Chapter 36

Resource Acquisition and Transport in Vascular Plants

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

Overview: Underground Plants

- The success of plants depends on their ability to gather and conserve resources from their environment
- The transport of materials is central to the integrated functioning of the whole plant
- Diffusion, active transport, and bulk flow work together to transfer water, minerals, and sugars

Fig. 36-1

Fig. 36-2-1

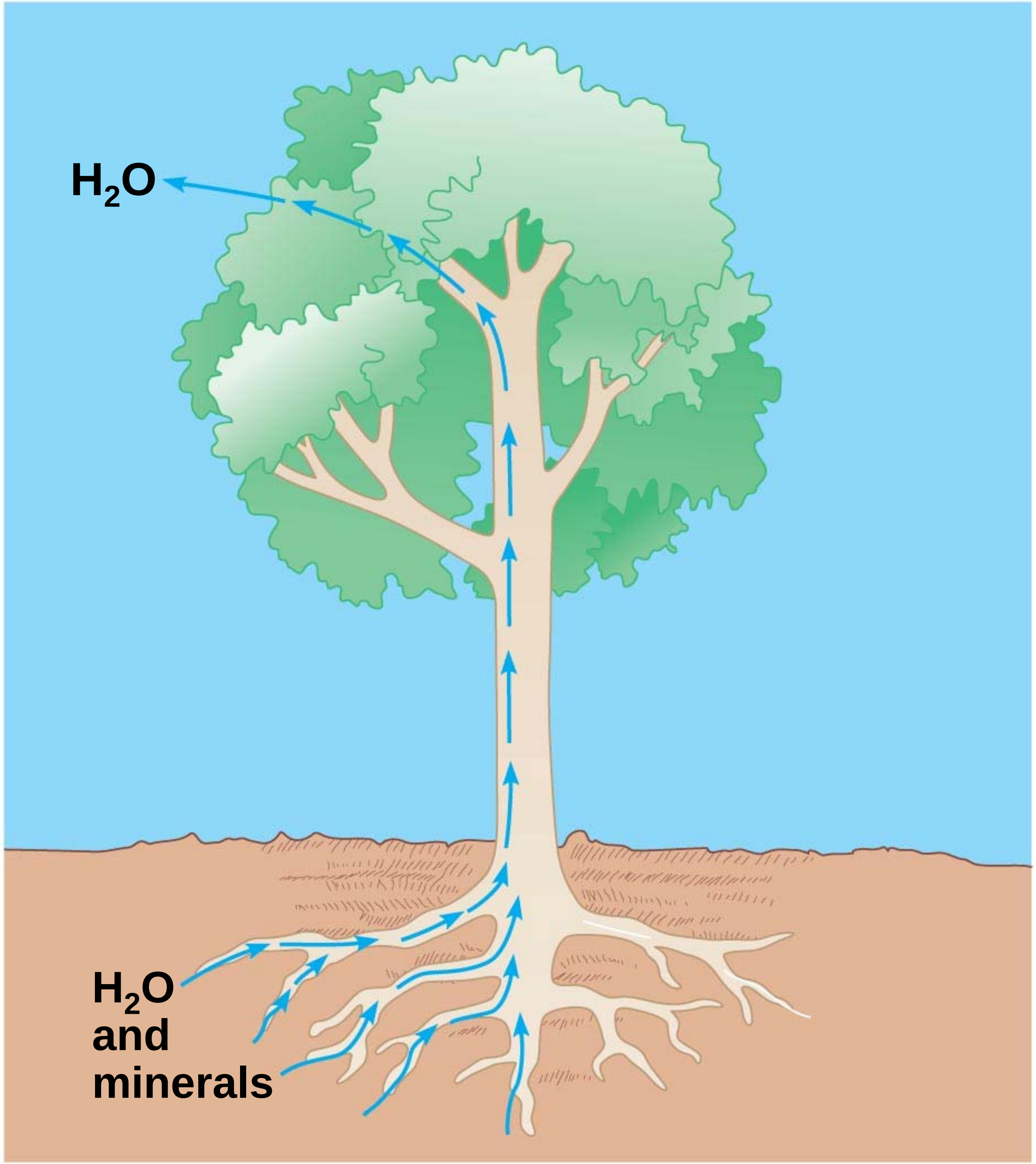


Fig. 36-2-2

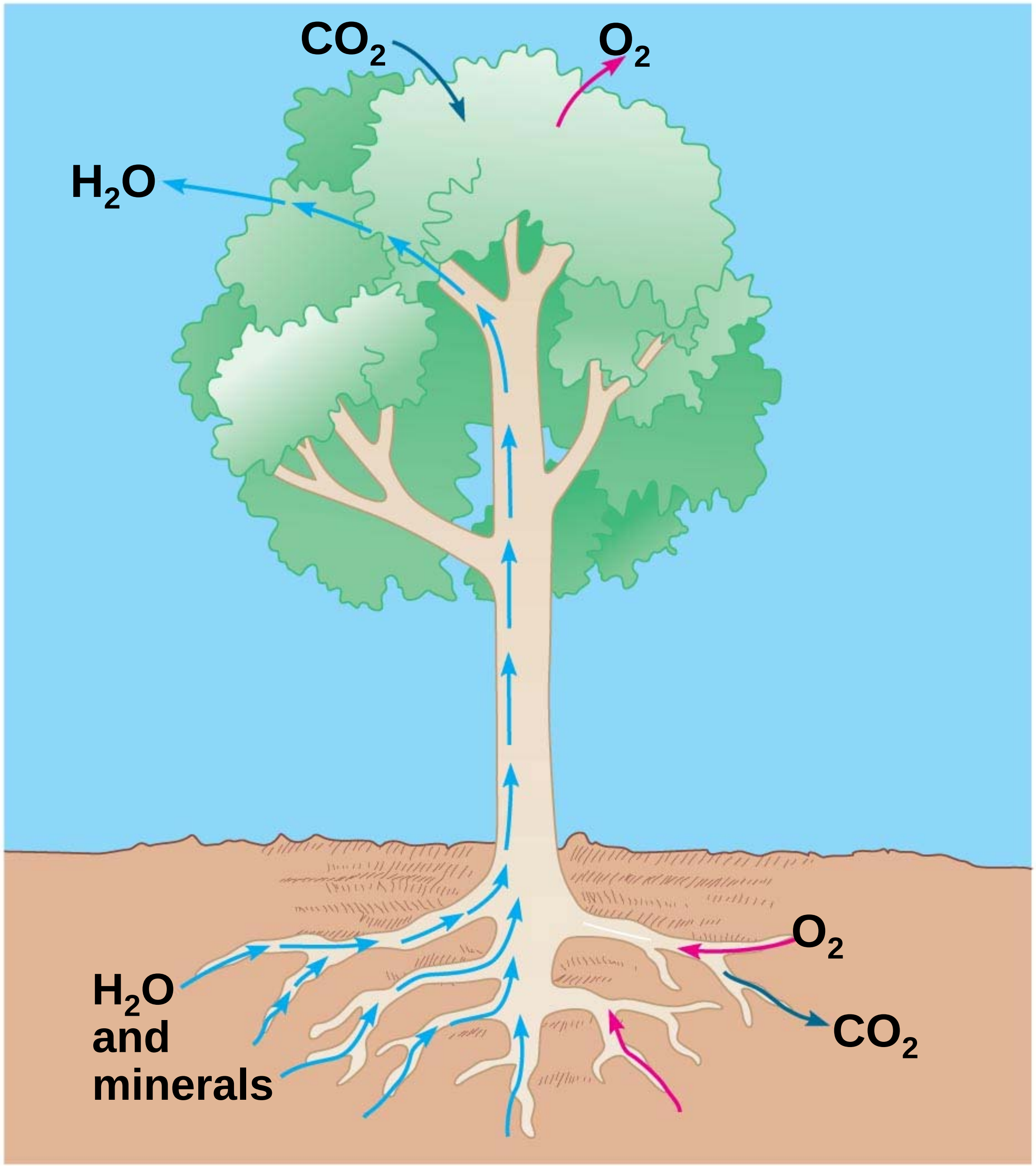
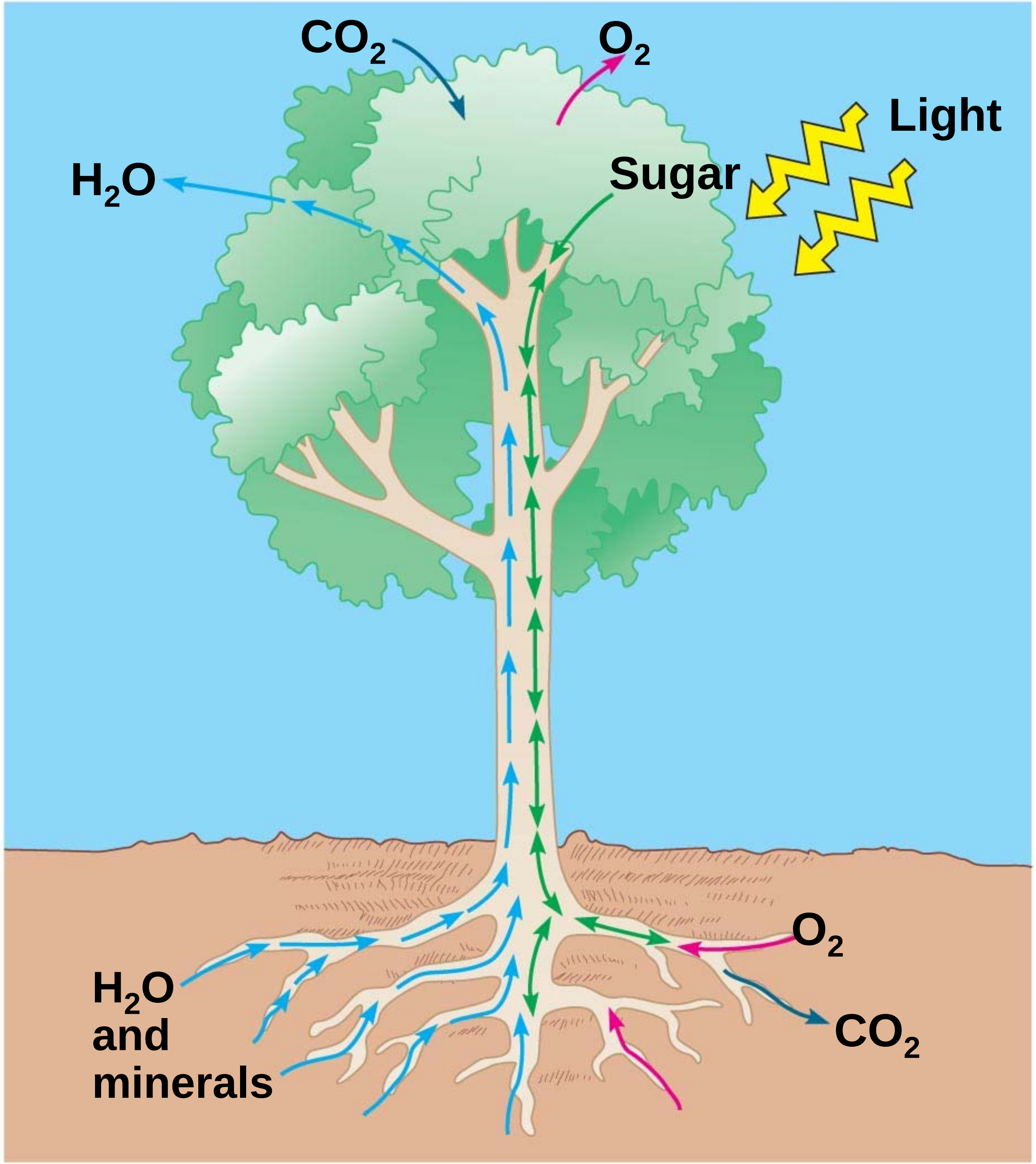


