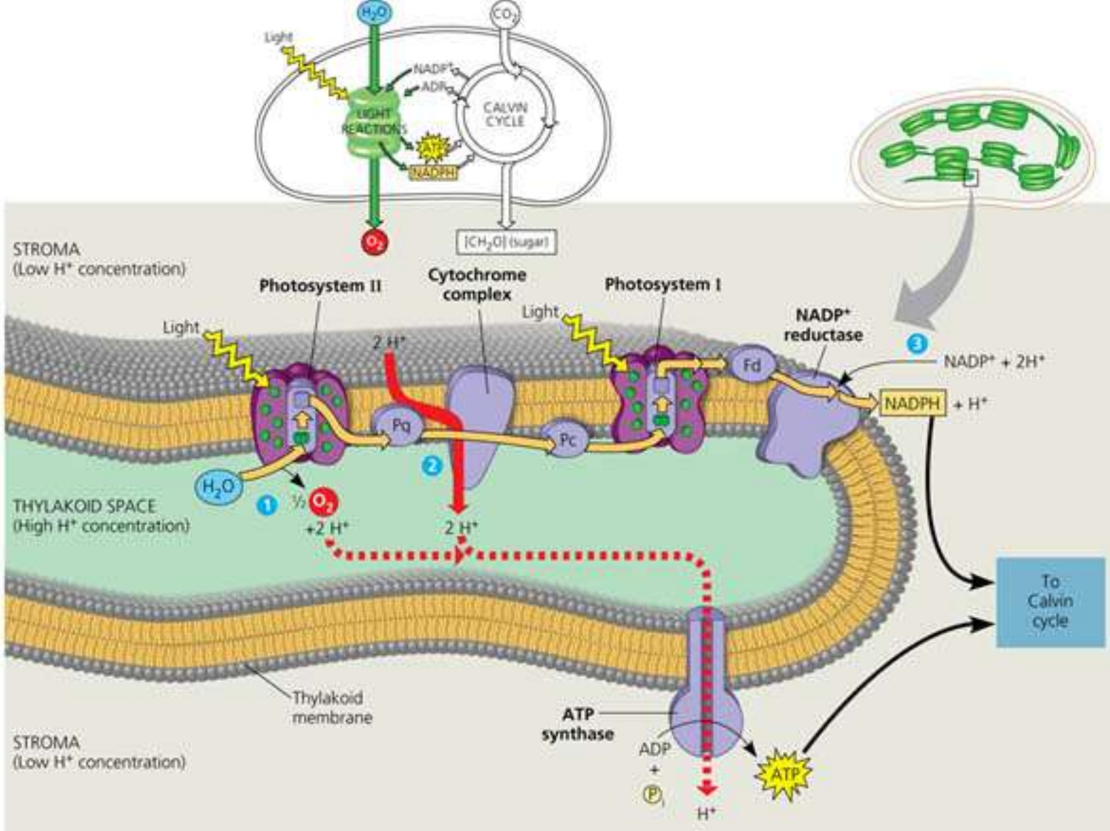
Primary acceptor
Pq
Cytochrome complex
Fd
Pc
Primary acceptor
Fd
NADP$^+$ reductase
NADP$^+$ + H$^+$
NADPH
ATP
Photosystem II
Photosystem I

Cyclic Electron Flow

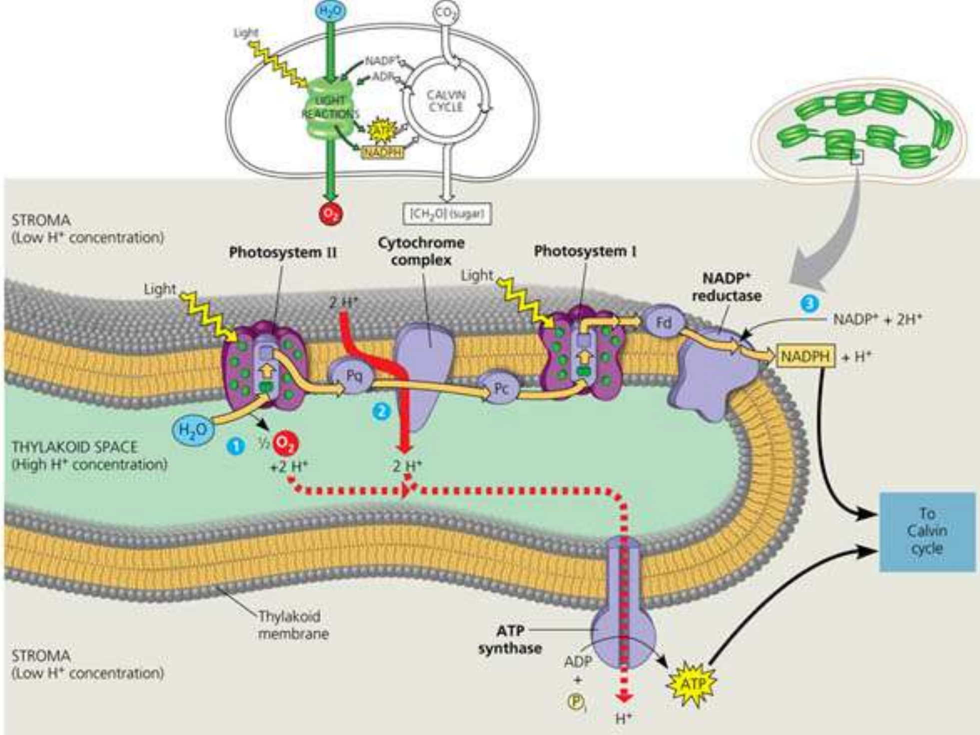
- **Cyclic electron flow** uses photosystem I only
- The electrons cycle back from ferredoxin (Fd) to the cytochrome complex and then to the PS I reaction center.
- There is no production of NADPH and no release of oxygen.
- Cyclic flow generate ATP.
- Noncyclic electron flow produces ATP and NADPH in equal quantities, but the Calvin cycle consumes more ATP than NADPH.
- Cyclic electron flow makes up the difference.



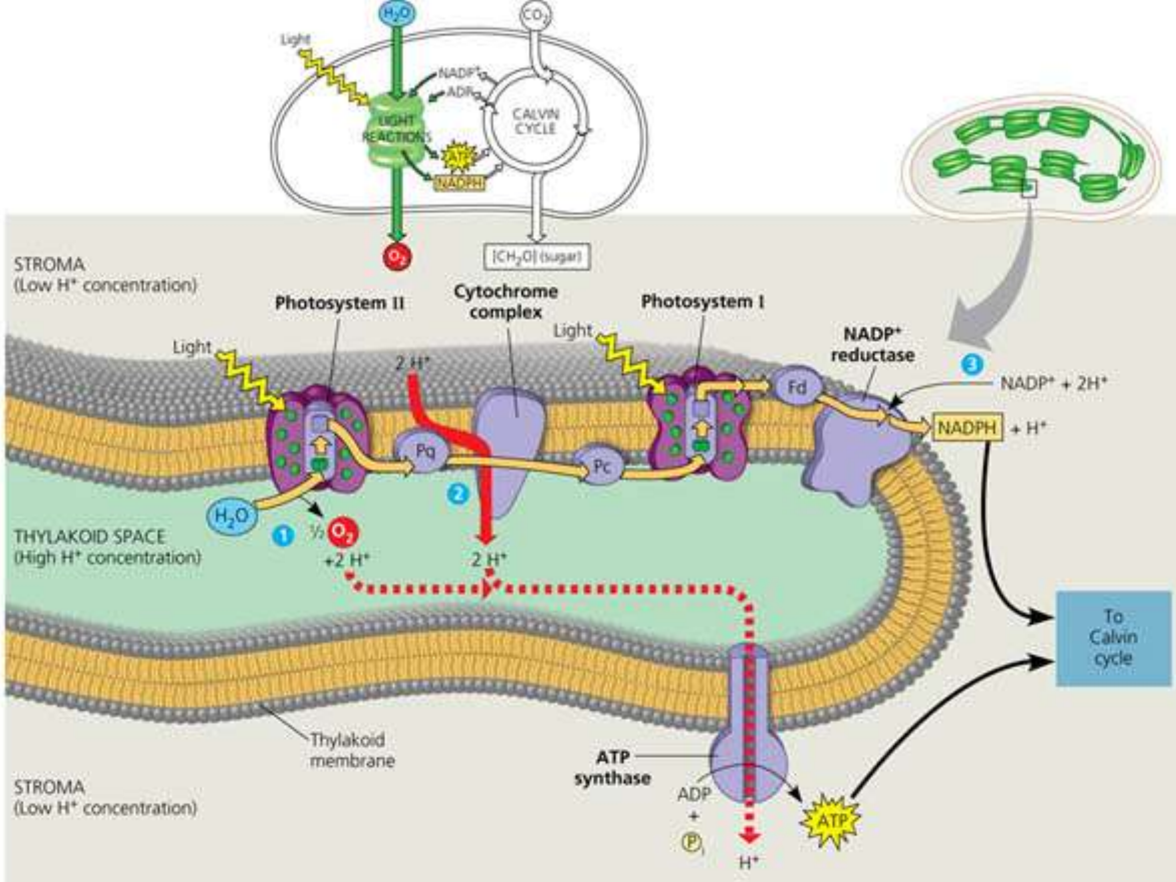
- ATP and NADPH are produced on the side facing the stroma, where the Calvin cycle takes place
- In summary, light reactions generate ATP and increase the potential energy of electrons by moving them from H_2O to NADPH



- As electrons pass from carrier to carrier in redox reactions, H+ removed from the stroma are deposited in the thylakoid space, storing energy as a proton–motive force (H+ gradient).

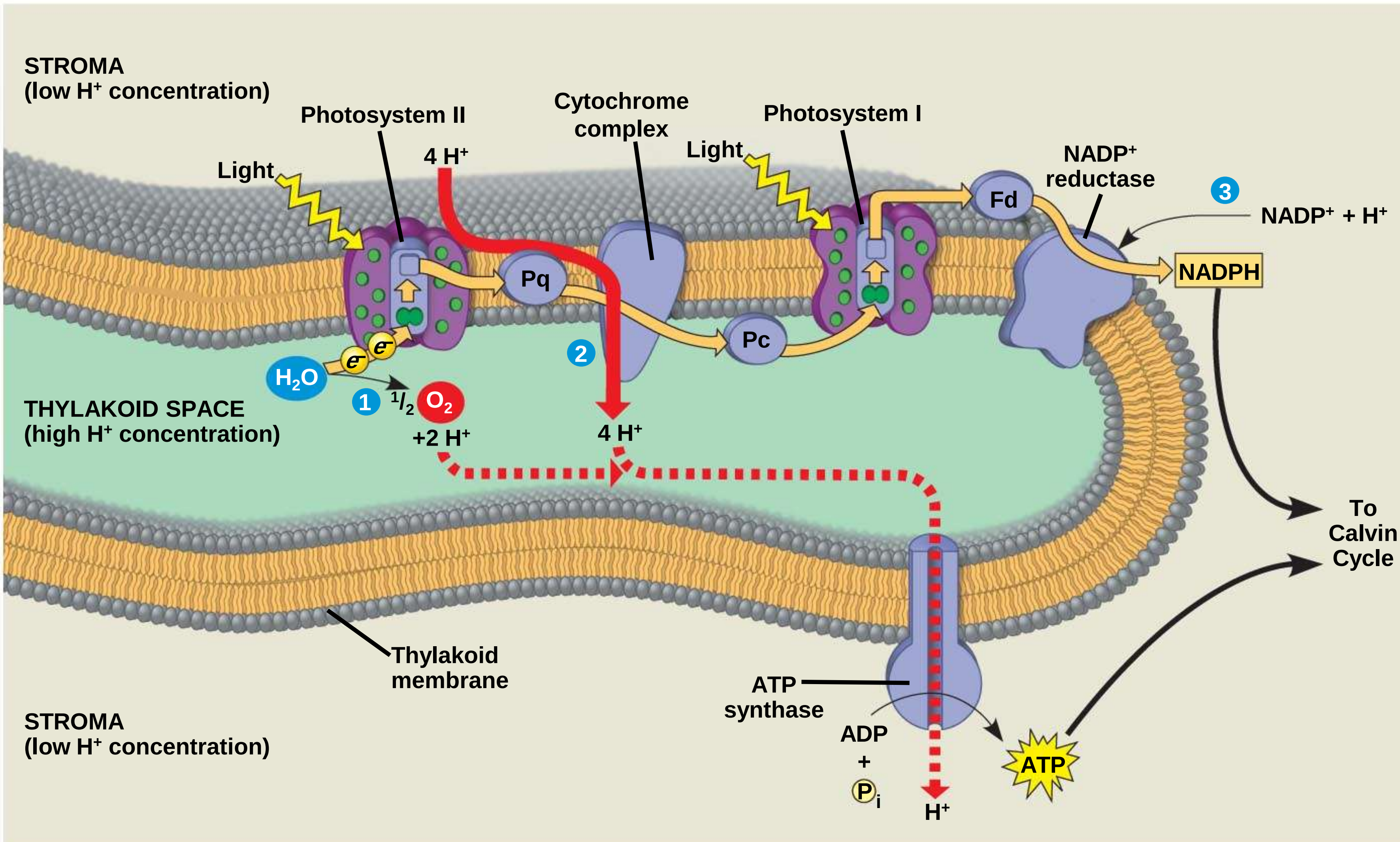


- At least three steps in the light reactions contribute to the proton gradient:
  1. Water is split by photosystem II
  2. as plastoquinone (Pq), a mobile carrier, transfers electrons to the cytochrome complex, protons are translocated across the membrane into the thylakoid space
  3. a hydrogen ion is removed from the stroma when it is taken up by NADP+.