Fig. 36-2-3



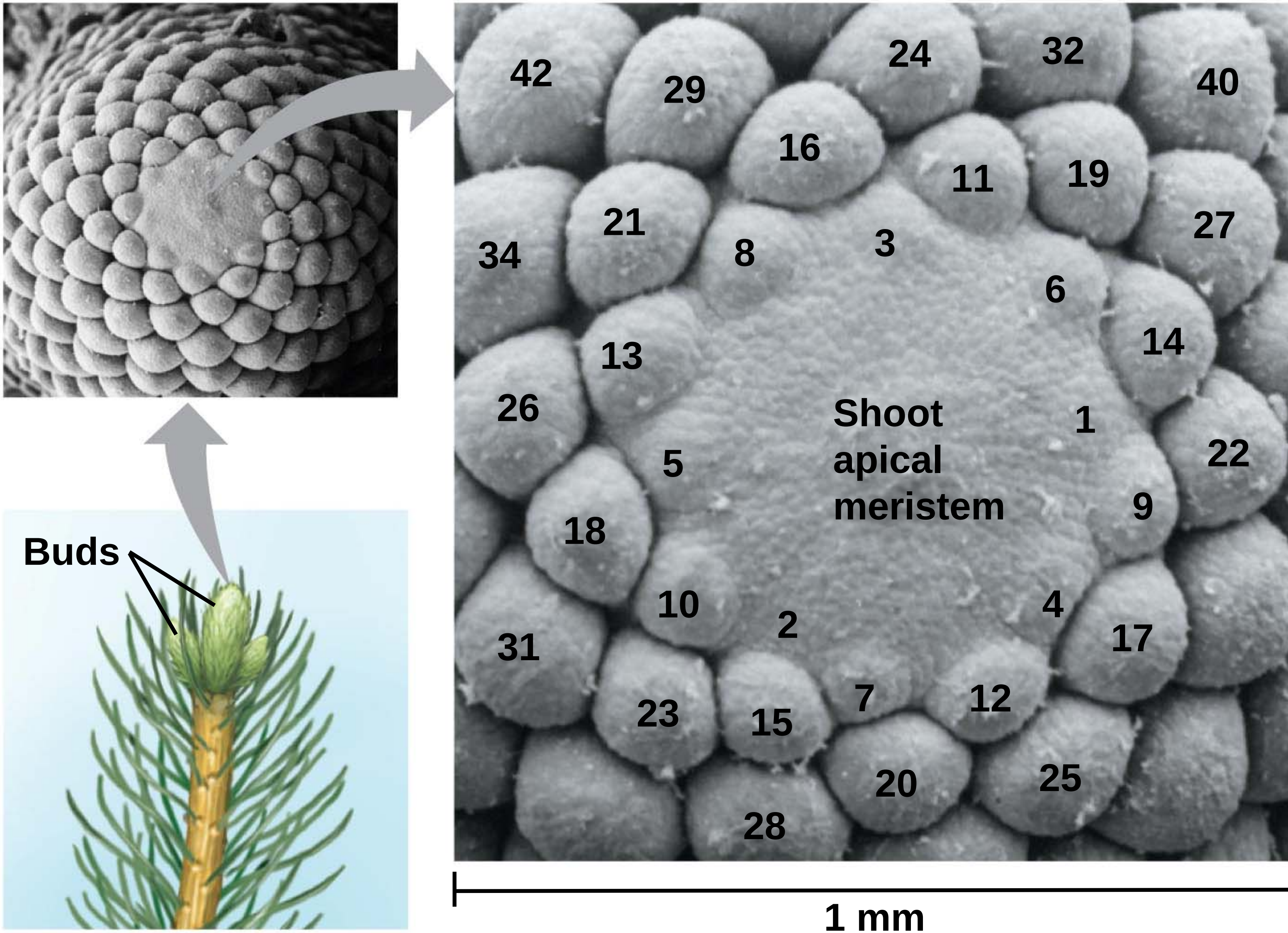
Concept 36.1: Land plants acquire resources both above and below ground

- The algal ancestors of land plants absorbed water, minerals, and CO_2 directly from the surrounding water
- The evolution of xylem and phloem in land plants made possible the long-distance transport of water, minerals, and products of photosynthesis
- Adaptations in each species represent compromises between enhancing photosynthesis and minimizing water loss

Shoot Architecture and Light Capture

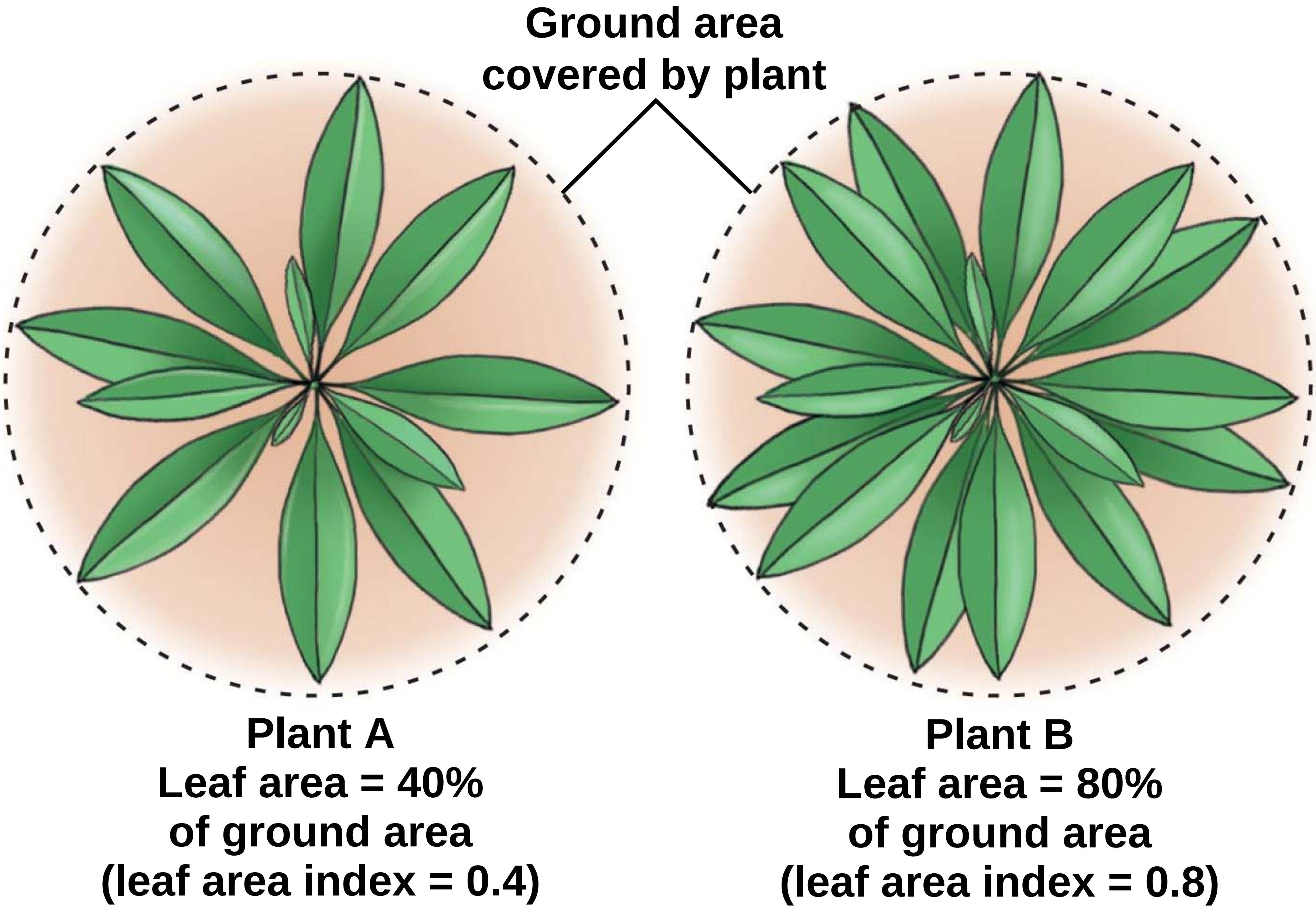
- Stems serve as conduits for water and nutrients, and as supporting structures for leaves
- **Phyllotaxy**, the arrangement of leaves on a stem, is specific to each species

Fig. 36-3


Buds
42
29
24
32
40
16
11
19
21
3
27
34
8
6
14
13
Shoot apical meristem
1
26
22
5
9
18
10
4
2
17
31
7
12
23
15
20
25
28
1 mm

- Light absorption is affected by the *leaf area index*, the ratio of total upper leaf surface of a plant divided by the surface area of land on which it grows
- Leaf orientation affects light absorption

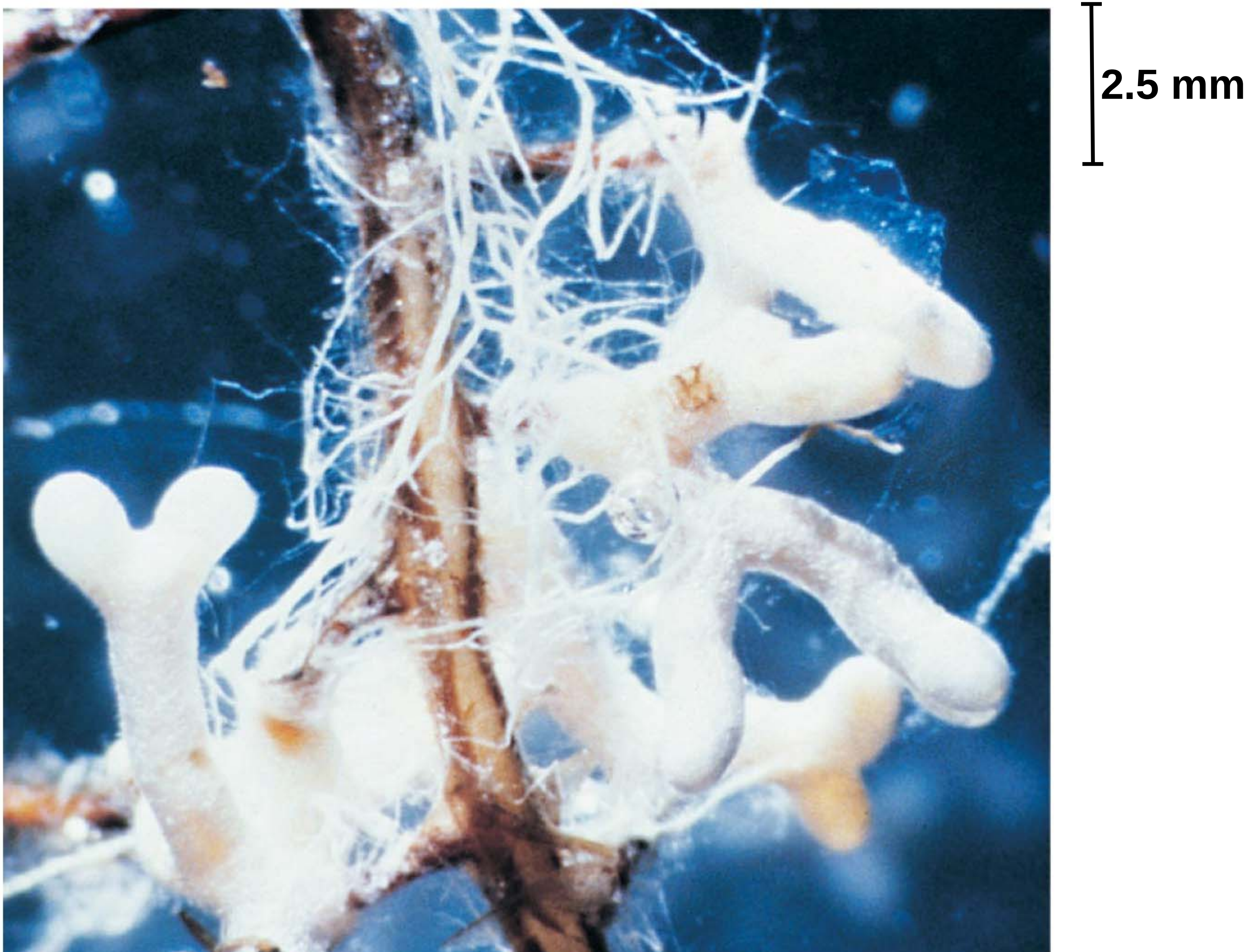
Fig. 36-4


Ground area
covered by plant
Plant A
Leaf area = 40%
of ground area
(leaf area index = 0.4)
Plant B
Leaf area = 80%
of ground area
(leaf area index = 0.8)

Root Architecture and Acquisition of Water and Minerals

- Soil is a resource mined by the root system
- Taproot systems anchor plants and are characteristic of most trees
- Roots and the hyphae of soil fungi form symbiotic associations called **mycorrhizae**
- Mutualisms with fungi helped plants colonize land

Fig. 36-5



Concept 36.2: Transport occurs by short-distance diffusion or active transport and by long-distance bulk flow

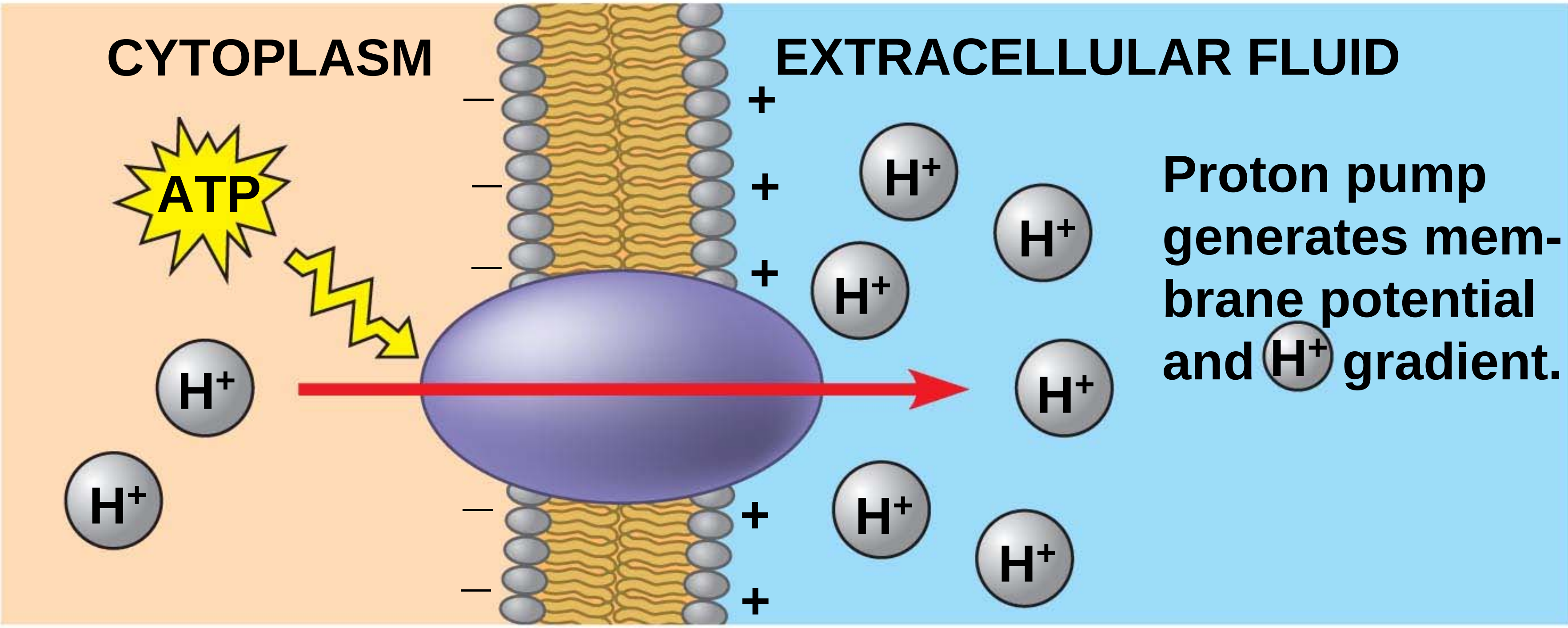
- Transport begins with the absorption of resources by plant cells
- The movement of substances into and out of cells is regulated by selective permeability

Diffusion and Active Transport of Solutes

- Diffusion across a membrane is passive, while the pumping of solutes across a membrane is active and requires energy
- Most solutes pass through **transport proteins** embedded in the cell membrane

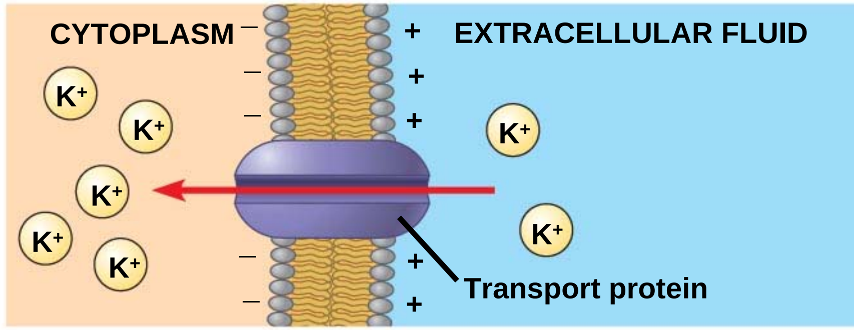
- The most important transport protein for active transport is the **proton pump**
- Proton pumps in plant cells create a hydrogen ion gradient that is a form of potential energy that can be harnessed to do work
- They contribute to a voltage known as a **membrane potential**

Fig. 36-6

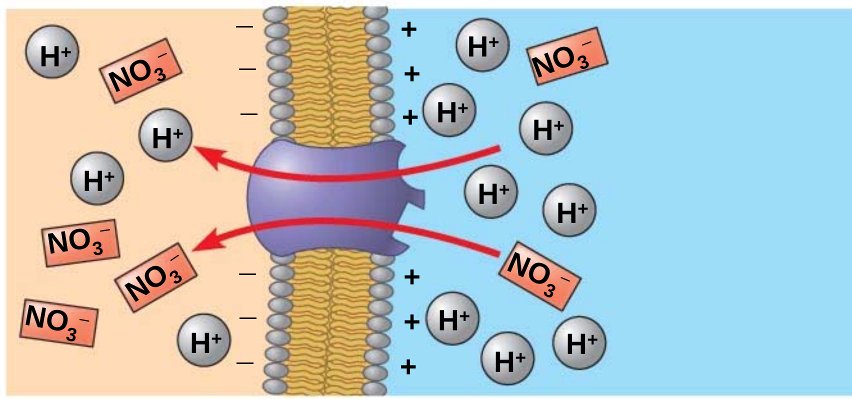

CYTOPLASM
EXTRACELLULAR FLUID
ATP
H^+
Proton pump generates mem-brane potential and H^+ gradient.

- Plant cells use energy stored in the proton gradient and membrane potential to drive the transport of many different solutes

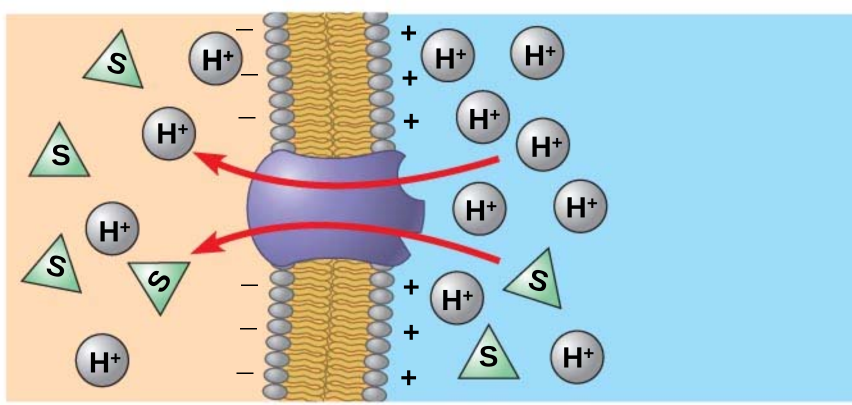
Fig. 36-7



(a) Membrane potential and cation uptake

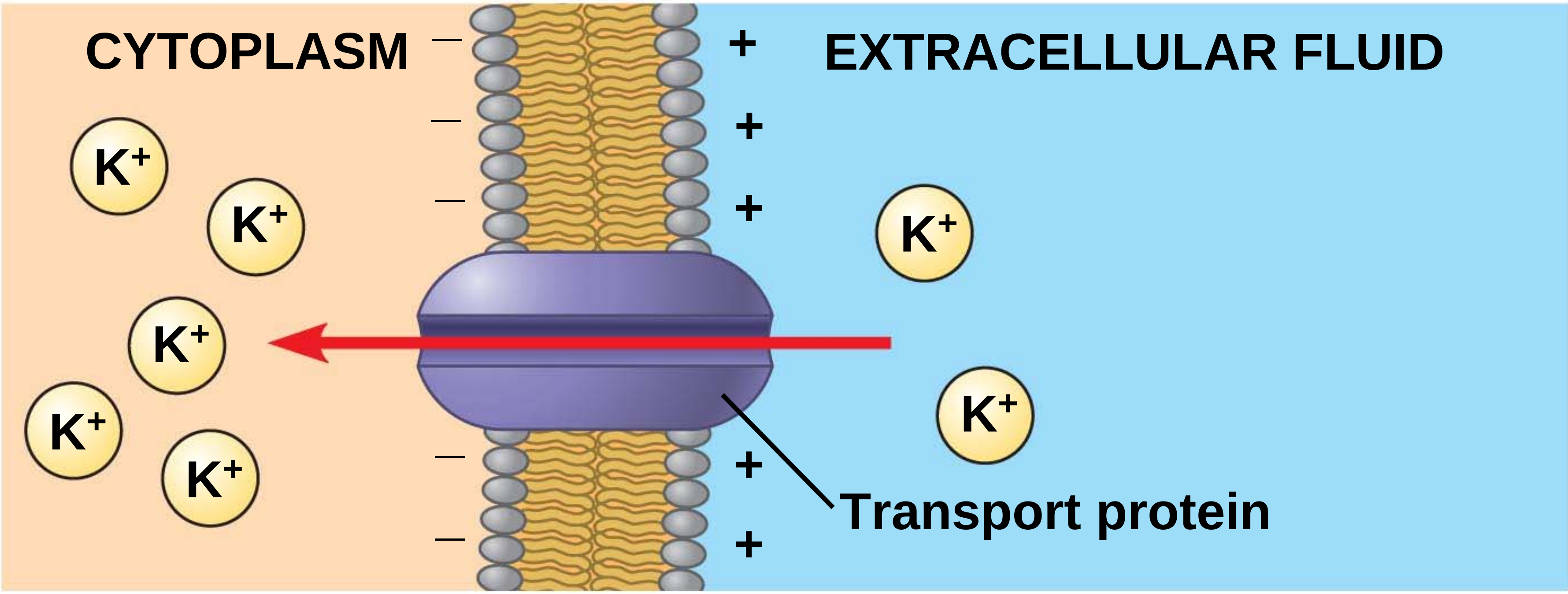


(b) Cotransport of an anion with H^+



(c) Cotransport of a neutral solute with H^+

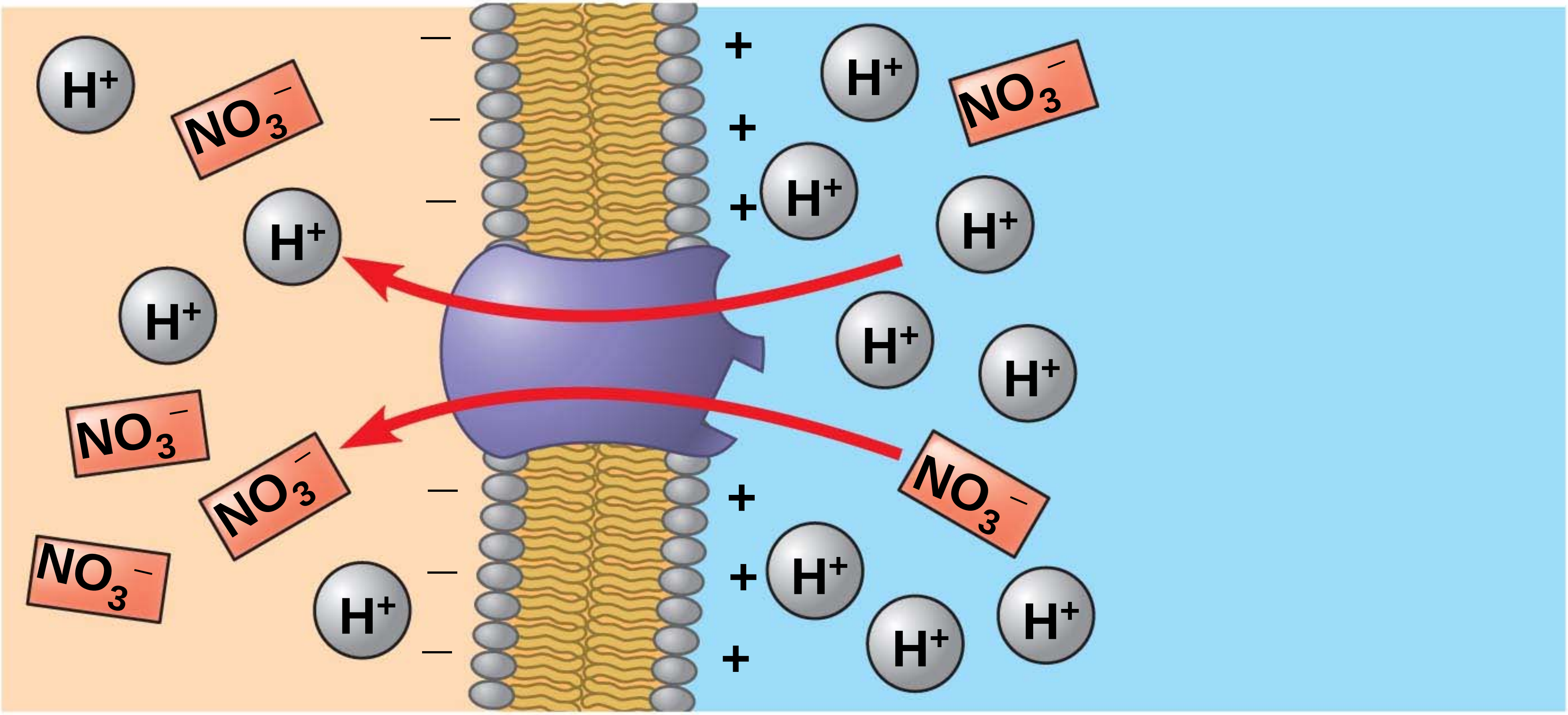
Fig. 36-7a



(a) Membrane potential and cation uptake

- In the mechanism called **cotransport**, a transport protein couples the diffusion of one solute to the active transport of another

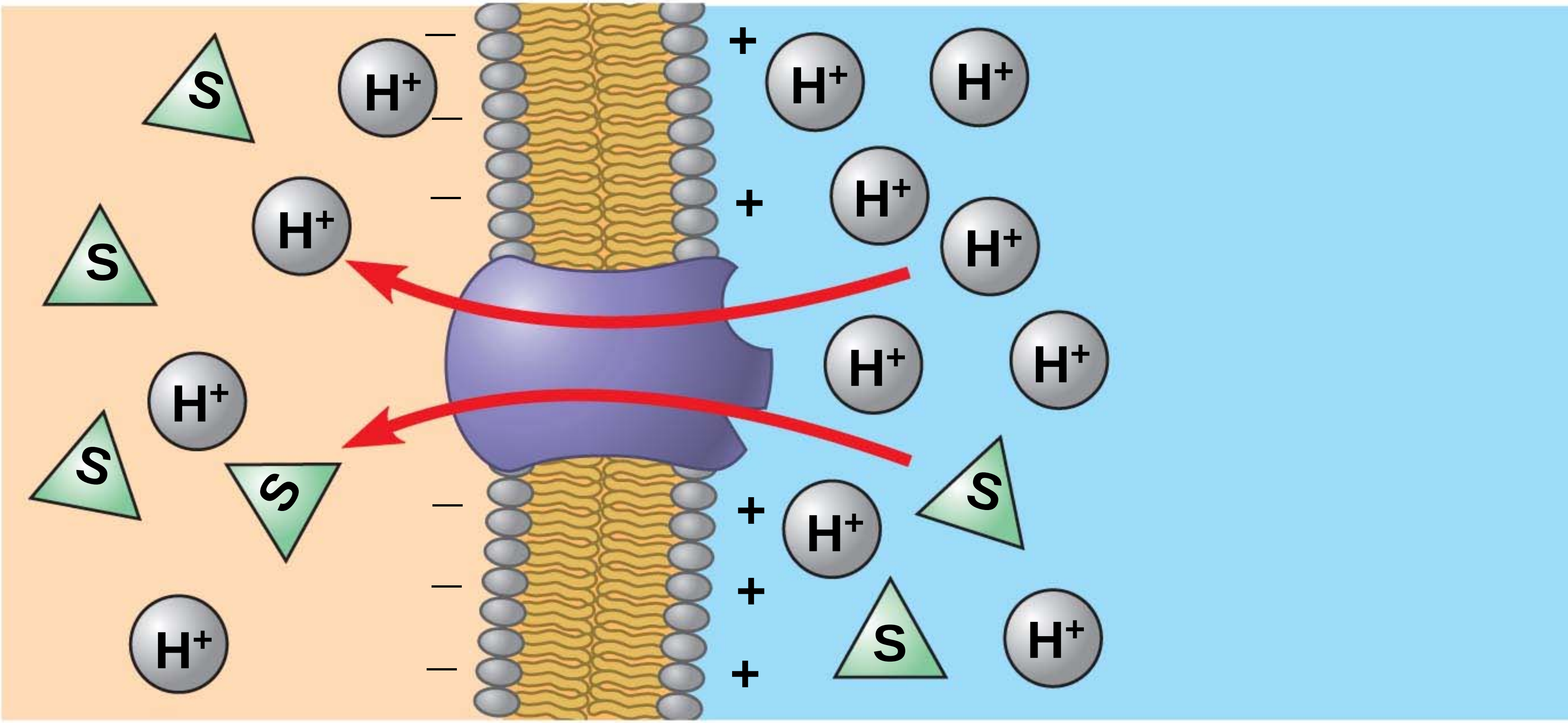
Fig. 36-7b



(b) Cotransport of an anion with H^+

- The “coattail” effect of cotransport is also responsible for the uptake of the sugar sucrose by plant cells