- The diffusion of H+ from the thylakoid space back to the stroma (along the H+ concentration gradient) powers the ATP synthase. These light–driven reactions store chemical energy in NADPH and ATP, which shuttle the energy to the sugar–producing Calvin cycle.

Fig. 10-17



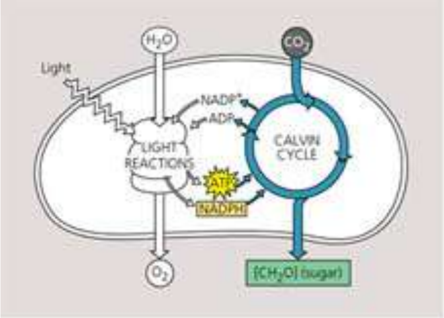
STROMA
(low H+ concentration)
Photosystem II
Cytochrome complex
Photosystem I
Light
4 H+
Light
NADP+ reductase
3
NADP+ + H+
Fd
Pq
NADPH
Pc
e-
e-
H2O
2
1
1/2 O2
THYLAKOID SPACE
(high H+ concentration)
+2 H+
4 H+
To Calvin Cycle
Thylakoid membrane
ATP synthase
STROMA
(low H+ concentration)
ADP
+
Pi
ATP
H+

The Calvin cycle uses ATP and NADPH to convert CO_2 to sugar

- The Calvin cycle, like the citric acid cycle, regenerates its starting material after molecules enter and leave the cycle
- The cycle builds sugar from smaller molecules by using ATP and the reducing power of electrons carried by NADPH

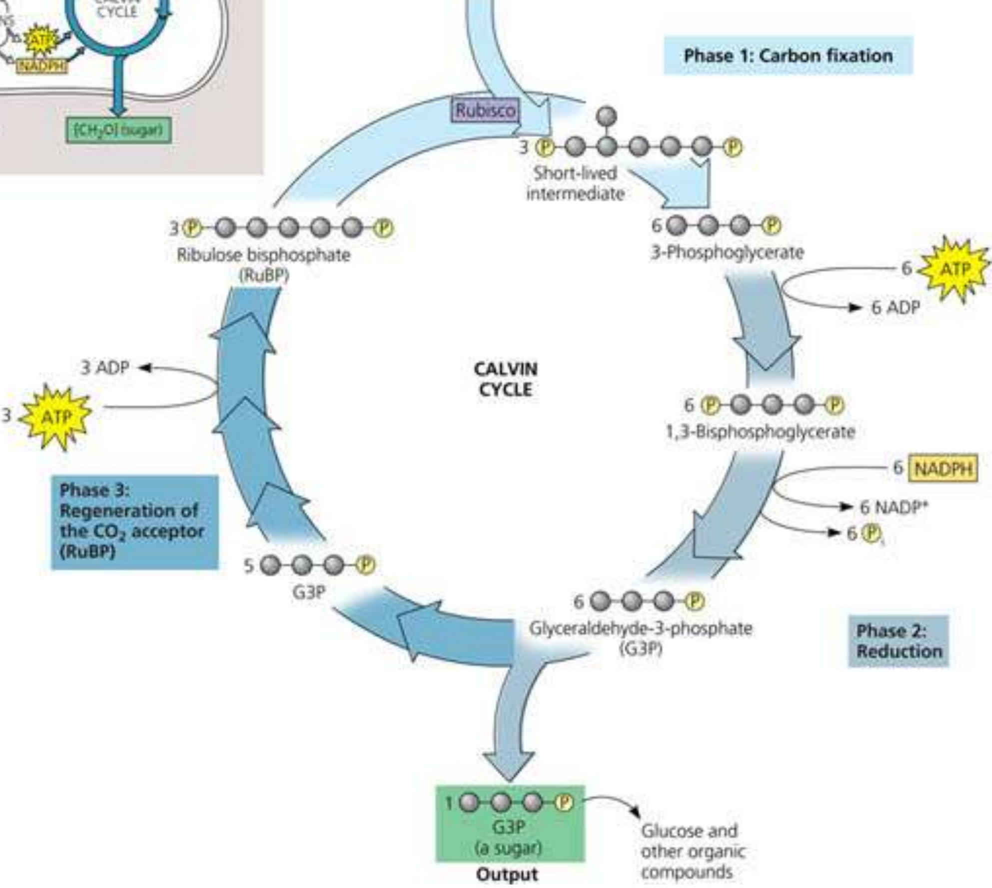
- Carbon enters the cycle as CO_2 and leaves as a sugar named **glyceraldehyde-3-phospate (G3P)**
- For net synthesis of 1 G3P, the cycle must take place three times, fixing 3 molecules of CO_2
- The Calvin cycle has three phases:
  - **Carbon fixation** (catalyzed by **rubisco**)
  - **Reduction**
  - **Regeneration of the CO_2 acceptor (RuBP)**

Calvin cycle divided into three phases:

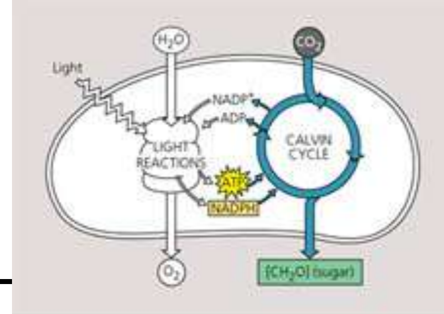


Phase 1: Carbon fixation.

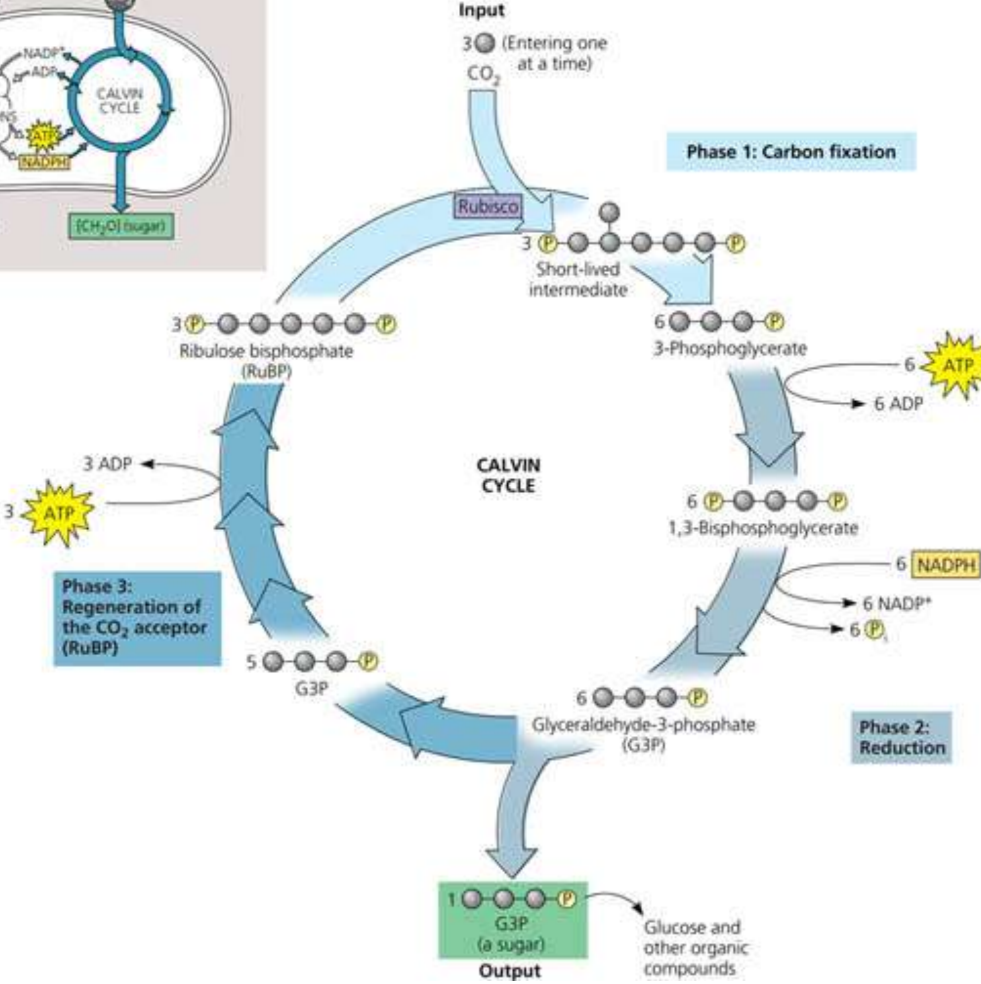
- The Calvin cycle incorporates each CO_2 molecule by attaching it to a five–carbon sugar named ribulose bisphosphate (RuBP).
- The enzyme that catalyzes this first step is RuBP carboxylase, or **rubisco**.
- The product of the reaction is a six–carbon intermediate
- So unstable that it immediately splits in half, forming two molecules of 3–phosphoglycerate (for each CO2).



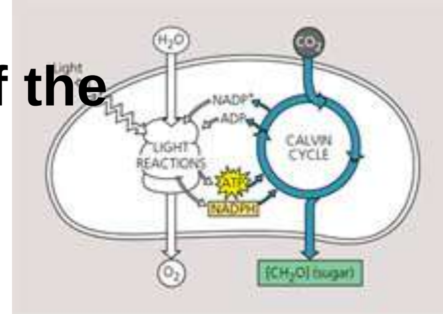
Phase 2: Reduction.



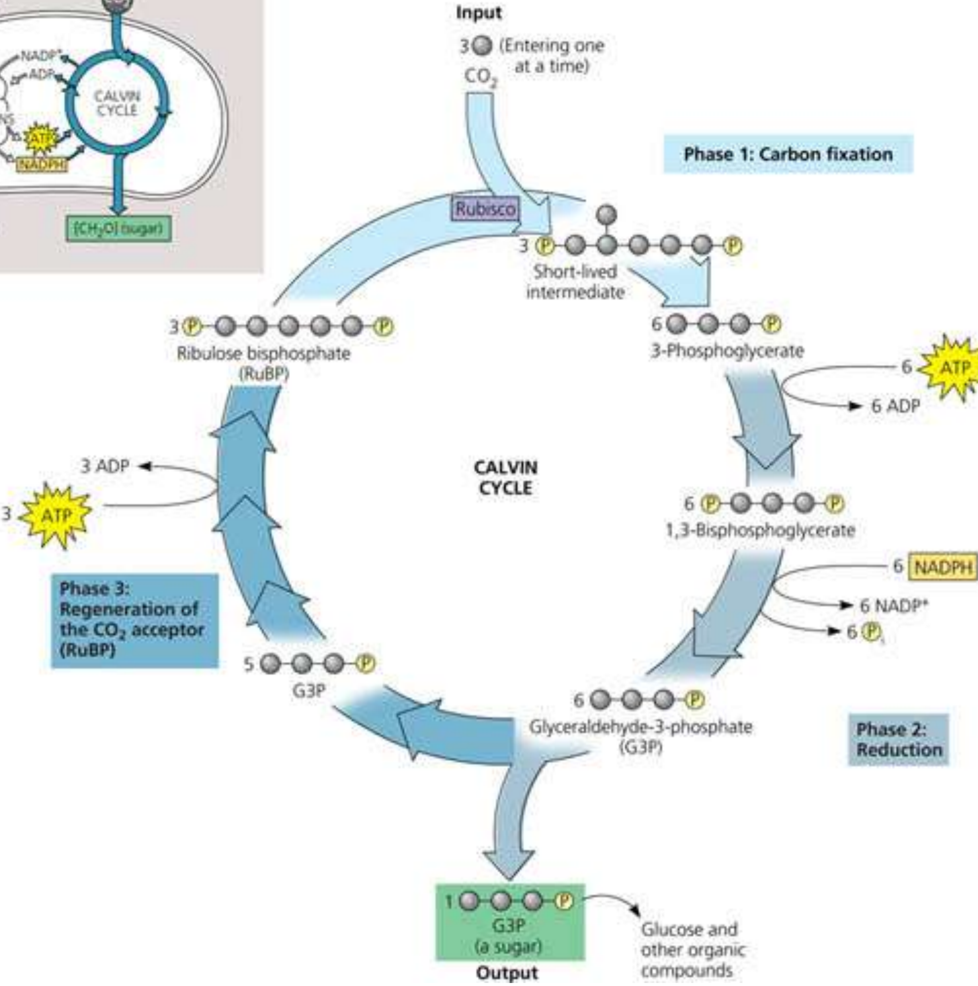
- Each molecule of 3–phosphoglycerate receives Pi from ATP, becoming 1,3–bisphosphoglycerate.
- Next, 2 electrons donated from NADPH reduces 1,3–bisphosphoglycerate to G3P.
- The electrons reduce the carboyxl group of 3–phosphoglycerate to the aldehyde group of G3P, which stores more potential energy.



Phase 3: Regeneration of the CO 2 acceptor (RuBP)



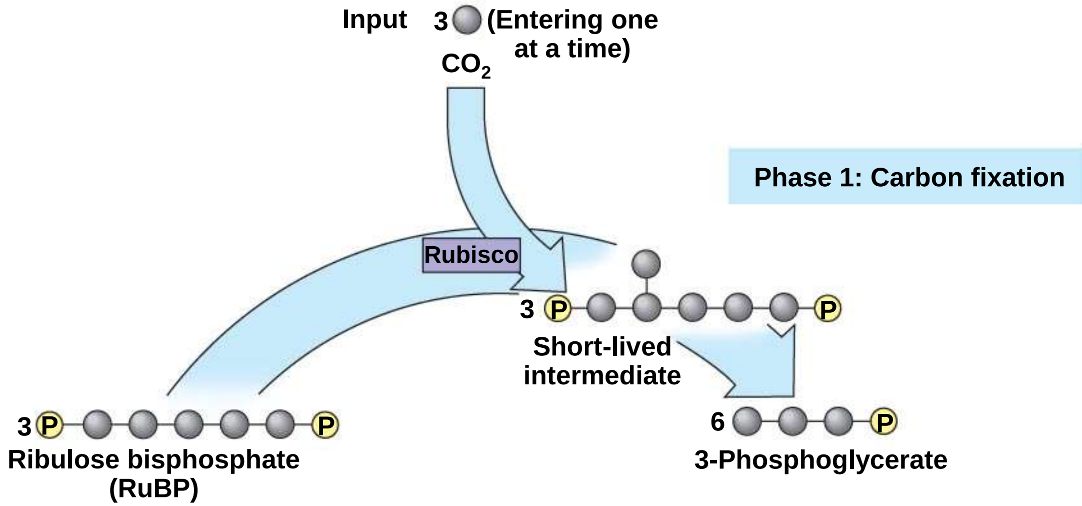
- In a complex series of reactions, the carbon skeletons of five molecules of G3P are rearranged by the last steps of the Calvin cycle into three molecules of RuBP.
- The cycle spends three more molecules of ATP.
- The RuBP is now prepared to receive CO2 again, and the cycle continues.