Fig. 36-7c



(c) Cotransport of a neutral solute with H^+

Diffusion of Water (Osmosis)

- To survive, plants must balance water uptake and loss
- **Osmosis** determines the net uptake or water loss by a cell and is affected by solute concentration and pressure

- **Water potential** is a measurement that combines the effects of solute concentration and pressure
- Water potential determines the direction of movement of water
- Water flows from regions of higher water potential to regions of lower water potential

- Water potential is abbreviated as Ψ and measured in units of pressure called **megapascals (MPa)**
- Ψ = 0 MPa for pure water at sea level and room temperature

How Solutes and Pressure Affect Water Potential

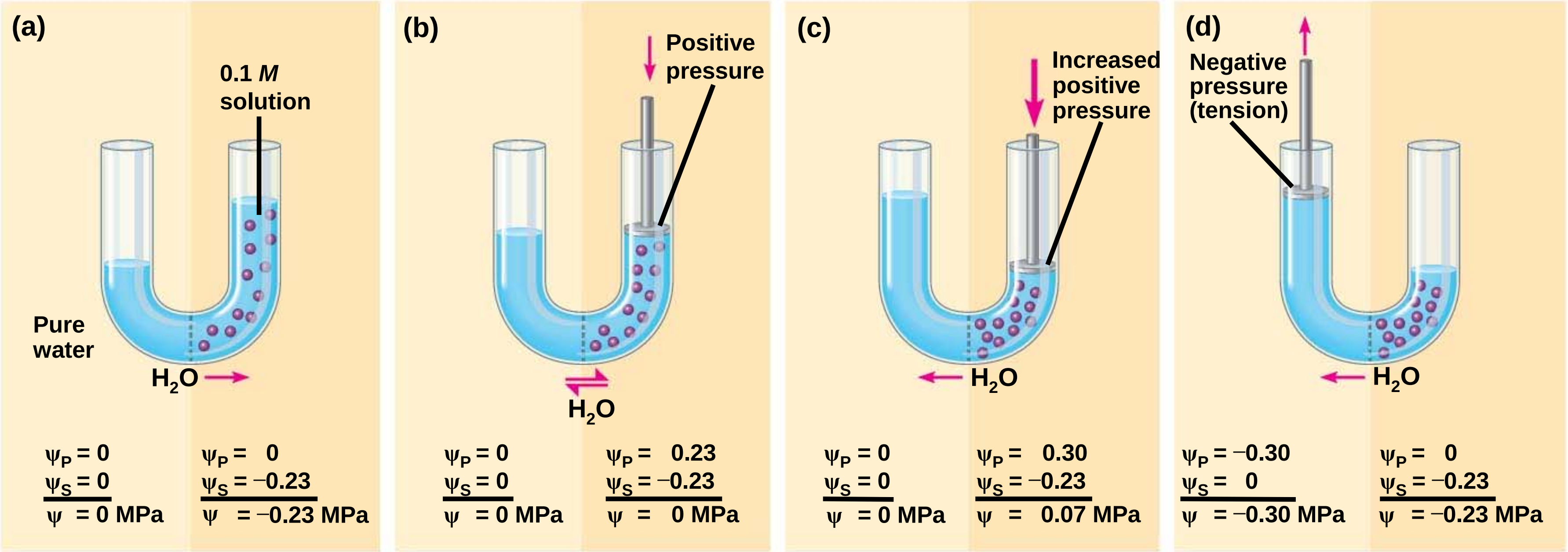
- Both pressure and solute concentration affect water potential
- The **solute potential (Ψ_S)** of a solution is proportional to the number of dissolved molecules
- Solute potential is also called **osmotic potential**

- **Pressure potential (Ψ_P)** is the physical pressure on a solution
- **Turgor pressure** is the pressure exerted by the plasma membrane against the cell wall, and the cell wall against the protoplast

Measuring Water Potential

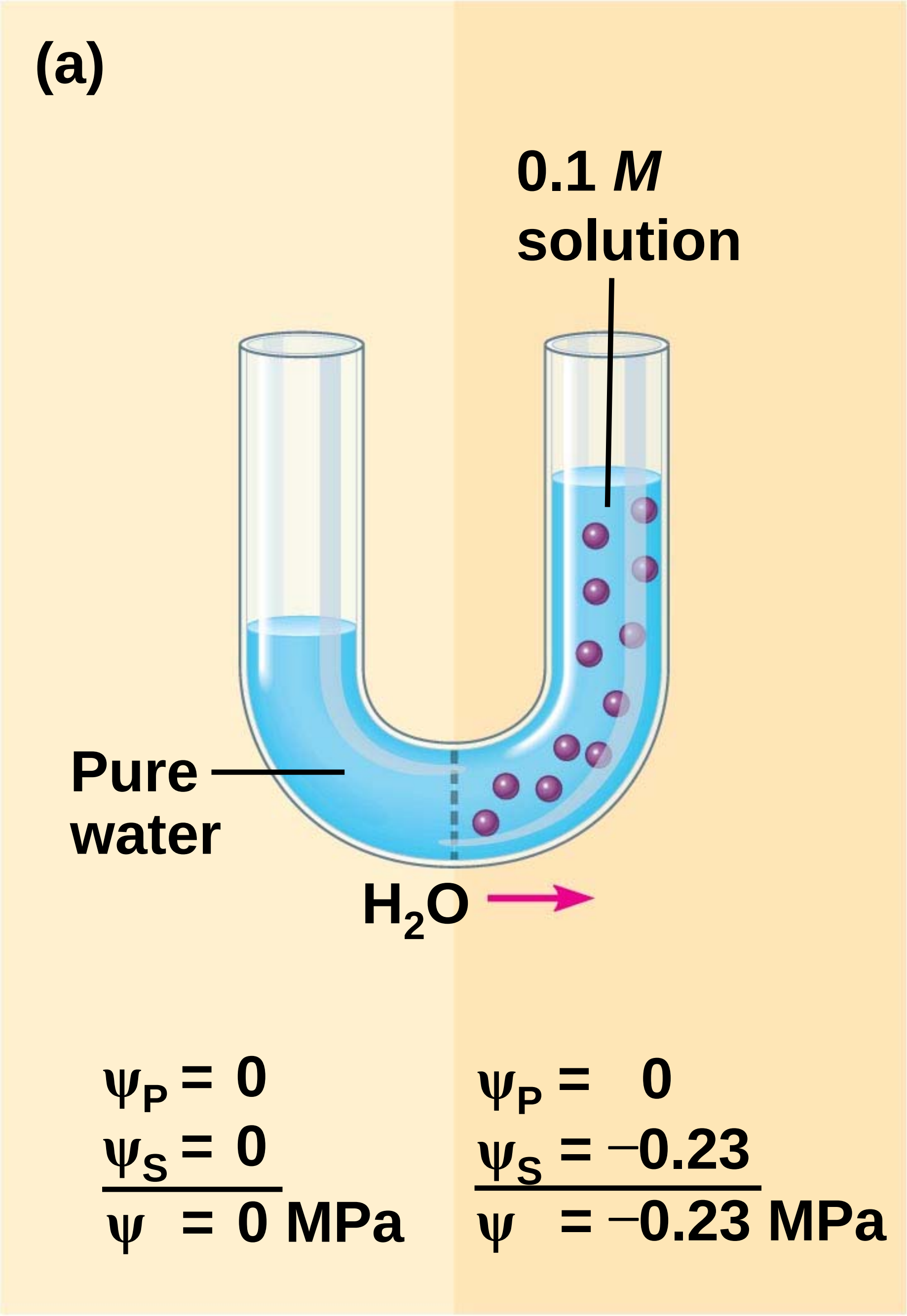
- Consider a U-shaped tube where the two arms are separated by a membrane permeable only to water
- Water moves in the direction from higher water potential to lower water potential

Fig. 36-8



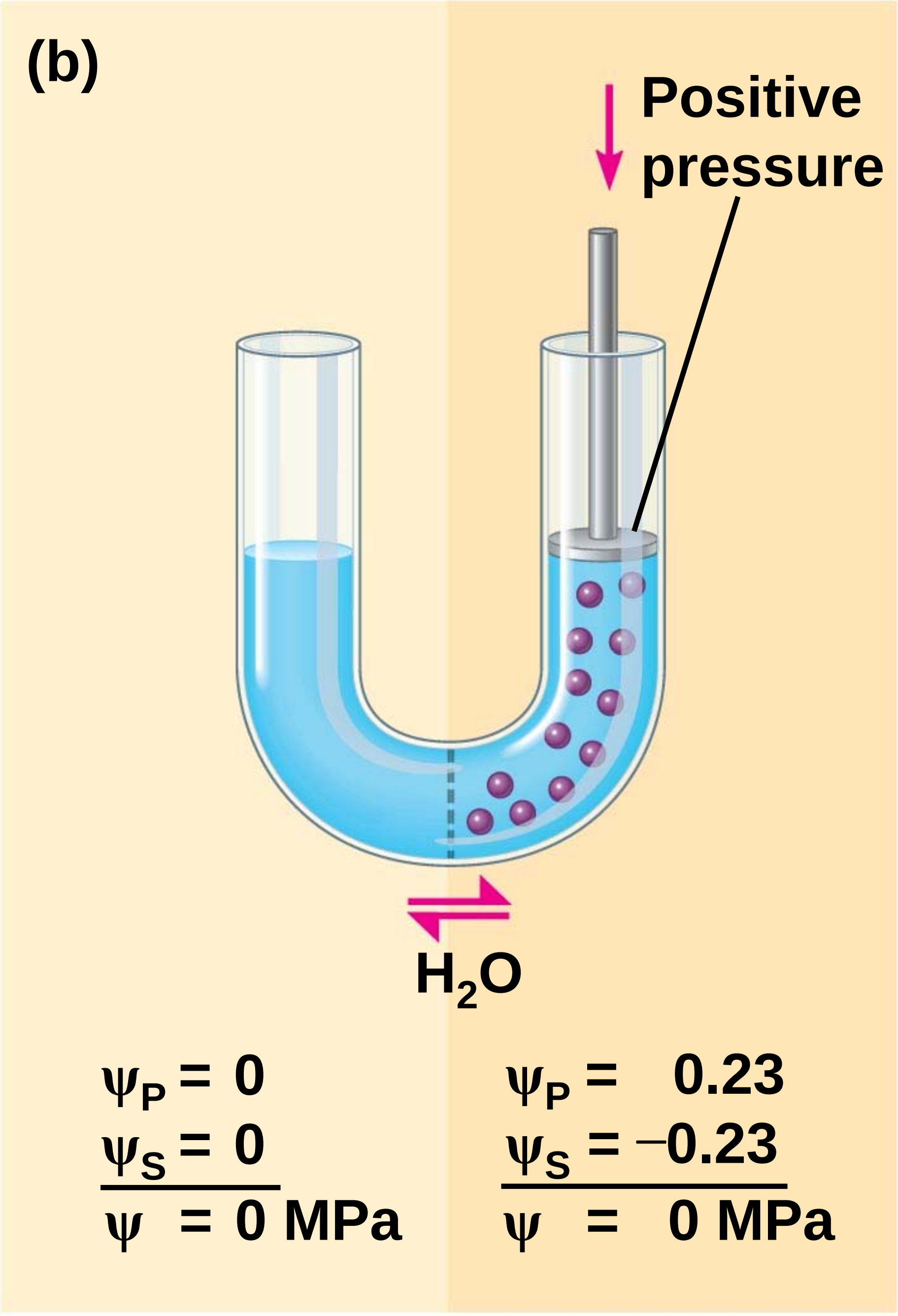
(a)
0.1 *M* solution
Pure water
H_2O
$\psi_P = 0$
$\psi_S = 0$
$\psi = 0$ MPa
$\psi_P = 0$
$\psi_S = -0.23$
$\psi = -0.23$ MPa
(b)
Positive pressure
H_2O
$\psi_P = 0$
$\psi_S = 0$
$\psi = 0$ MPa
$\psi_P = 0.23$
$\psi_S = -0.23$
$\psi = 0$ MPa
(c)
Increased positive pressure
H_2O
$\psi_P = 0$
$\psi_S = 0$
$\psi = 0$ MPa
$\psi_P = 0.30$
$\psi_S = -0.23$
$\psi = 0.07$ MPa
(d)
Negative pressure (tension)
H_2O
$\psi_P = -0.30$
$\psi_S = 0$
$\psi = -0.30$ MPa
$\psi_P = 0$
$\psi_S = -0.23$
$\psi = -0.23$ MPa

Fig. 36-8a


(a)
0.1 *M* solution
Pure water
H_2O
ψ_P = 0
ψ_S = 0
ψ = 0 MPa
ψ_P = 0
ψ_S = −0.23
ψ = −0.23 MPa

- The addition of solutes reduces water potential

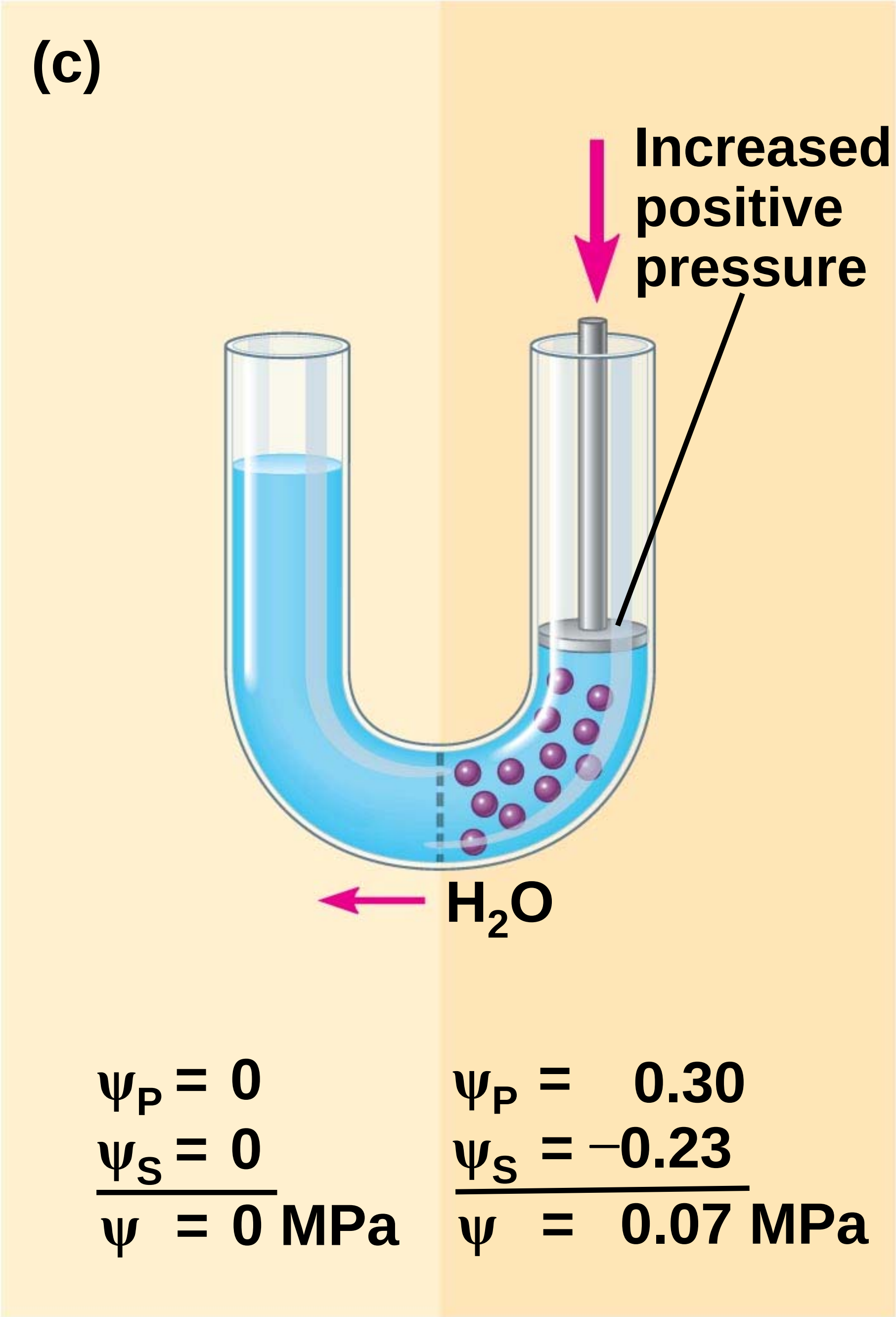
Fig. 36-8b



(b)
Positive pressure
H_2O
ψ_P = 0
ψ_S = 0
ψ = 0 MPa
ψ_P = 0.23
ψ_S = –0.23
ψ = 0 MPa

- Physical pressure increases water potential

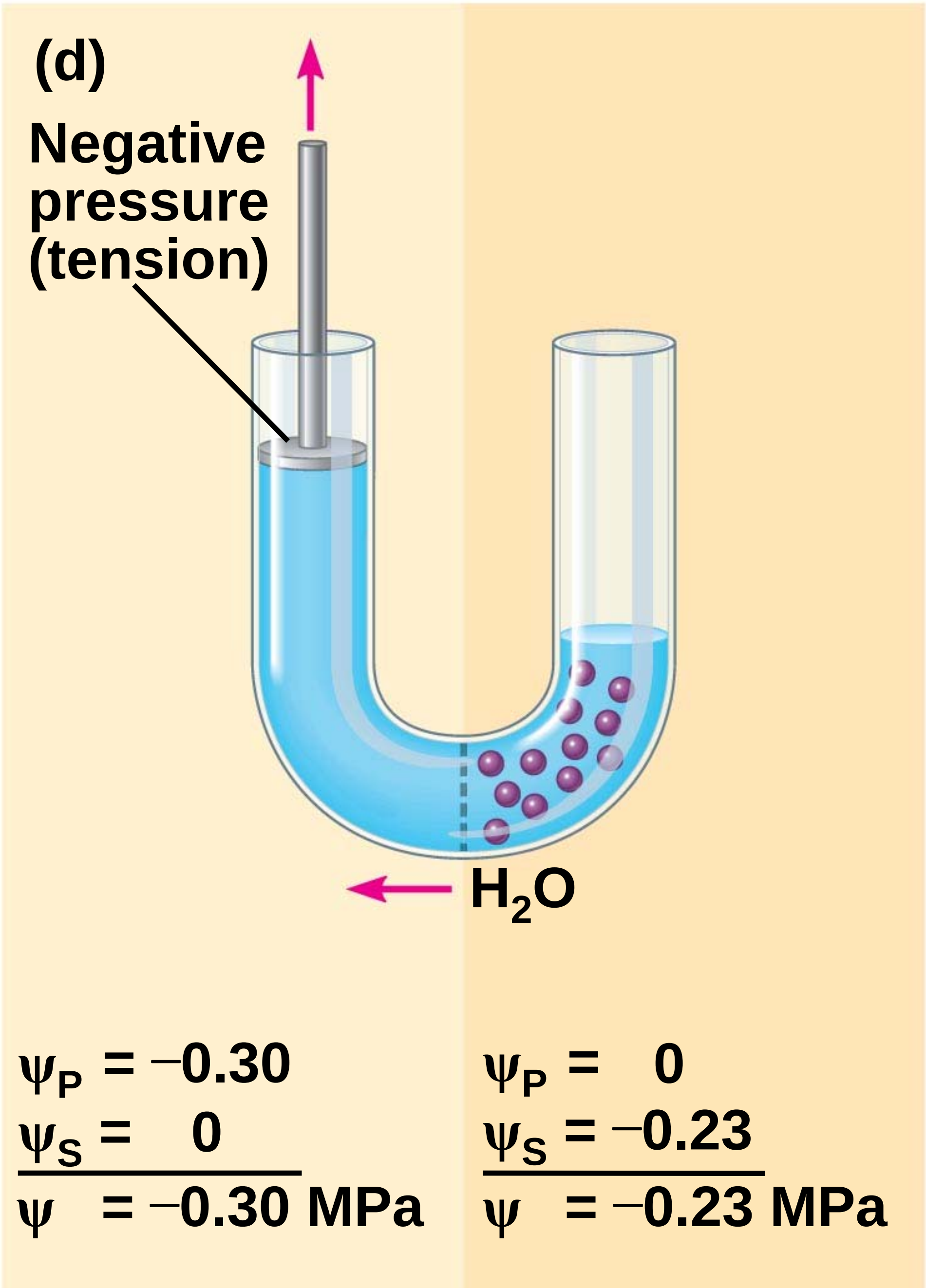
Fig. 36-8c



(c)
Increased positive pressure
H2O
ψP = 0
ψS = 0
ψ = 0 MPa
ψP = 0.30
ψS = –0.23
ψ = 0.07 MPa

- Negative pressure decreases water potential

Fig. 36-8d

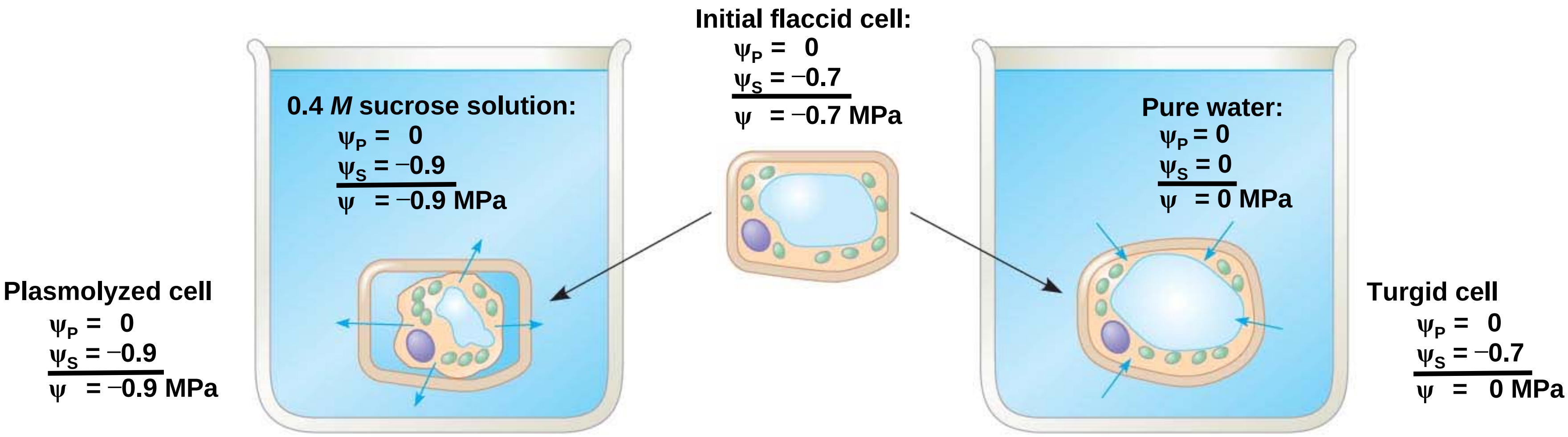


(d)
Negative pressure (tension)
H_2O
ψ_P = –0.30
ψ_S = 0
ψ = –0.30 MPa
ψ_P = 0
ψ_S = –0.23
ψ = –0.23 MPa

- Water potential affects uptake and loss of water by plant cells
- If a **flaccid** cell is placed in an environment with a higher solute concentration, the cell will lose water and undergo **plasmolysis**