- For one G3P molecule, the Calvin cycle consumes **nine ATP and six NADPH**.
- The light reactions regenerate the ATP and NADPH.

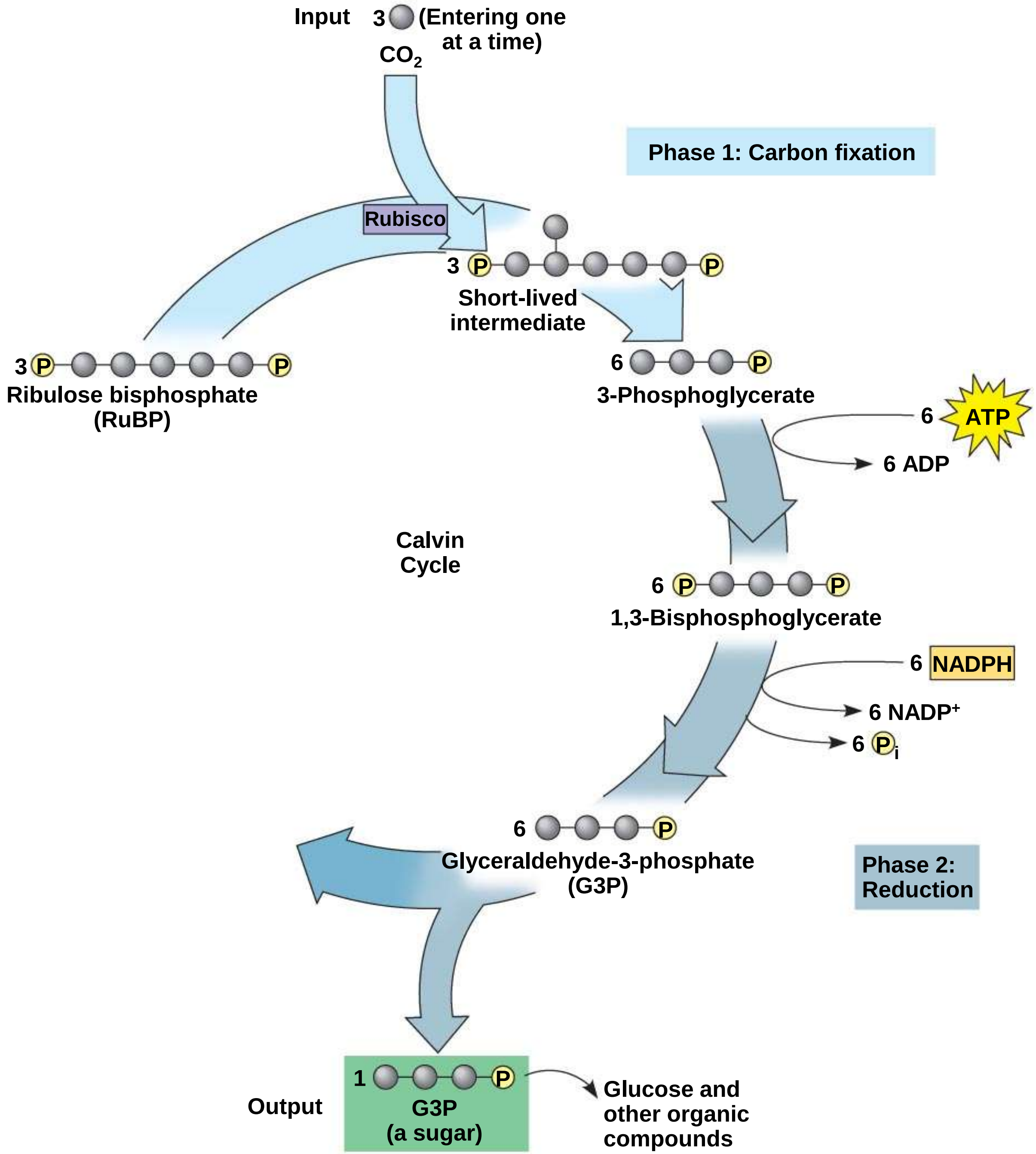
- In most plants, initial fixation of carbon occurs via **rubisco**, the Calvin cycle enzyme that adds CO2 to ribulose bisphosphate. Such plants are called **C3 plants** because the first organic product of carbon fixation is a three–carbon compound, 3–phosphoglycerate
- With stomata partially closed:
  – low CO_2 in the air spaces within the leaf
  – high O2 released from the light reactions.
- These conditions within the leaf favor a wasteful process called **photorespiration**.

Fig. 10-18-1



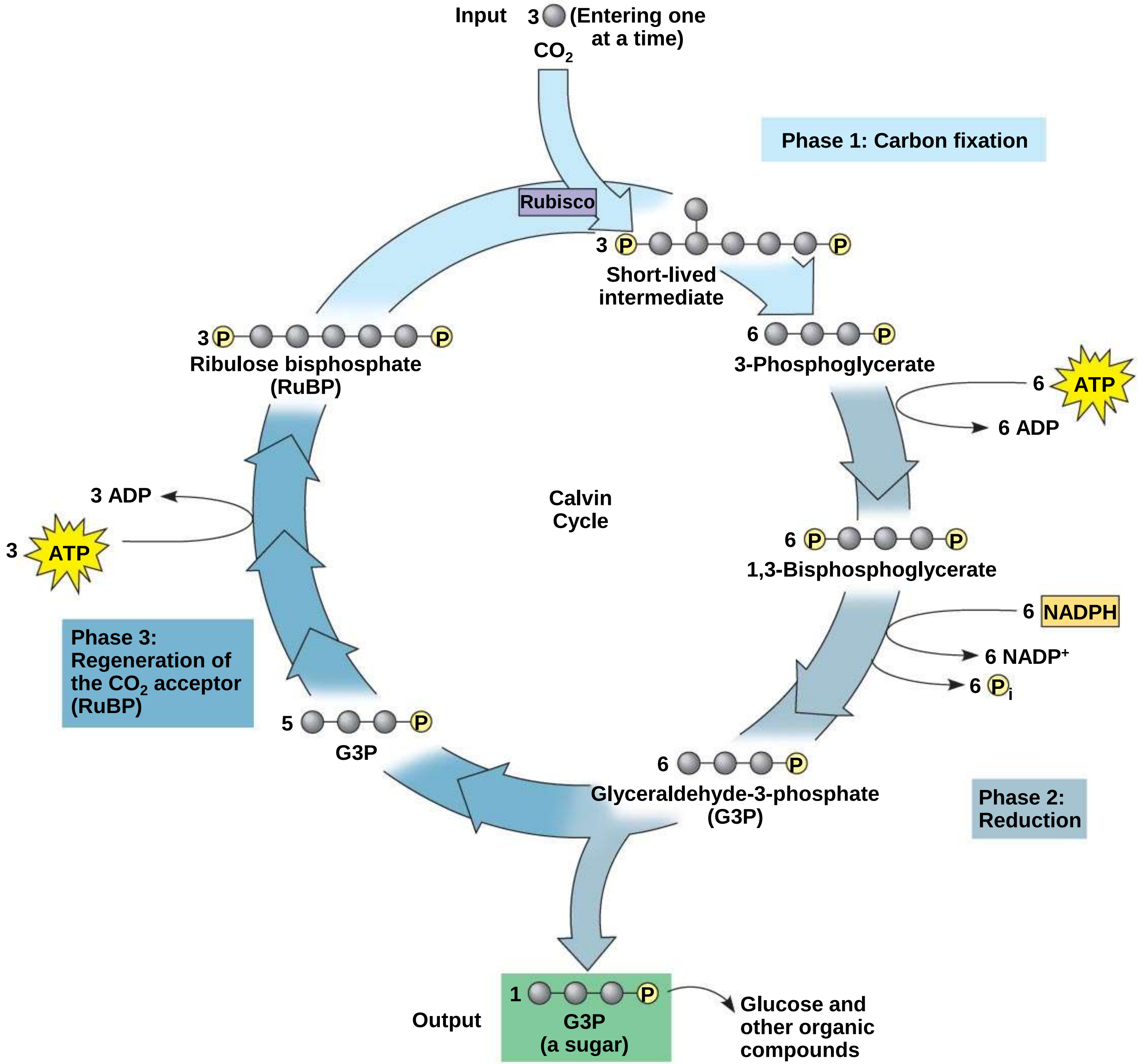
Input
3
(Entering one at a time)
CO_2
Phase 1: Carbon fixation
Rubisco
3 P P
Short-lived intermediate
3 P P
Ribulose bisphosphate (RuBP)
6 P
3-Phosphoglycerate

Fig. 10-18-2



Input
3
(Entering one at a time)
CO_2
Phase 1: Carbon fixation
Rubisco
3 P P
Short-lived intermediate
6 P
3-Phosphoglycerate
3 P P
Ribulose bisphosphate (RuBP)
6 ATP
6 ADP
Calvin Cycle
6 P P
1,3-Bisphosphoglycerate
6 NADPH
6 $NADP^+$
6 P_i
6 P
Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
1 P
Output
G3P (a sugar)
Glucose and other organic compounds

Fig. 10-18-3



Input
3
(Entering one at a time)
CO_2
Phase 1: Carbon fixation
Rubisco
3 P P
Short-lived intermediate
6 P
3-Phosphoglycerate
6 ATP
6 ADP
3 P P
Ribulose bisphosphate (RuBP)
Calvin Cycle
3 ADP
3 ATP
6 P P
1,3-Bisphosphoglycerate
6 NADPH
6 $NADP^+$
6 P_i
Phase 3: Regeneration of the CO_2 acceptor (RuBP)
5 P
G3P
6 P
Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
1 P
Output
G3P (a sugar)
Glucose and other organic compounds

Alternative mechanisms of carbon fixation have evolved in hot, arid climates

- Dehydration is a problem for plants, sometimes requiring trade-offs with other metabolic processes, especially photosynthesis
- On hot, dry days, plants close stomata, which conserves H_2O but also limits photosynthesis
- The closing of stomata reduces access to CO_2 and causes O_2 to build up
- These conditions favor a seemingly wasteful process called photorespiration

Photorespiration

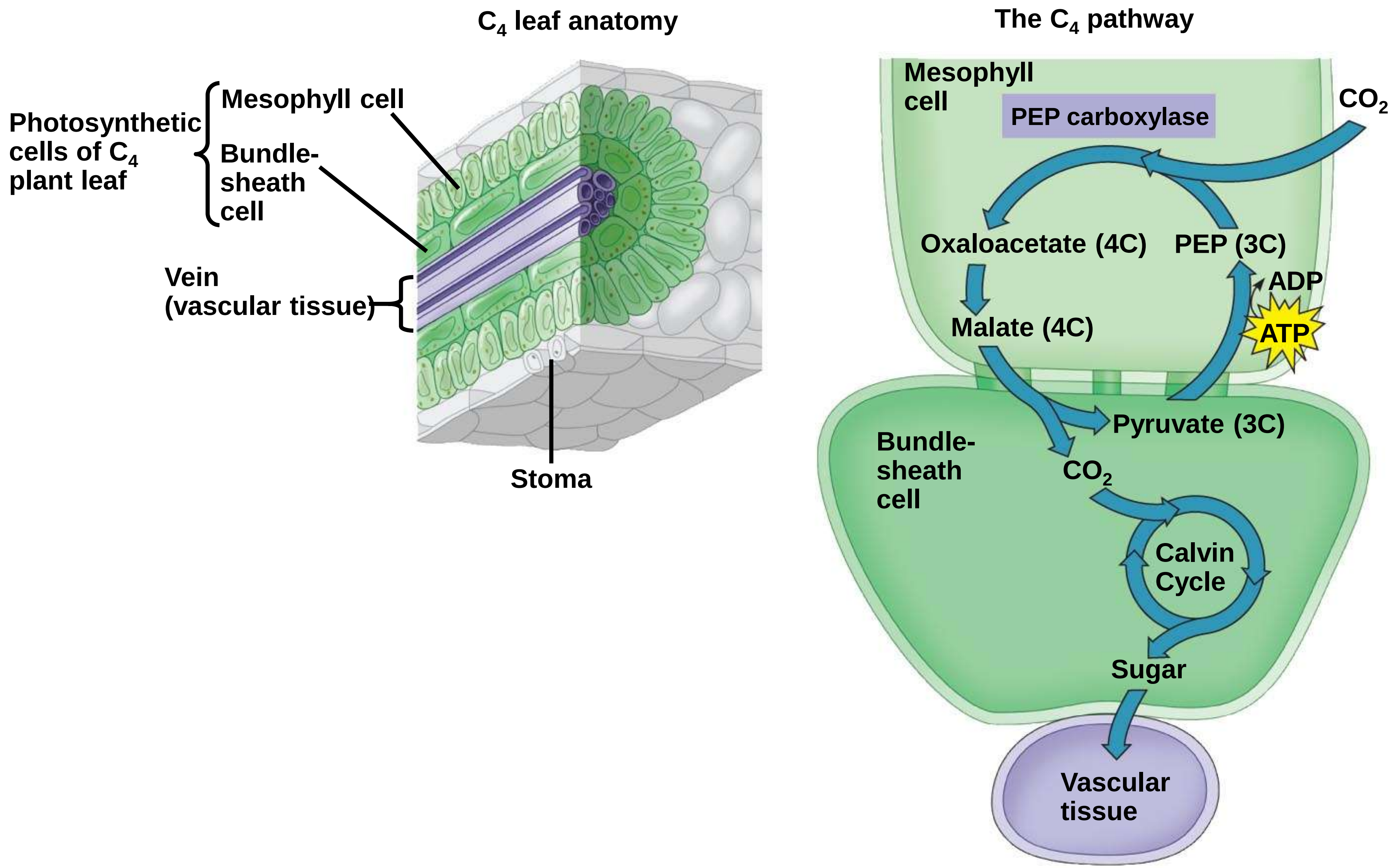
- In most plants (**C_3 plants**), initial fixation of CO_2, via rubisco, forms a three-carbon compound
- In **photorespiration**, rubisco adds O_2 instead of CO_2 in the Calvin cycle
- Photorespiration consumes O_2 and organic fuel and releases CO_2 without producing ATP or sugar