PLAY Video: Plasmolysis

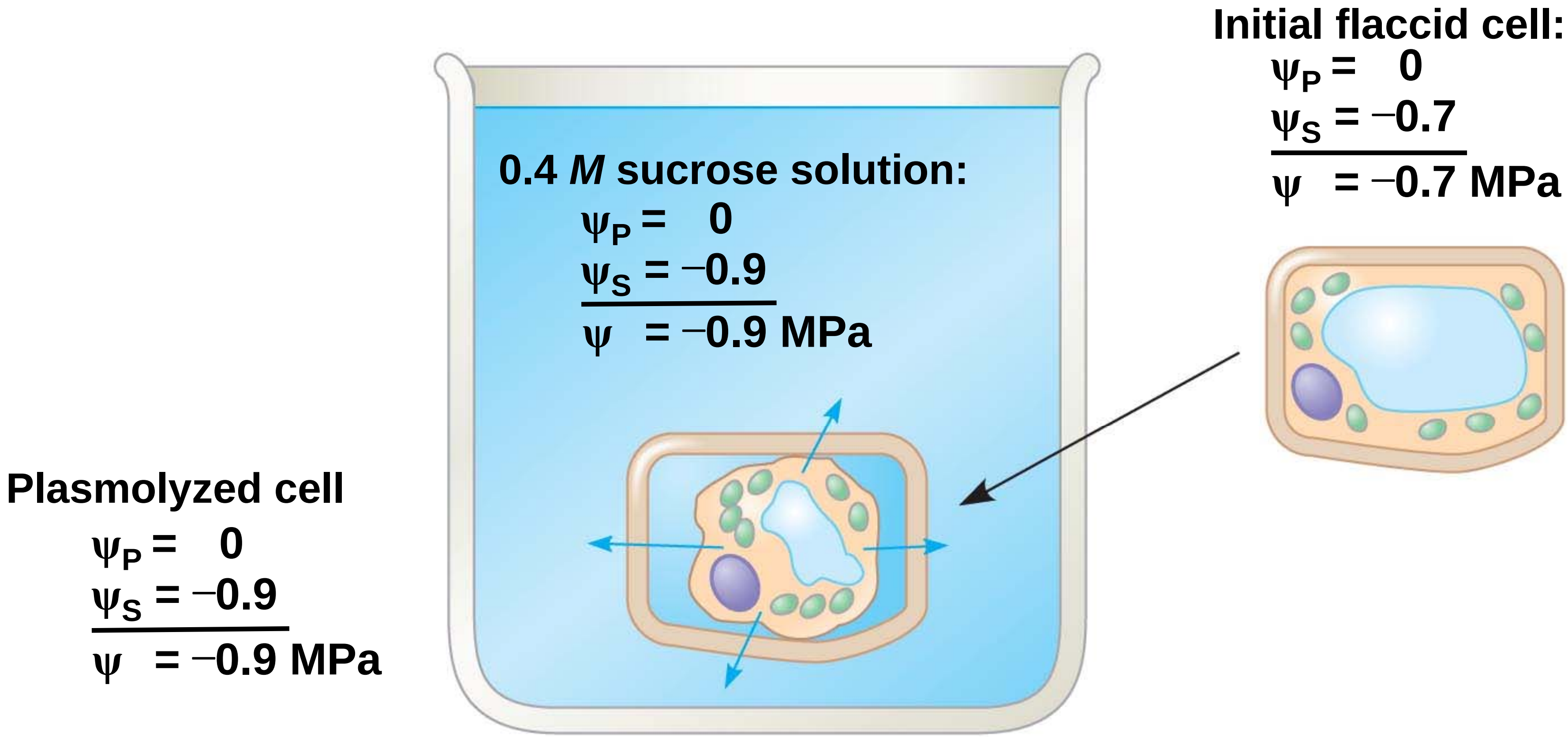
Fig. 36-9



(a) Initial conditions: cellular ψ > environmental ψ

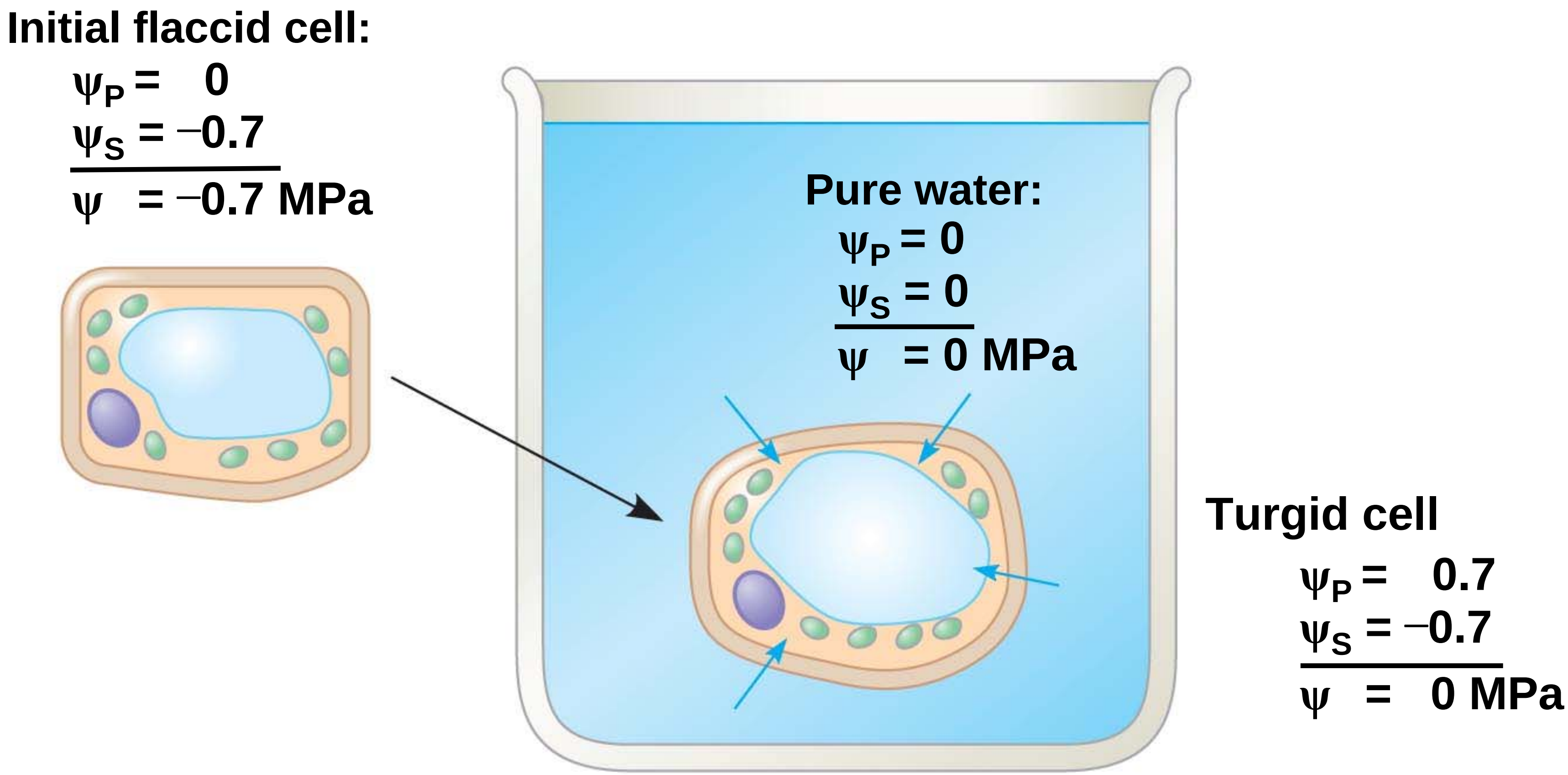
(b) Initial conditions: cellular ψ < environmental ψ

Fig. 36-9a



(a) Initial conditions: cellular ψ > environmental ψ

Fig. 36-9b



(b) Initial conditions: cellular ψ < environmental ψ

- If the same flaccid cell is placed in a solution with a lower solute concentration, the cell will gain water and become **turgid**

PLAY Video: Turgid *Elodea*

- Turgor loss in plants causes **wilting**, which can be reversed when the plant is watered

Fig. 36-10

Aquaporins: Facilitating Diffusion of Water

- **Aquaporins** are transport proteins in the cell membrane that allow the passage of water
- The rate of water movement is likely regulated by phosphorylation of the aquaporin proteins

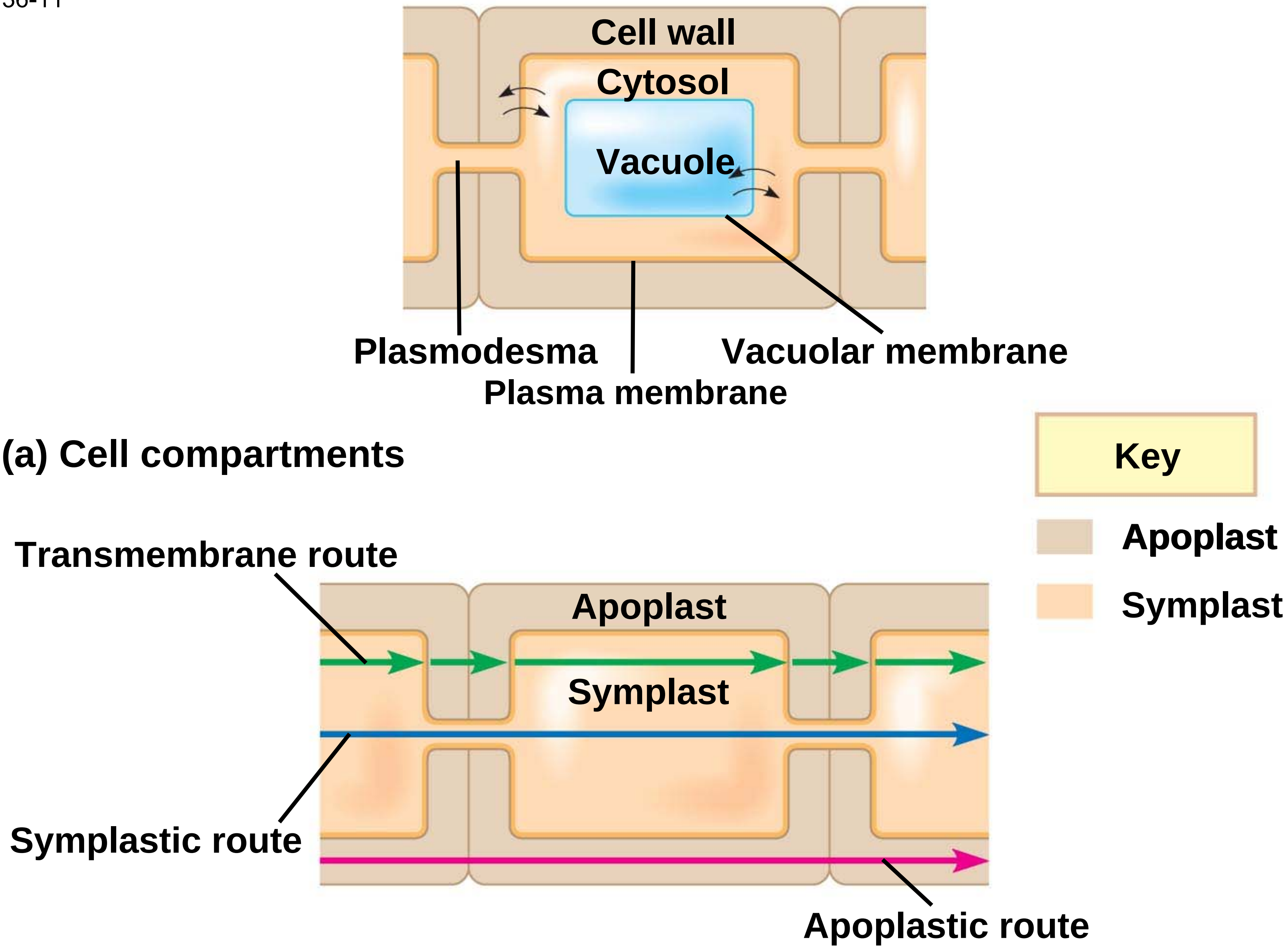
Three Major Pathways of Transport

- Transport is also regulated by the compartmental structure of plant cells
- The plasma membrane directly controls the traffic of molecules into and out of the protoplast
- The plasma membrane is a barrier between two major compartments, the cell wall and the cytosol

- The third major compartment in most mature plant cells is the vacuole, a large organelle that occupies as much as 90% or more of the protoplast’s volume
- The vacuolar membrane regulates transport between the cytosol and the vacuole

- In most plant tissues, the cell wall and cytosol are continuous from cell to cell
- The cytoplasmic continuum is called the **symplast**
- The cytoplasm of neighboring cells is connected by channels called **plasmodesmata**
- The **apoplast** is the continuum of cell walls and extracellular spaces

Fig. 36-11



(a) Cell compartments

(b) Transport routes between cells

- Water and minerals can travel through a plant by three routes:
  - Transmembrane route: out of one cell, across a cell wall, and into another cell
  - Symplastic route: via the continuum of cytosol
  - Apoplastic route: via the cell walls and extracellular spaces

Bulk Flow in Long-Distance Transport

- Efficient long distance transport of fluid requires **bulk flow**, the movement of a fluid driven by pressure
- Water and solutes move together through tracheids and vessel elements of xylem, and sieve-tube elements of phloem
- Efficient movement is possible because mature tracheids and vessel elements have no cytoplasm, and sieve-tube elements have few organelles in their cytoplasm

Concept 36.3: Water and minerals are transported from roots to shoots

- Plants can move a large volume of water from their roots to shoots

Absorption of Water and Minerals by Root Cells

- Most water and mineral absorption occurs near root tips, where the epidermis is permeable to water and root hairs are located
- Root hairs account for much of the surface area of roots
- After soil solution enters the roots, the extensive surface area of cortical cell membranes enhances uptake of water and selected minerals

PLAY Animation: Transport in Roots

Transport of Water and Minerals into the Xylem

- The **endodermis** is the innermost layer of cells in the root cortex
- It surrounds the vascular cylinder and is the last checkpoint for selective passage of minerals from the cortex into the vascular tissue

- Water can cross the cortex via the symplast or apoplast
- The waxy **Casparian strip** of the endodermal wall blocks apoplastic transfer of minerals from the cortex to the vascular cylinder

Fig. 36-12

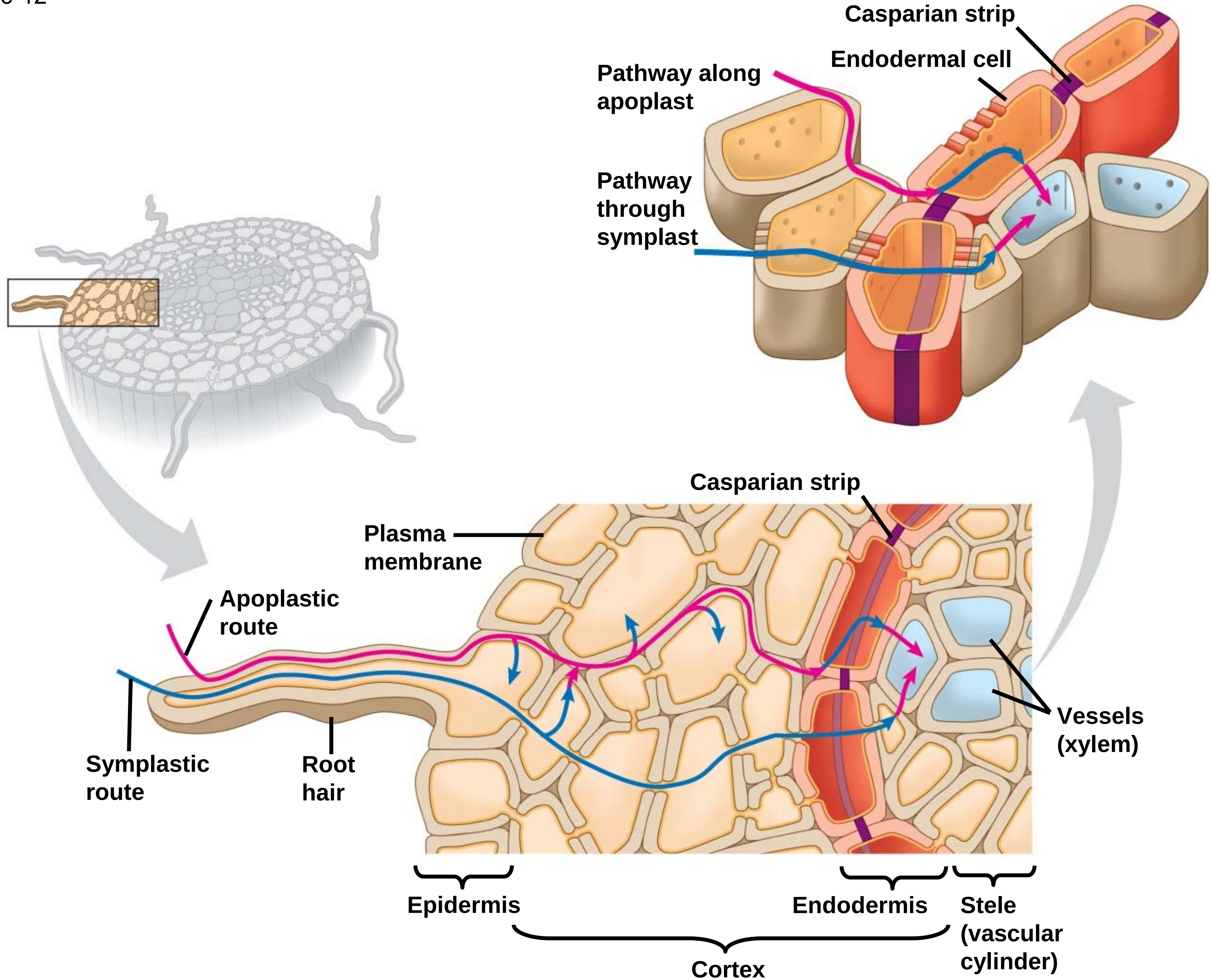
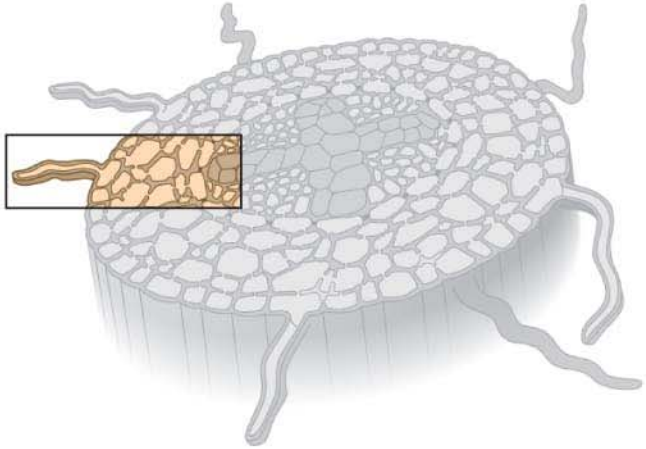

Casparian strip
Endodermal cell
Pathway along apoplast
Pathway through symplast
Casparian strip
Plasma membrane
Apoplastic route
Symplastic route
Root hair
Vessels (xylem)
Epidermis
Endodermis
Stele (vascular cylinder)
Cortex

Fig. 36-12a



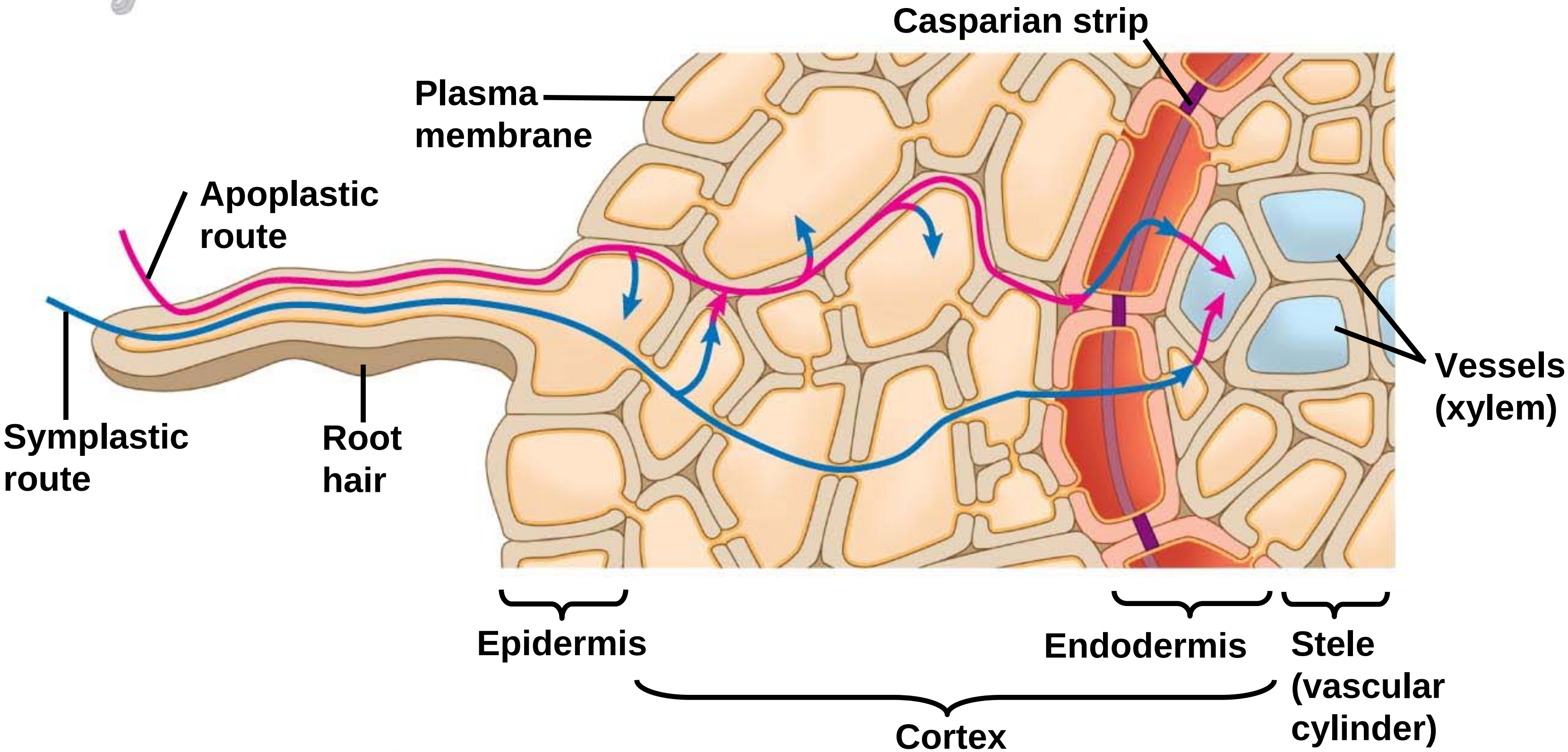
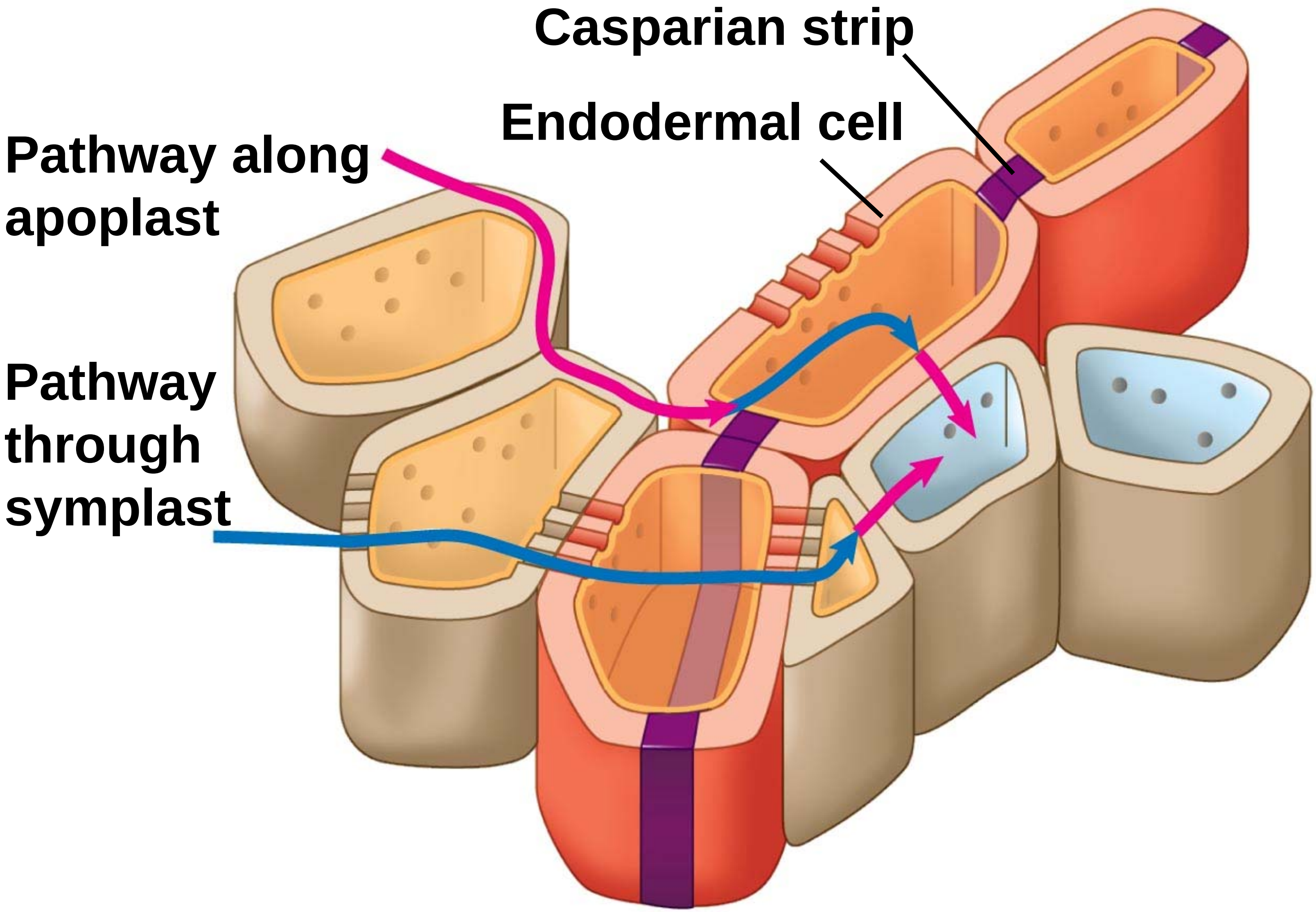

Casparian strip
Plasma membrane
Apoplastic route
Symplastic route
Root hair
Vessels (xylem)
Epidermis
Endodermis
Stele (vascular cylinder)
Cortex

Fig. 36-12b



Casparian strip
Endodermal cell
Pathway along apoplast
Pathway through symplast

Bulk Flow Driven by Negative Pressure in the Xylem

- Plants lose a large volume of water from **transpiration**, the evaporation of water from a plant's surface
- Water is replaced by the bulk flow of water and minerals, called **xylem sap,** from the steles of roots to the stems and leaves
- Is sap mainly pushed up from the roots, or pulled up by the leaves?