- Photorespiration may be an evolutionary relic because rubisco first evolved at a time when the atmosphere had far less O_2 and more CO_2
- Photorespiration limits damaging products of light reactions that build up in the absence of the Calvin cycle
- In many plants, photorespiration is a problem because on a hot, dry day it can drain as much as 50% of the carbon fixed by the Calvin cycle

C_4 Plants

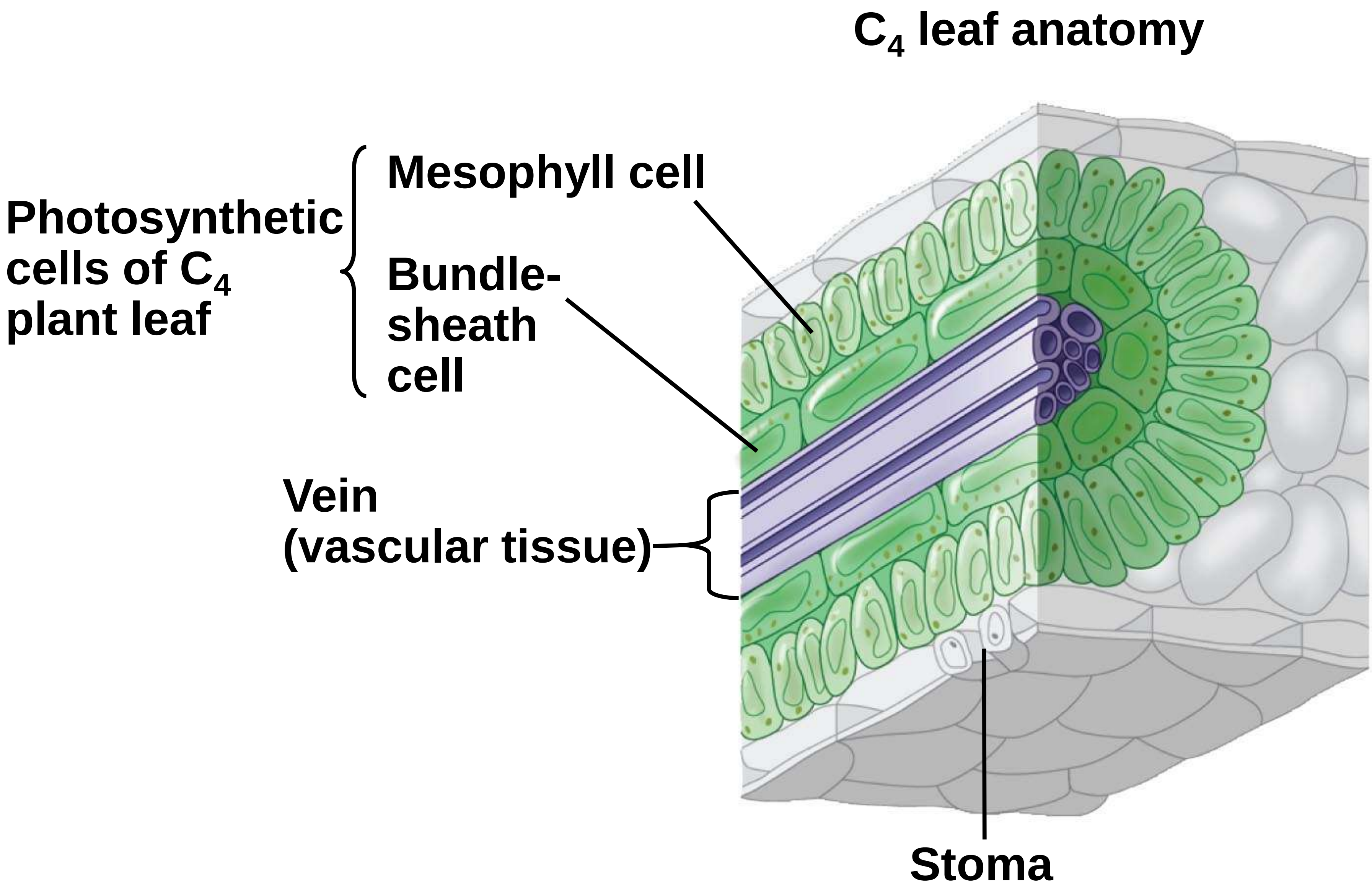
- **C_4 plants** minimize the cost of photorespiration by incorporating CO_2 into four-carbon compounds in **mesophyll cells**
- This step requires the enzyme **PEP carboxylase**
- PEP carboxylase has a higher affinity for CO_2 than rubisco does; it can fix CO_2 even when CO_2 concentrations are low
- These four-carbon compounds are exported to **bundle-sheath cells**, where they release CO_2 that is then used in the Calvin cycle

Fig. 10-19



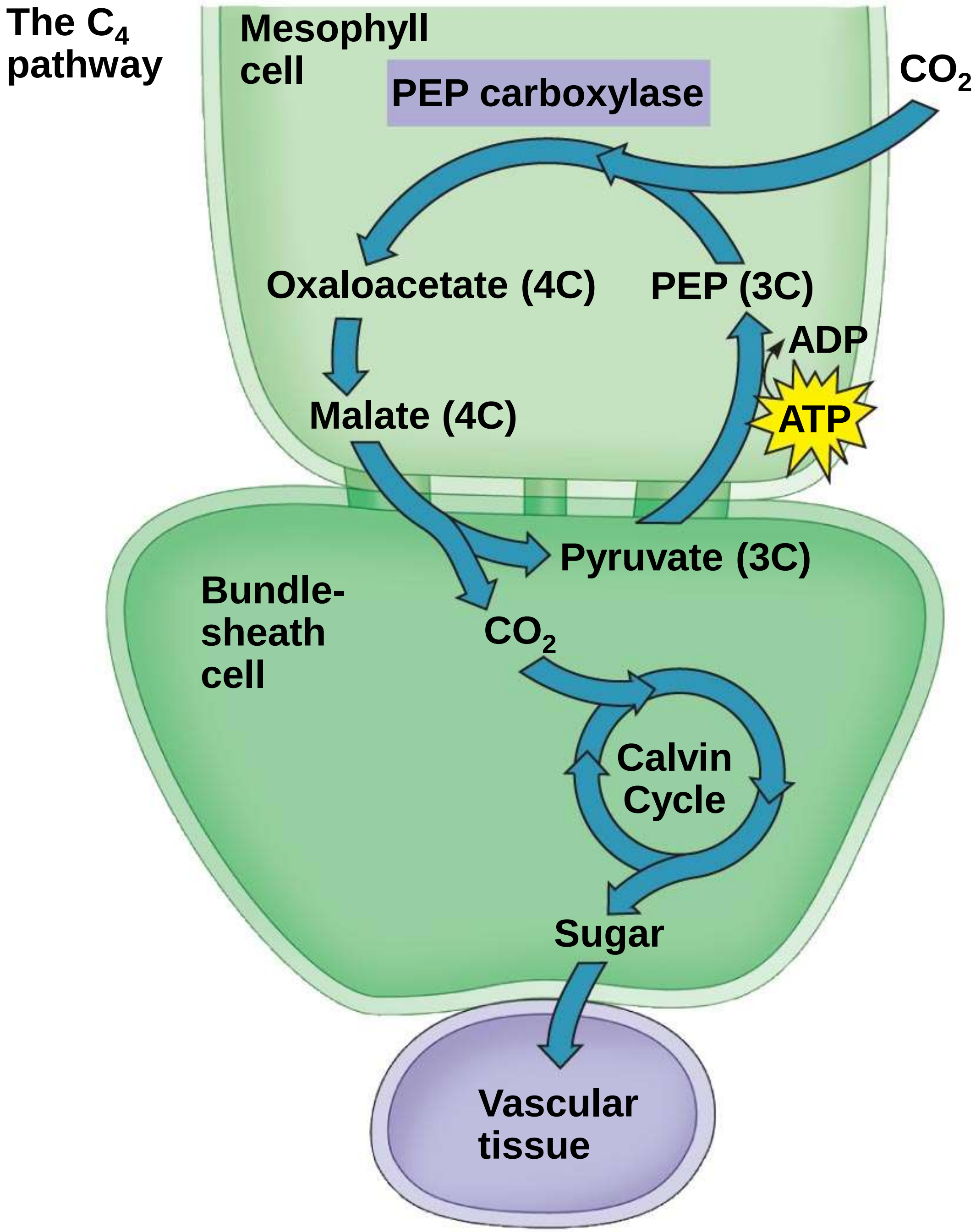
C4 leaf anatomy
Photosynthetic cells of C4 plant leaf
Mesophyll cell
Bundle-sheath cell
Vein (vascular tissue)
Stoma
The C4 pathway
Mesophyll cell
PEP carboxylase
CO2
Oxaloacetate (4C)
PEP (3C)
ADP
ATP
Malate (4C)
Pyruvate (3C)
Bundle-sheath cell
CO2
Calvin Cycle
Sugar
Vascular tissue

Fig. 10-19a



C_4 leaf anatomy
Photosynthetic cells of C_4 plant leaf
Mesophyll cell
Bundle-sheath cell
Vein (vascular tissue)
Stoma

Fig. 10-19b

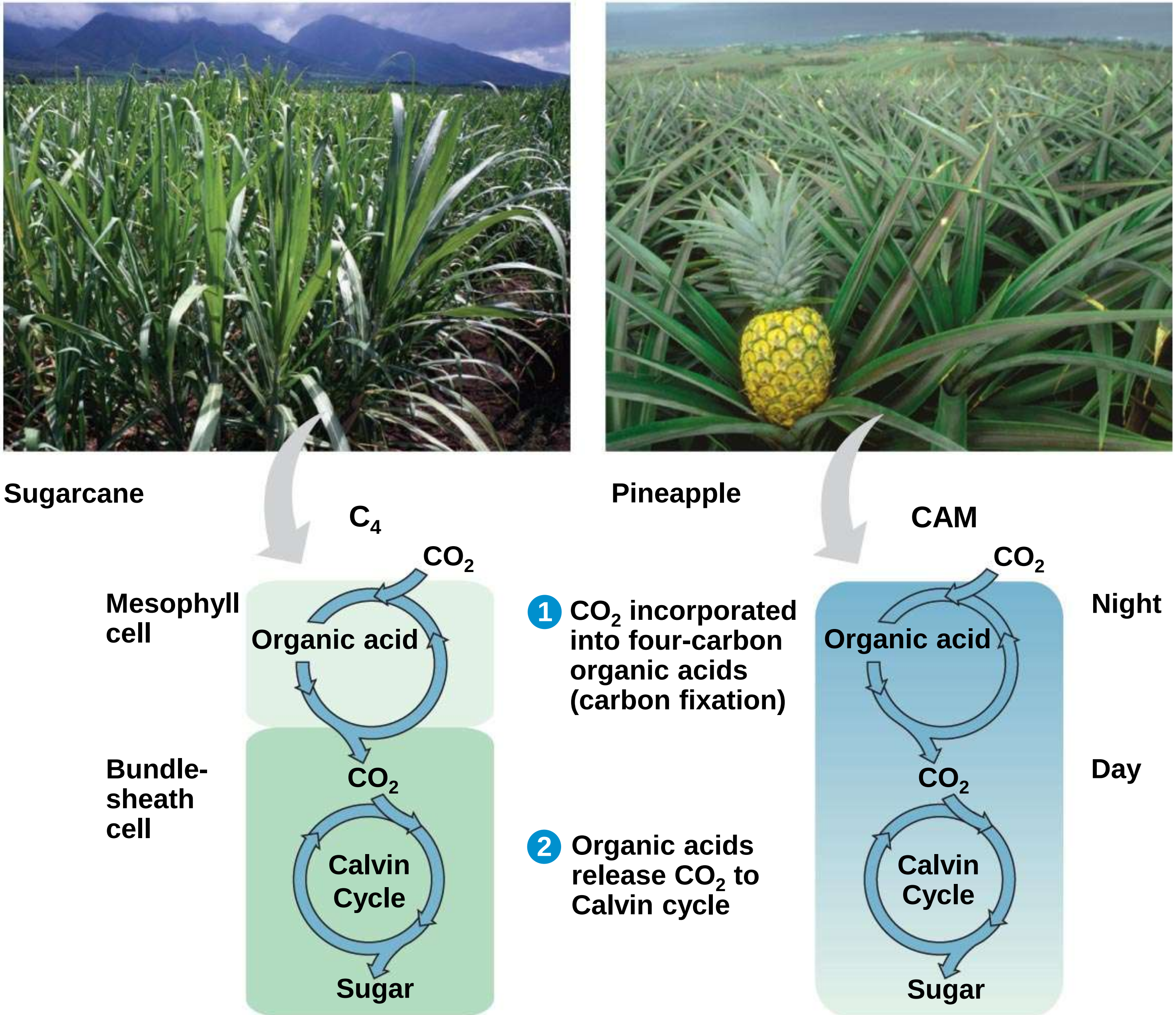


The C_4 pathway
Mesophyll cell
PEP carboxylase
CO_2
Oxaloacetate (4C)
PEP (3C)
ADP
Malate (4C)
ATP
Pyruvate (3C)
Bundle-sheath cell
CO_2
Calvin Cycle
Sugar
Vascular tissue

CAM Plants

- Some plants, including succulents, use **crassulacean acid metabolism (CAM)** to fix carbon
- **CAM plants** open their stomata at night, incorporating CO_2 into organic acids
- Stomata close during the day, and CO_2 is released from organic acids and used in the Calvin cycle

Fig. 10-20



(a) Spatial separation of steps

(b) Temporal separation of steps

Chapter 5

Roots, Soils, and Nutrient Uptake

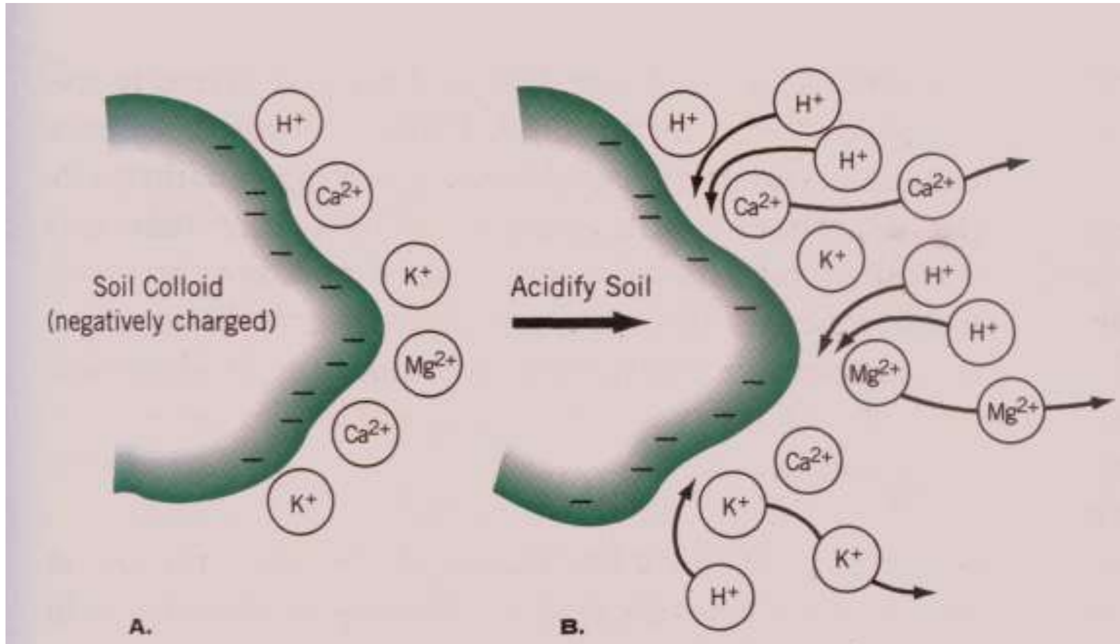
- With the exception of carbon and oxygen, plants generally take up nutrient elements from the soil solution through the root system.
- soil consists of a solid phase comprised of mineral particles, organic material, water or the soil solution, gasses, and a variety of microorganisms.
- Availability of nutrient elements is
- Availability of nutrient elements governed by soil properties.
- Access to elements is enhanced by the continual growth of the root system into new regions of the soil.

THE SOIL AS A NUTRIENT RESERVOIR

- The mineral component of soils consisted predominantly of **sand, silt, and clay,** which are differentiated on the basis of particle size.

Particle class	Particle size (mm)	Water retention	Aeration
Coarse sand	2.00-0.2	Poor	Excellent
sand	0.20-0.02	Poor	Excellent
Silt	0.02-0.002	good	good
Clay	<0.002	Excellent	Poor

- **Colloids** are particles small enough to remain in suspension but too large to go into true solution.
- Colloidal clay characteristics :
- large specific surface area
- numerous negative charges on the colloid surface that are able to bind **cations.**
- Many soils also contain colloidal carbonaceous residue, called **humus,** which is organic material that has been slowly but incompletely degraded to colloidal dimension through the action of weathering and microorganisms.
- Colloids, whether mineral or organic, are highly hydrated. forming a hydration shell.



- The association of cations with negative surfaces depends on electrostatic interactions; hence, binding affinity varies:
- $Al^{3+} > H^{+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$
- Both the degree of association and ion concentration decline in a continuous gradient with increasing distance from the surface of the colloid.

- As the soluble nutrients are taken up by the roots from the dilute soil solution, they are continually replaced by exchangeable ions held in the colloidal reservoir.
- Roots secrete hydrogen ions, which assist in the uptake of nutrients.
- Nutrients supplied in the form of anions, in particular nitrogen (NO_3^-), must be provided in large quantity to ensure sufficient uptake by the plants.

MEMBRANE TRANSPORT

- Solutes cross membranes by:
- **Simple diffusion**, nonpolar solutes (O_2, CO_2, NH_3) and Water
- **Facilitated diffusion**
- **Active transport**. to accumulate solutes in the cell when solute concentration in the environment is very low. active transport systems move solutes against a concentration or electrochemical gradient

SELECTIVE ACCUMULATION OF IONS

- two characteristics of solute transport across the membranes of all cells: **accumulation** and **selectivity.**

	Accumulation Ratio		
Ion	C^o (m)	C^i (m)	$[C^i/C^o]$
K^+	0.14	160	1142
Na^+	0.51	0.6	1.18
NO_3^-	0.13	38	292
SO_4^{2-}	0.61	14	23

ELECTROCHEMICAL GRADIENTS AND ION MOVEMENT

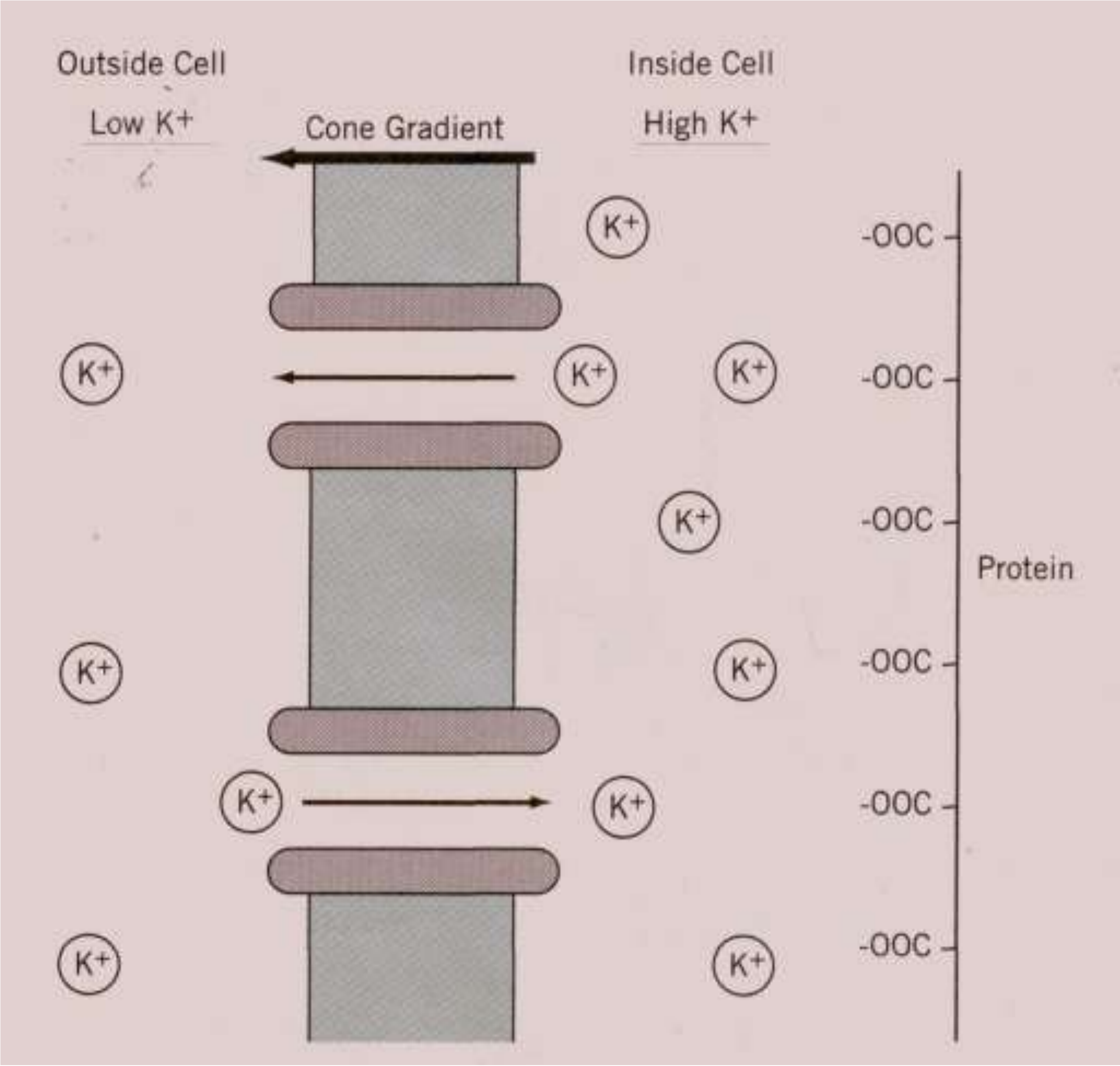
- The movement of ions is determined by a gradient that has two components: one concentration and one electrical.
- The cytosol contains charges. At the same time, cells use energy to actively pump cations, in particular H^+, Ca^{2+}, and Na^+, into the exterior space. The resulting unequal distribution of cations establishes a potential difference, or voltage, across the membrane.

assumed that:

(a) the internal K+ concentration is high relative to that outside the cell

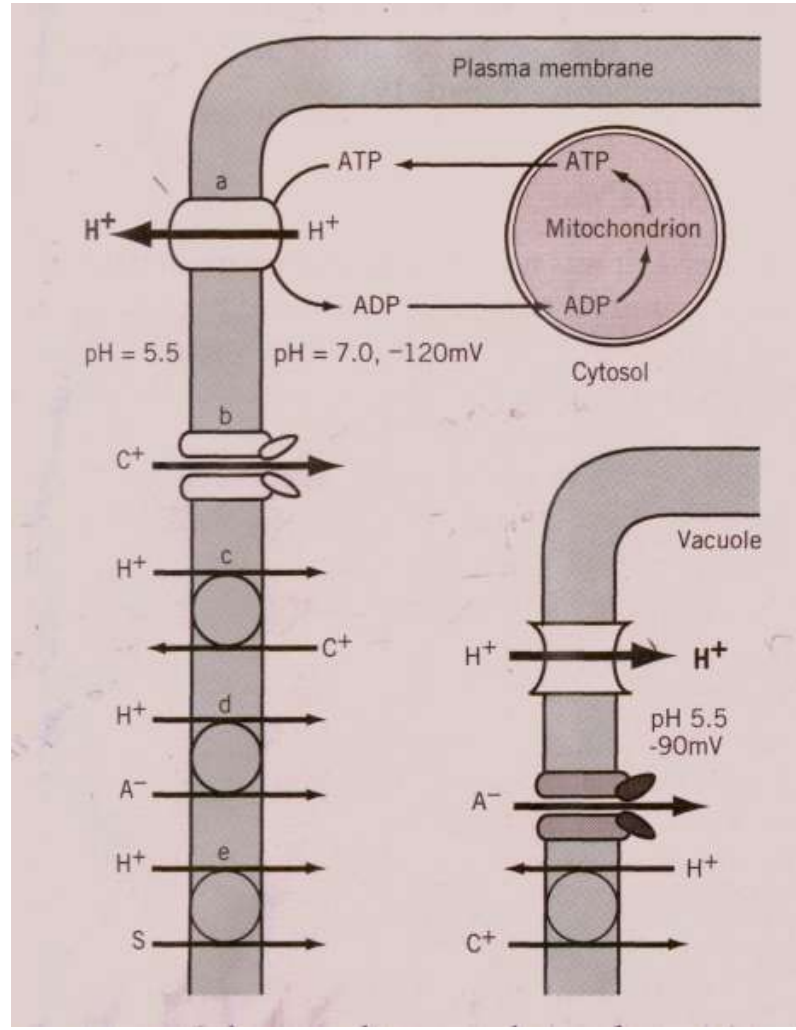
(b) K+ can move freely across the membrane, perhaps through K+ channels

(c) the internal K+ concentration is balanced by a number of organic anions restrained within the cell



ATPase-proton pumps

- The proton pump
- *(a)* uses the energy of ATP to establish both a proton gradient and a potential difference (negative inside) across the membrane.
- *(b)* activate an ion channel
- *(c)* drive the removal of ions from the cell by an antiport carrier,
- *(d)* drive the uptake of ions
- *(e)* or uncharged solute by a symport carrier.



- **Aquaporins:** integral membrane proteins that appear to function as water-selective channels
- Aquaporins are channel-forming proteins that facilitate the diffusion of water through membranes.
- The driving force behind water movement is the difference in water potential.

ION UPTAKE BY ROOTS

TABLE 5.3 **Uptake and translocation of potassium and calcium as a function of position along a corn root.**

Zone of application[1]	Ion	Total Uptake[2]	Percent Retained	Percent translocated to Root Tip	Percent translocated to Shoot
0–3	K^+	15.3	75	—	25
	Ca^{2+}	6.3	63	—	37
6–9	K^+	22.7	17	19	64
	Ca^2	3.8	42	—	58
12–15	K^+	19.5	10	10	80
	Ca^{2+}	2.8	14	—	86

- **ROOT-MICROBE INTERACTIONS**
  - **Bacteria and mycorrhiza**

Self reading!!!!!!!!!!!!!!!!!

Chapter 4
Plants and inorganic nutrients

- Essential nutrient elements:
  - With out is plants is unable to complete normal life cycle (no seeds).
  - Element is part of essential plant constituent or metabolites (Mg- constitute of chlorophyll).
  - 17 elements are essential for growth for higher plants.
  - See (Table 4.2). Differentiate between macronutrients and micronutrients, and available form.

- Macronutrients: required in large amounts.
- Micronutrients : required in small amounts.

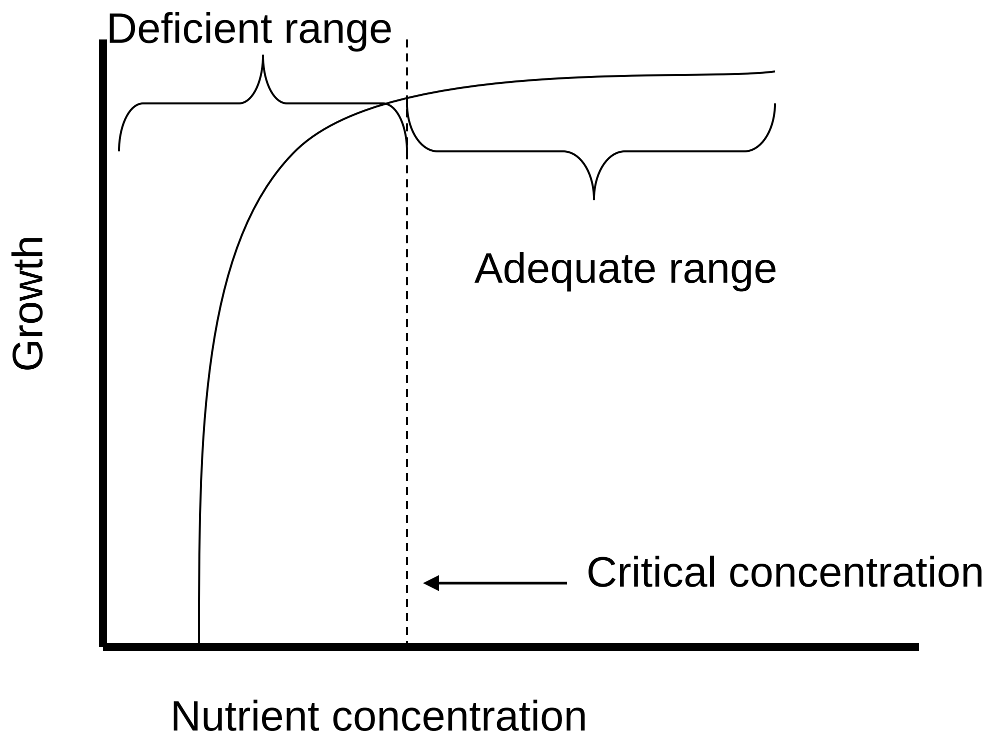
- This classification does not reflect amount of application (example, availability of Fe).

- At high pH Fe form insoluble iron hydroxide, and in acidic reacts with Al and precipitate.

- Beneficial elements: sodium, silicon, cobalt, and selenium.

Nutrient roles ad deficiency symptoms

- **Critical concentration**: concentration of nutrient in plant tissues, just below the level which gives maximum growth.



- Each nutrient element has one or more specific structural or functional role in the plant.
- Absence of an element cause morphological or biochemical symptoms. (chlorosis occur in the absence of Mg).
- Deficiency symptoms depend on the mobility of an element in the plant.
  - Deficiency of mobilize elements appear first in older tissues.
  - Deficiency of immobilize elements appear first in developing or younger tissues.

Nitrogen

- Most plants absorbs nitrogen from the soil solution as inorganic nitrate ions (NO^-_3) or some times as (NH^+_4).
- Nitrogen is most often limiting in agriculture.
- Nitrogen is a constituent of important molecules including proteins, nucleic acids, some hormones and chlorophyll.

Nitrogen, cont'd

- Deficiency symptoms:
  - Stunted growth
  - Leaves chlorosis
- Nitrogen is very mobile in plants, deficiency symptoms appear first in older leaves and do not occur in the younger leaves until deficiency is severe.
- Excess nitrogen stimulate high root/shoot ratio, delay flowering (deficiency stimulate flowering).

Phosphorous

- Available in the soil solution as forms of **polyprotic** phosphoric acid (H_3PO_4).
- Availability of phosphorous depend on soil pH.
- $H_2PO^{-}_4$ is the predominant form of phosphorus at pH less than 6.8 and readily absorbed by roots.
- HPO^{-2}_4 is the predominant form of phosphorus at pH between 6.8 and 7.2, less readily absorbed by roots.
- HPO^{-3}_4 the predominant form of phosphorus in alkaline soils, unavailable for uptake by plants.
- Usually concentration of soluble P is low:
  - At nutral pH, P form insoluble complexes with Al and Fe.
  - At basic soils P form insoluble complexes with Ca and Mg

Phosphorous, cont’d

- Phosphorus found combine with other molecules which play important roles in photosynthesis, and is part of DNA, RNA, phospholipids, ATP.
- Deficiency symptoms:
  - Intense green coloration of leaves.
  - Leaves malformation and necrosis
  - Shortened and cylinder stems.
  - Reduced fruits and seeds yield
- Phosphorous is readily mobilized, deficiency symptoms appear first in older leaves.
- Excess of phosphorous has opposite effect of nitrogen, highly applied when transplanting perennial plants

Potassium

- Available as K^+, applied as Potash (K_2CO_3).
- Deficient in sandy soils.
- K^+, activate enzymes involved in photosynthesis and respiration.
- Has important function in osmoregulation.
- Plant movement, change daily leaves orientation, and opening and closing of guard cells.
- Highly mobile, deficiency symptoms appear first in older leaves.
- Deficiency symptoms:
  - Chlorosis, followed by necrosis at the leaf margins.
  - Shortened and weakened stems. (lodged)
  - Plants become more susceptible to root-rotting.

Sulfur

- Available as SO^{2-}_4
- Sulfur deficiency is not a common problem.
- Important in the structure of proteins.
- Sulfur is important in respiration and fatty acid metabolism (constituent of coenzyme A).
- Iron-sulfur proteins important in electron transfer reactions of photosynthesis and nitrogen fixation.

Sulfur, cont,d

- Deficiency symptoms:
  - Leaf chlorosis, including the tissues surrounding the vascular buddles. (resulted from reduced protein synthesis).

- sulfur is **not** readily mobilized, deficiency symptoms appear first in younger leaves.

Calcium

- Available for plant as $Ca^{2+.}$
- Abundant in most soils.
- Important is cell division.
- Important in membrane integrity and function.
- Calcium is **not** readily mobilized, deficiency symptoms appear first in younger leaves
- Deficiency symptoms appear in the meristematic regions:
  - Deformed and necrotic young leaves
  - Death of meristem may follow.
  - Poor root growth in solution cultures
  - Discolored roots and slippery to touch

Magnesium

- Available for plant as Mg^{2+}.
- Required by plants in large amounts.
- Deficient in strongly acid sandy soils.
- Found in large proportion in chlorophyll molecule.
- Required to stabilize ribosome structure
- Activator for many critical enzymes in photosynthesis.
  - Ribulosebiphosphate carboxylaze and phosohoenolpyrovate carboxylase
  - Link ATP molecules to the active site of the enzyme.

Deficiency symptoms of Mg:

- Leaf chlorosis due to breakdown of chlorophyll in the leaves (the interveinal regions).
- Mg is quite mobile, deficiency symptoms appear first in older leaves

Iron

- Required relatively in large amounts.
- Available forms, (Fe^{3+}, Fe^{+2}).
- Importace:
  - Part of catalytic group for many redox enzymes
  - Required for synthesis of chlorophyll
- Deficiency symptoms:
  - Loss of chlorophyll and degeneration of chloroplast structure.
  - Mobility of iron is very low, chlorosis appear first in the interveinal regions of the youngest leaves.
  - Deficiency of iron is common because of the high tendency of Fe^{3+} to form hydrous oxides at biological pH, specially in nutral or alkaline soils.
  - In strongly acidic soils, iron is very soluble (toxicity)

- Chelated iron used to solve iron deficiency (to the soil or foliar spray).
- Chelate: stable complex formed between a metal ion and organic molecule.
- Ethylendiaminetetraacitic acid (EDTA) is a common chelating agent, can bind a range of cations (iron, zinc, manganese, and calcium).

Boron

- Found as boric acid (H_3BO_3)
- Available form is Bo_3^{3-}
- Important in the cell wall integrity.
- Stimulate pollen tube germination and elongation.
- Cell division and elongation (shoots and roots). Shorten internodes
- Necrosis of meristem

Copper

- Available as Cu^{2+}.
- Forms a chelate with humic acids.
- Copper function as a cofactor for many oxidative enzymes.
- Deficiency symptoms:
  - Stunted growth
  - twist of youngest leaves and dieback

Zinc

- Available form is Zn^{2+}.
- Activator of a large number of enzymes.
- Deficient plants have shortened internodes and smaller leaves.
- Zinc deficiency associated with auxin metabolism. Auxin levels decline before symptoms appear, and increased when zinc supplied, then plants resume growth.

Manganese

- Available as Mn^{2+}
- Required as a cofactor for a number of enzymes.
- Hardly absorbed at pH<6 and high organic content.
- Deficiency symptoms:
  - Grey speck at the basal region of young leaves of cereal grains.
  - Discoloration and abnormality of legume seeds

Molybdenum

- Available as Mo_4^{2-}.
- Primary related to nitrogen metabolism.
- Part of:
  - **dinitrogenase**: used by prokaryotes to reduce atmospheric nitrogen.
  - **nitrate reductase**: found in roots and leaves, catalyses the reduction of nitrate to nitrite.
- Nitrogen fixation in legumes (deficiency of Mo give rise to symptoms of nitrogen deficiency).
- Deficiency of Mo caused whiptail (young leaves twisted and deformed).
- Hardly absorbed in acidic soils with high iron.

Chlorine

- Cl^- is ubiquitous in nature and highly soluble.
- Highly mobile
- Two main functions:
  - Maintain electrical neutrality across membranes.
  - One of the principal osmoticaly active solutes in the vacuole
- required for cell division
- Symptoms:
  - Reduced growth
  - Wilting of leaf tips.
  - General chlorosis

Nickel

- Available form is Ni^{2+}.
- Abundant in nature and readely absorbed by roots.
- Abundant in plant tissues and required in very low amounts.
- Related to nitrogen fixation

THE PLANT HORMONES

THE PLANT HORMONES

- **Plant hormones**: naturally occurring organic substances that profoundly influence physiological processes at low concentration.
- There are five recognized groups of plant hormones:
  - **Auxins**
  - **Gibberellins**
  - **Cytokinins**
  - **abscisic acid** (ABA)
  - **ethylene.**

In addition to two other groups **brassinosteroids and polyamines**

	Hormone Group				
	Auxin	Gibberellin	Cytokinin	Abscisic Acid	Ethylene
Dormancy		x	x	x	x
Juvenility	x	x			
Extension Growth	x	x	x	x	x
Root Development	x	x	x		x
Flowering	x	x	x	x	x
Fruit Development	x	x	x	x	x
Senescence	x	x	x		x

Auxins

- Auxins were the first plant hormones discovered.
- Auxins are synthesized in the stem and roots apices and transported through the plant axis.
- stimulate cell elongation in stem
- influence a host of other developmental responses, including:
  - root initiation, vascular differentiation, and the development of axillary buds, flowers, and fruits.

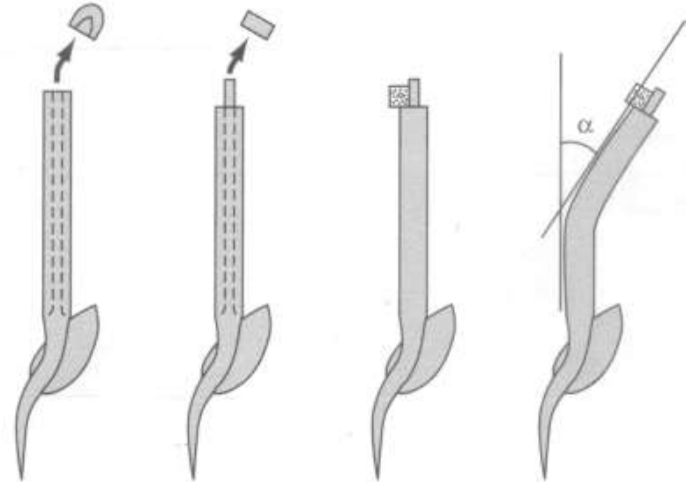
- The principal auxin in plants is indole-3-acetic acid (IAA)
- indole derivatives :
  - indole-3-ethanol,
  - indole-3-acetaldehyde
  - and indole-3-acetonitrile.

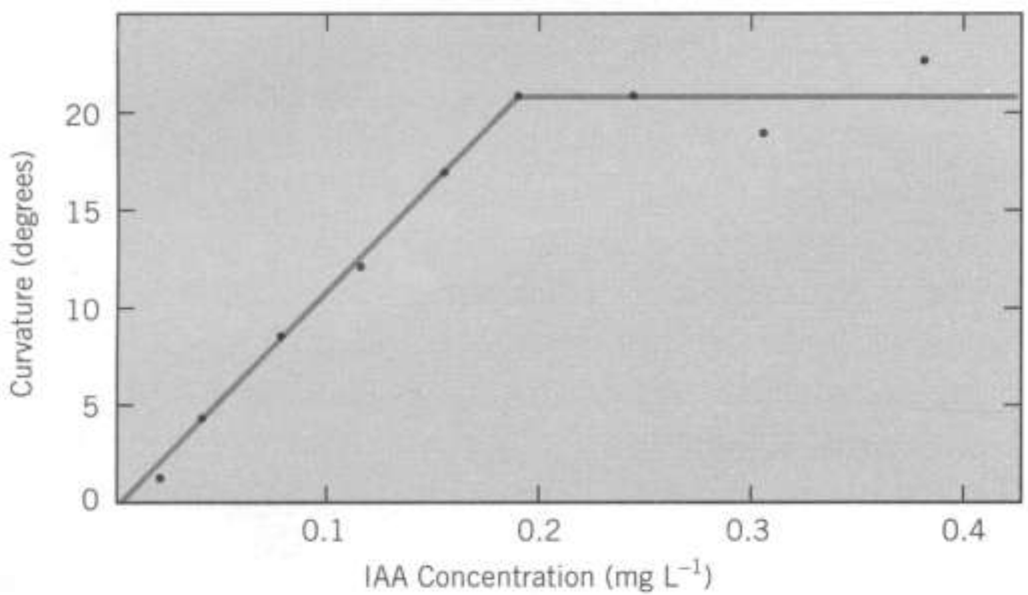
  these compounds all serve as **precursors** to IAA and their activity is probably due to conversion to IAA in the tissue.
- synthetic chemicals that express auxinlike activity such as **Indole butyric acid (IBA)**

physiological action of auxin

Cell Growth and Differentiation

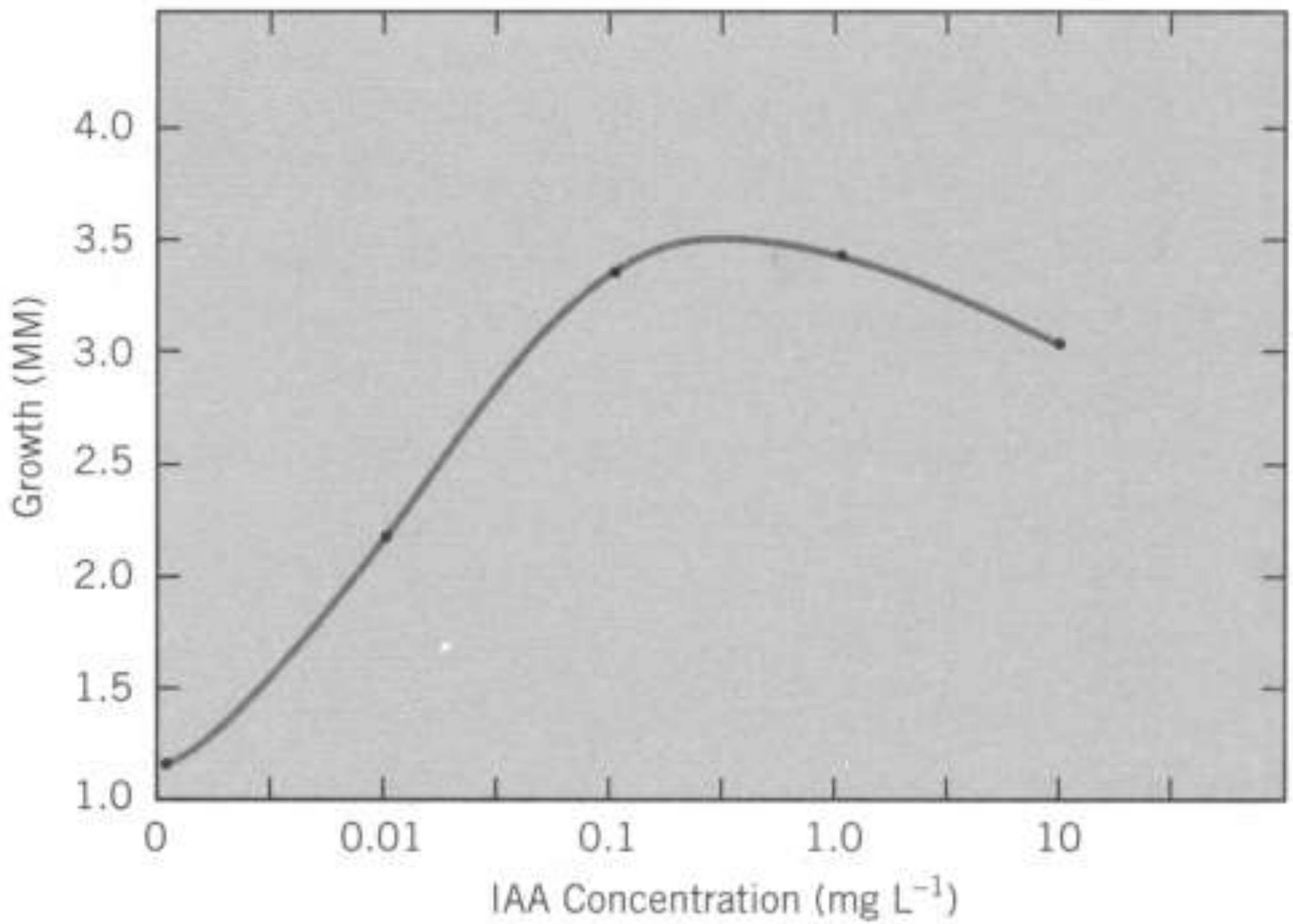
- auxin serves primarily to regulate cell growth.*and* stem elongation.
- Auxin regulated cell elongation
- Auxin regulate cellular differentiation (induction of vascular differentiation in shoots is controlled by auxin produced in young leaves)


α

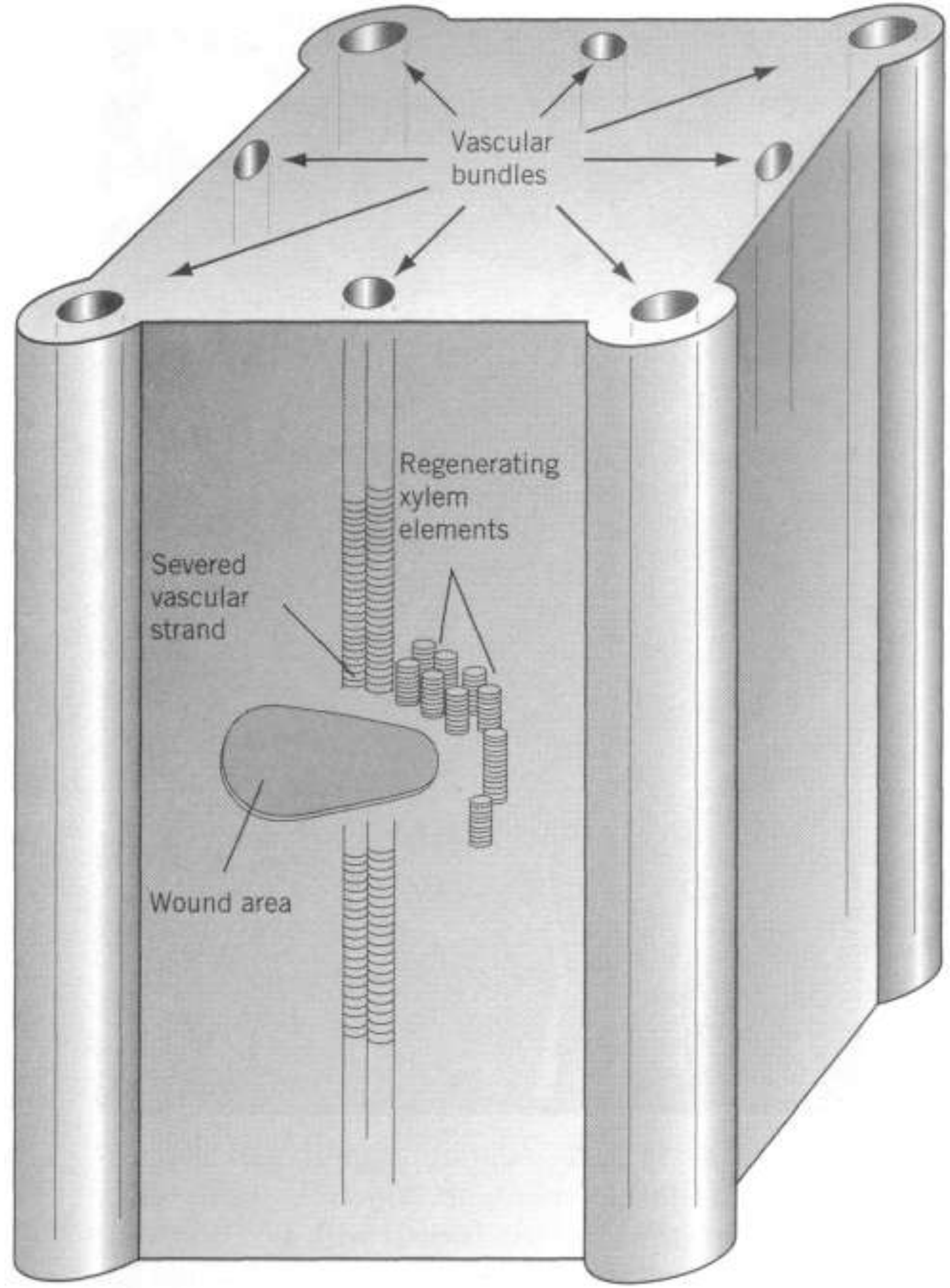

Curvature (degrees)
0
5
10
15
20
0.1
0.2
0.3
0.4
IAA Concentration (mg L⁻¹)

B.

- Auxin concentration-response curves



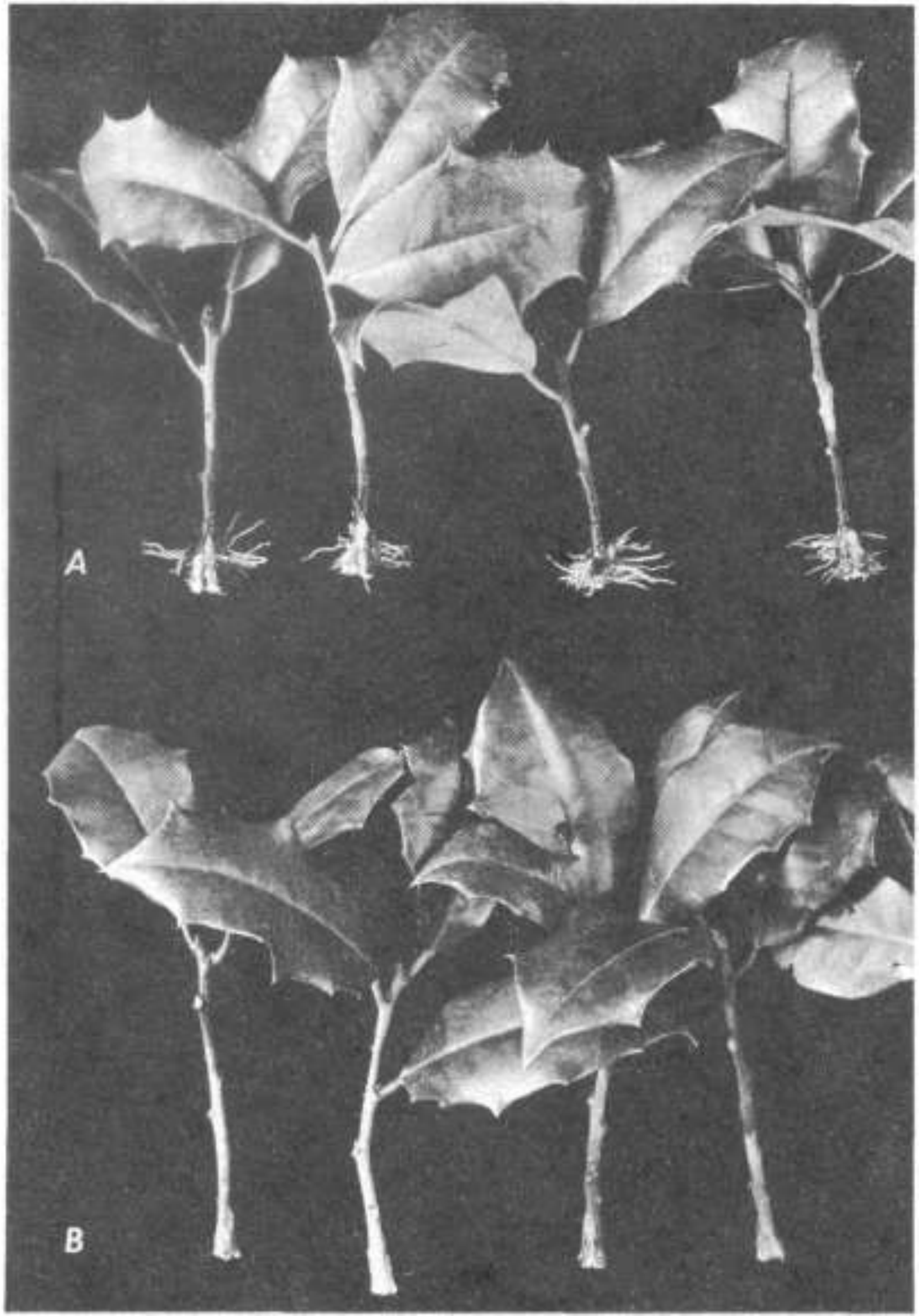
- The differentiation of both xylem elements and phloem sieve tubes around the wound is limited and controlled by auxin supply. This can be shown by removal of leaves (a source of auxin) above the wound



Shoot and root development

- Axillary Bud Growth (apical dominance)
- *Leaf Abscission*
- Abscission occurs as a result of the development of a special layer of cells, called the abscission layer,
- Abscission appears to be dependent on the relative concentrations of auxin on either side of the abscission layer.

- **Root *Elongation and Development***
- IAA promote the growth of roots but only at very low concentrations (10^{-8} M or less).
- Higher concentrations of auxin, in the range that normally stimulates elongation of shoots (10^{-5} to 10^{-6}M), cause a significant inhibition of root growth.
- Inhibition of root growth by auxin is at least partly due to ethylene production, which is stimulated by high auxin concentrations.
- High conc. Of Auxin inhibit root elongation and promote secondary roots


A
B

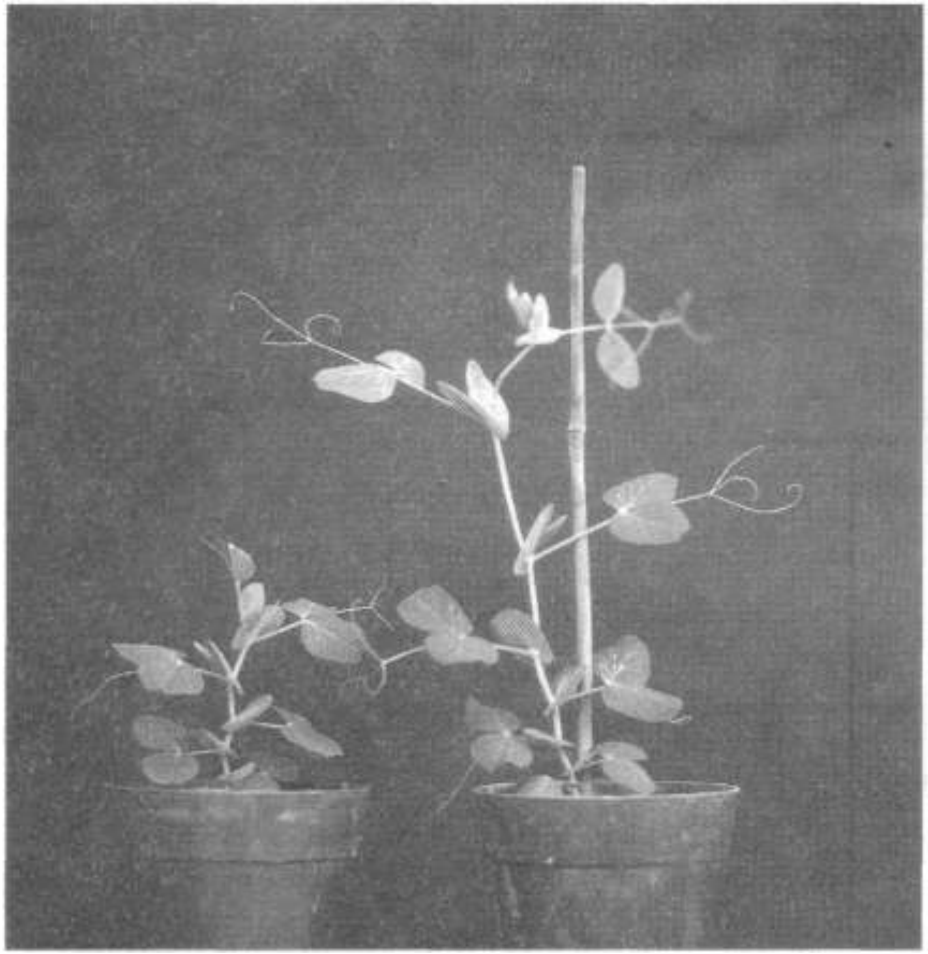
Flower *and Fruit* Development

- Once flowers have been initiated, auxin appears to play important roles in subsequent floral and fruit development
- Application of auxin during the bisexual stage ensures the formation of female flowers (auxin promotes femaleness in flowers).
- **Parthenocarpy:** fruit development in the absence of pollination
- Because parthenocarpy results in seedless fruits, the phenomenon has significant economic implications.
- Depending upon the timing and level of application, auxin may cause early fruit drop or prevent premature fruit drop.

GIBBERELLINS

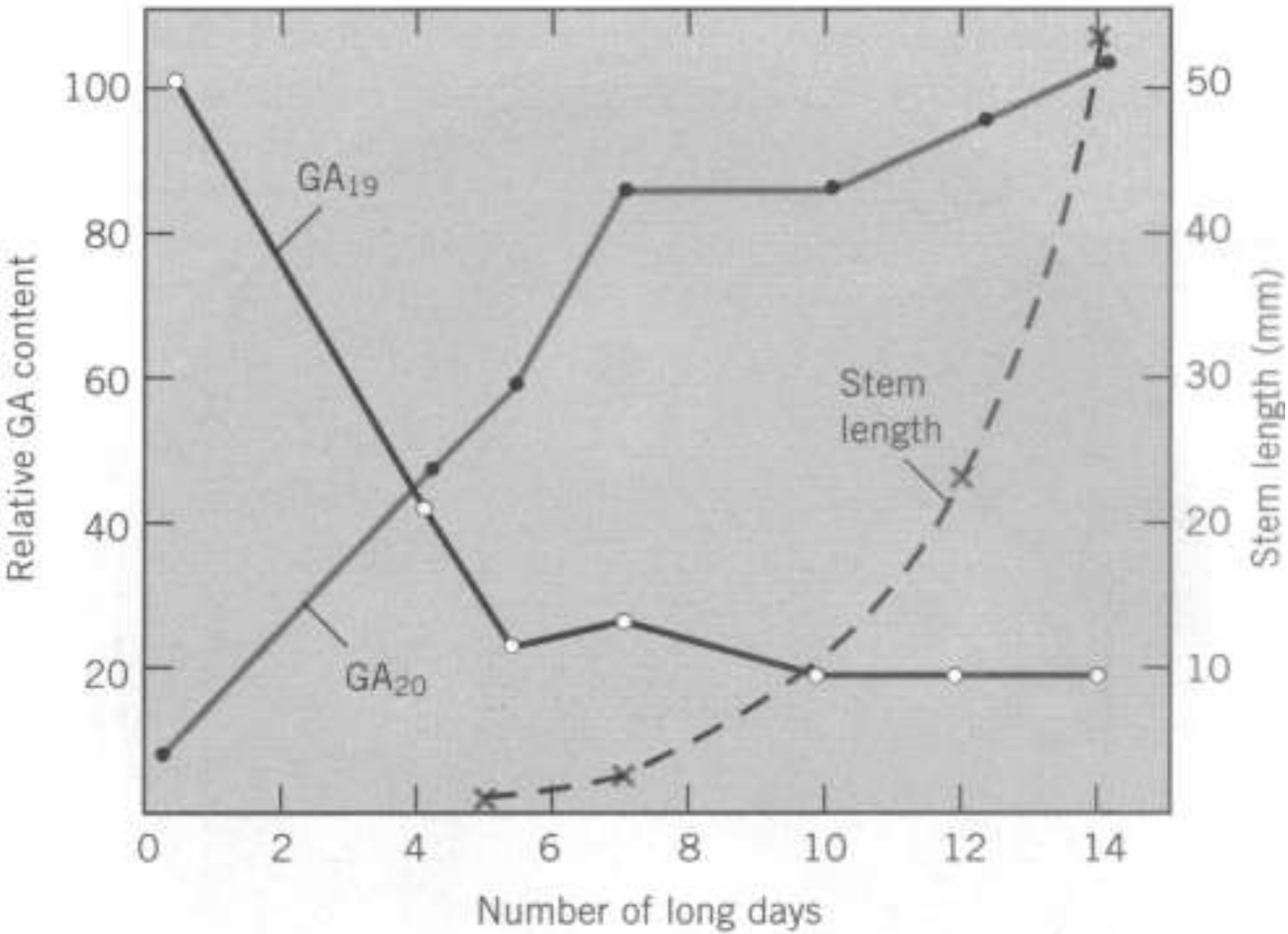
the physiological action of gibberellins

- ***Control of Shoot Elongation***
- gibberellins promote elongation
- application of exogenous gibberellin to the dwarf mutant restores a normal, tall phenotype.
- Exogenous gibberellin has no appreciable effect on the genetically normal plant.



Rosette Plants

- A rosette is an extreme case of dwarfism in which the absence of any signifant internode elongation results a compact growth habit characterized by closely spaced leaves.
- hyperelongation of stems in rosette plants is invariably brought about by the application of small amounts of gibberellin



100
80
60
40
20
50
40
30
20
10
0
2
4
6
8
10
12
14
GA_{19}
GA_{20}
Stem
length
Relative GA content
Stem length (mm)
Number of long days

Inhibition *of Stem Growth*

- The growth of many stems can be reduced or inhibited by synthetic chemicals that block gibberellin biosynthesis.
- Growth retardants or antigibberellins include AMO-1618, cycocel (or, CCC), Phosphon-D, ancymidol (known commercially as A-REST) and alar (or, B-nine)
- These inhibitors mimic the dwarfing genes by blocking specific steps in gibberellin biosynthesis, thus reducing endogenous gibberellin levels and suppressing internode elongation and commercially important.

Seed Germination

- gibberellic acid stimulate the the release of α-amylase

Flowering

- Self reading!!!!!!!!!!!

CYTOKININS

- ***Cytokinins*** are characterized by their ability to stimulate cell division in tissue culture.
- **zeatin is t**he most widespread naturally occurring cytokinin in higher plants**.**
- **Cytokinins:**
  - Stimulate cell division
  - Influence shoot and root differentiation in tissue culture
  - The growth of lateral buds and leaf expansion
  - Chloroplast development
  - Leaf senescence.

the physiological roles of cytokinins

Cell Division and Morphogenesis

- most mature, differentiated plant cells do not normally divide,
- cells may undergo division when cultured on artificial media containing vitamins, mineral salts a carbon source, and an optimal concentration of hormones.
- **callus tissue** a mass of largely undifferentiated cells
- Cell division and growth does not normally occur in the absence of cytokinin

- Cytokinins influence morphogenesis in cultured tissues.
- Maintenance of undifferentiated callus growth is generally achieved with equal molar concentrations of cytokinin and auxins.
- High molar ratios of cytokinin to auxin tend to induce bud development
- High ratios of auxin to cytokinin encourage root development

- Another example of cytokinin-mediated cell division is the development of tumorous growths (called **crown gall)** following bacterial infection.
- *Agrobacterium tumefaciens* is a bacterium capable of invading wounds or lesions and form large, undifferentiated cell masses, called crown gall tumors.
- These infected cells have been genetically transformed with the capacity to produced cytokinins.
- Crown gall tissue may be rid of viable bacteria by heating to a temperature of 42 °C.
- Bacteria-free tissue can then be **subcultured** in the absence of added cytokinin.
- The tumorous tissue, has the ability to produce cytokinins

Nutrient Mobilization and Senescence

Senescence is characterized by:

- the breakdown of protein, nucleic acids and other macromolecules
- a loss of chlorophyll
- the accumulation of soluble nitrogen products such as amino acids.

- Senescence is normal consequence of the aging process and will occur even when the supply of water and minerals is maintained

- three kinds of evidence indicating a role for cytokinins in control of senescence:
- First is the exogenous application of cytokinin to detached leaves:
  - delay the onset of senescence,
  - maintain protein levels
  - prevent chlorophyll breakdown.
  - Application of cytokinins delay the natural senescence of leaves on intact plants.

- The second kind of evidence consists of correlations between endogenous cytokinin content and senescence.
- when a mature plant begins its natural senescence, there is a sharp decrease in the level of cytokinins exported from the root
- For example, detached leaves that have been treated with auxin to induce root formation at the base of the petiole will remain healthy for weeks.
- the growing root is a site of cytokinin synthesis and the hormone is transported through the xylem to the leaf blade. If the roots are continually removed as they form, senescence of the leaf will be accelerated

- A third evidence comes from employing recombinant DNA techniques
- Tobacco plants *(Nicotiana tobacum)* have been transformed with the *Agrobacterium* gene for cytokinin biosynthesis, designated *tmr.*
- The *tmr* gene encodes for the enzyme iso-pentenyl transferase, which catalyzes the rate-limiting step in cytokinin biosynthesis .
- the *tmr* gene linked to a **heat shock promoter.**
- The heat shock response consists of the synthesis of a new set of proteins called the **heat shock proteins.**
- The heat shock promoter is active only when subjected to a high temperature treatment.

- cytokinin biosynthesis can be turned on in the transformed plants by subjecting the plants to a brief period at high temperature.

- a heat shock of 42 °C for 2 hours caused a 17-fold increase in zeatin levels in transformed plants compared with untransformed control plants

- transformed plants exhibited a marked release of lateral buds from apical dominance as well as delayed senescence.

Cytokinin control of senescence and bud growth in transformed, cultured tobacco plants. From left to right: transformed heat-shocked plants; untransformed heat-shocked plants; transformed controls; untransformed controls.

ABSCISIC ACID

- ABA induce transport of photosynthate toward developing seeds
- Promote the synthesis of storage protein.
- During germination of cereal grains, ABA antagonizes the promotory effect of gibberellin on α-amylase synthesis.
- large amounts of ABA are rapidly synthesized in the leaves in response to water stress
- has a major role in regulating stomatal opening and closure.

the physiological roles of abscisic acid

- When cytokinin declines and the seed enters a period of rapid growth, both GA and IAA increase, ABA is very low.
- During later stages of embryo development, GA and IAA begin to decline, ABA begin to rise
- ABA prevent **vivipary.**
- High concentrations of ABA completely close stomata
- water deficit induce fortyfold increase in the ABA level within 30 min.

Ethylene

- Ethylene synthesized primarily in response to stress.
- produced in large amounts by tissues undergoing; senescence or ripening.
- ethylene is frequently produced when high concentrations of auxins are supplied to plant tissues.

the physiological roles of ethylene

- Vegetative development
- Fruit development
- flowering

Self reading!!!!!!!!!!!!!!