Pushing Xylem Sap: Root Pressure

- At night, when transpiration is very low, root cells continue pumping mineral ions into the xylem of the vascular cylinder, lowering the water potential
- Water flows in from the root cortex, generating **root pressure**

- Root pressure sometimes results in **guttation**, the exudation of water droplets on tips or edges of leaves

Fig. 36-13

- Positive root pressure is relatively weak and is a minor mechanism of xylem bulk flow

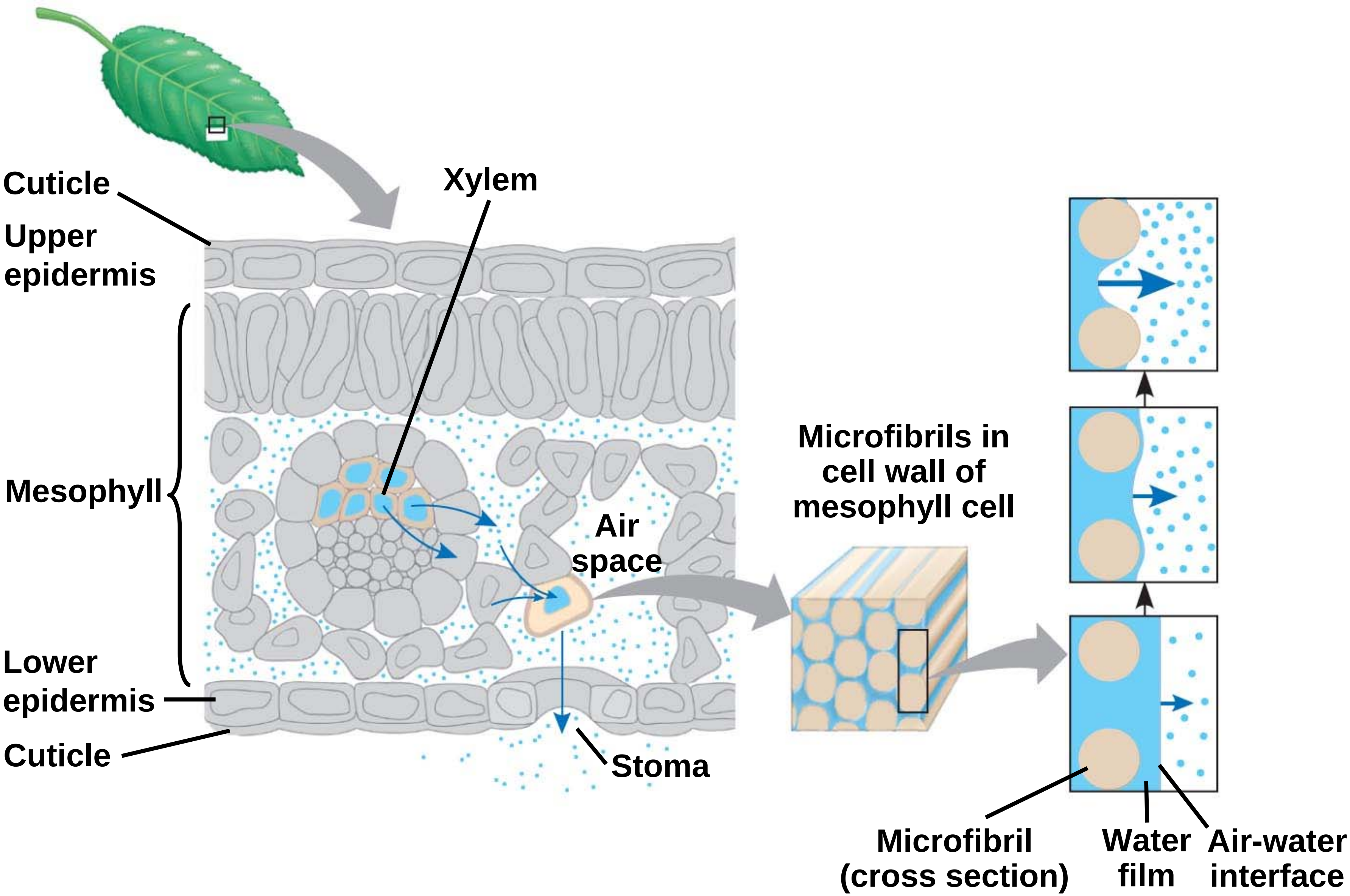
Pulling Xylem Sap: The Transpiration-Cohesion-Tension Mechanism

- Water is pulled upward by negative pressure in the xylem

Transpirational Pull

- Water vapor in the airspaces of a leaf diffuses down its water potential gradient and exits the leaf via stomata
- Transpiration produces negative pressure (tension) in the leaf, which exerts a pulling force on water in the xylem, pulling water into the leaf

Fig. 36-14



Cuticle
Upper epidermis
Mesophyll
Lower epidermis
Cuticle
Xylem
Air space
Stoma
Microfibrils in cell wall of mesophyll cell
Microfibril (cross section)
Water film
Air-water interface

Cohesion and Adhesion in the Ascent of Xylem Sap

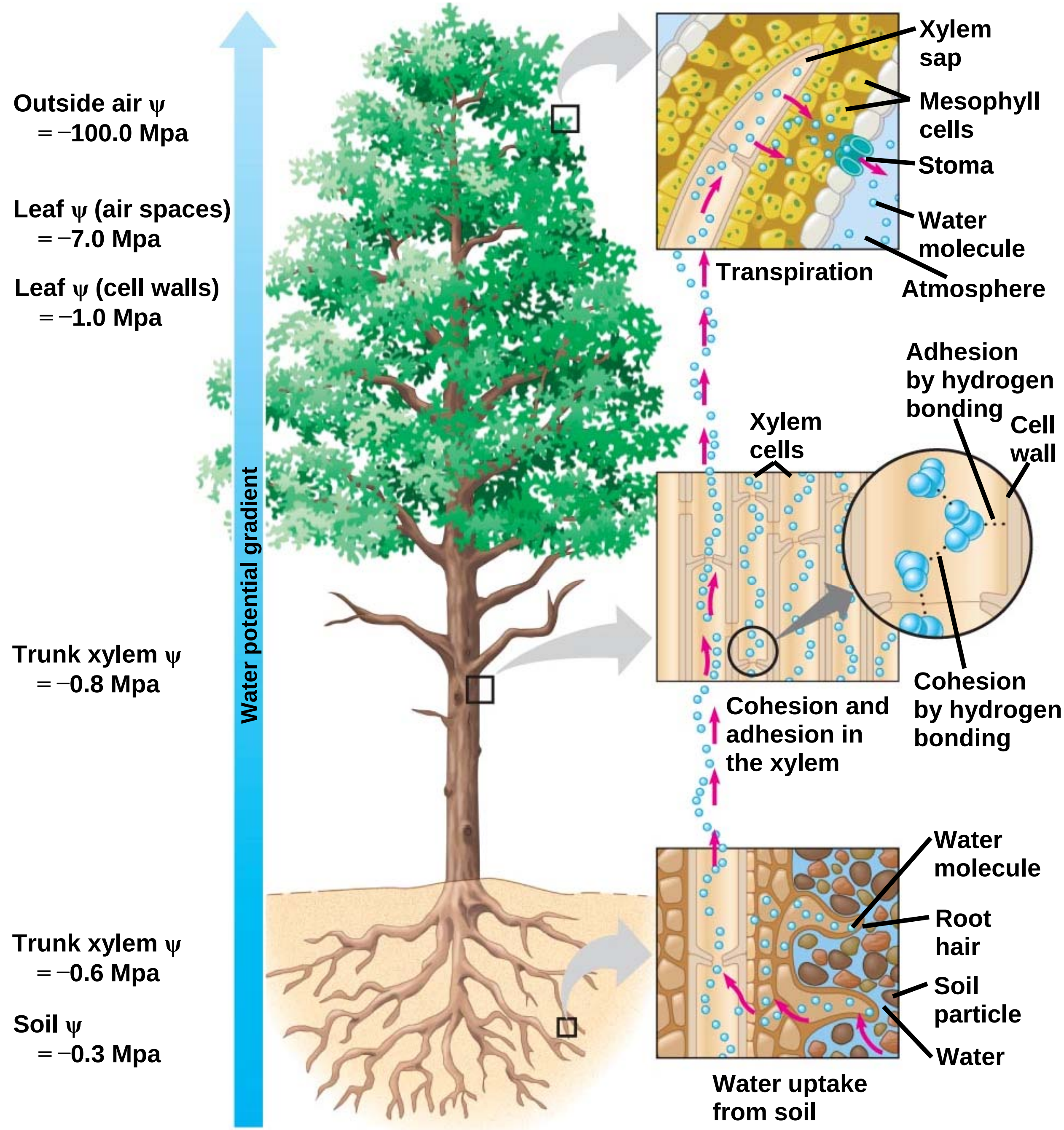
- The transpirational pull on xylem sap is transmitted all the way from the leaves to the root tips and even into the soil solution
- Transpirational pull is facilitated by cohesion of water molecules to each other and adhesion of water molecules to cell walls

PLAY Animation: Water Transport

PLAY Animation: Transpiration

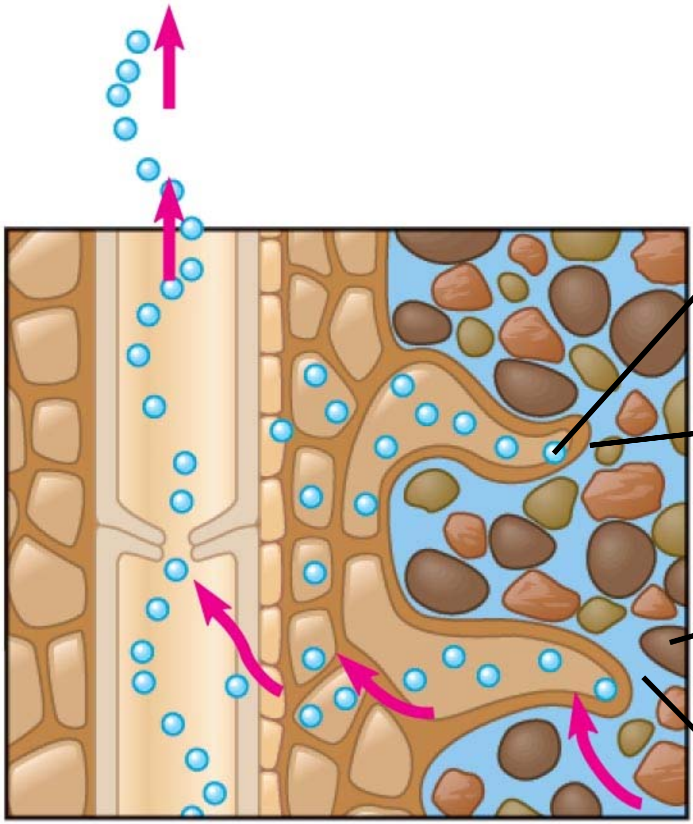
- Drought stress or freezing can cause cavitation, the formation of a water vapor pocket by a break in the chain of water molecules

Fig. 36-15



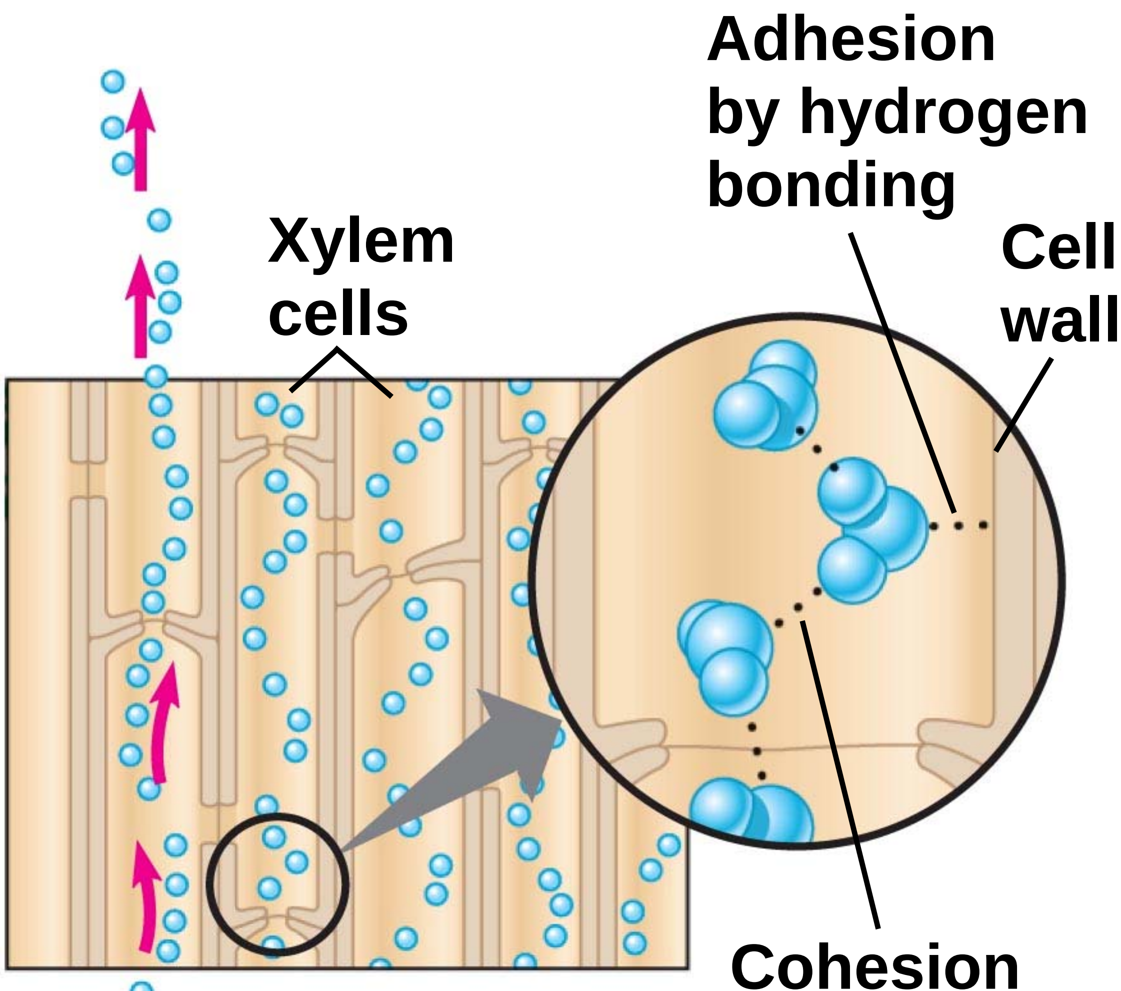
Outside air ψ
= −100.0 Mpa
Leaf ψ (air spaces)
= −7.0 Mpa
Leaf ψ (cell walls)
= −1.0 Mpa
Trunk xylem ψ
= −0.8 Mpa
Trunk xylem ψ
= −0.6 Mpa
Soil ψ
= −0.3 Mpa
Water potential gradient
Xylem sap
Mesophyll cells
Stoma
Water molecule
Atmosphere
Transpiration
Xylem cells
Adhesion by hydrogen bonding
Cell wall
Cohesion by hydrogen bonding
Cohesion and adhesion in the xylem
Water molecule
Root hair
Soil particle
Water
Water uptake from soil

Fig. 36-15a



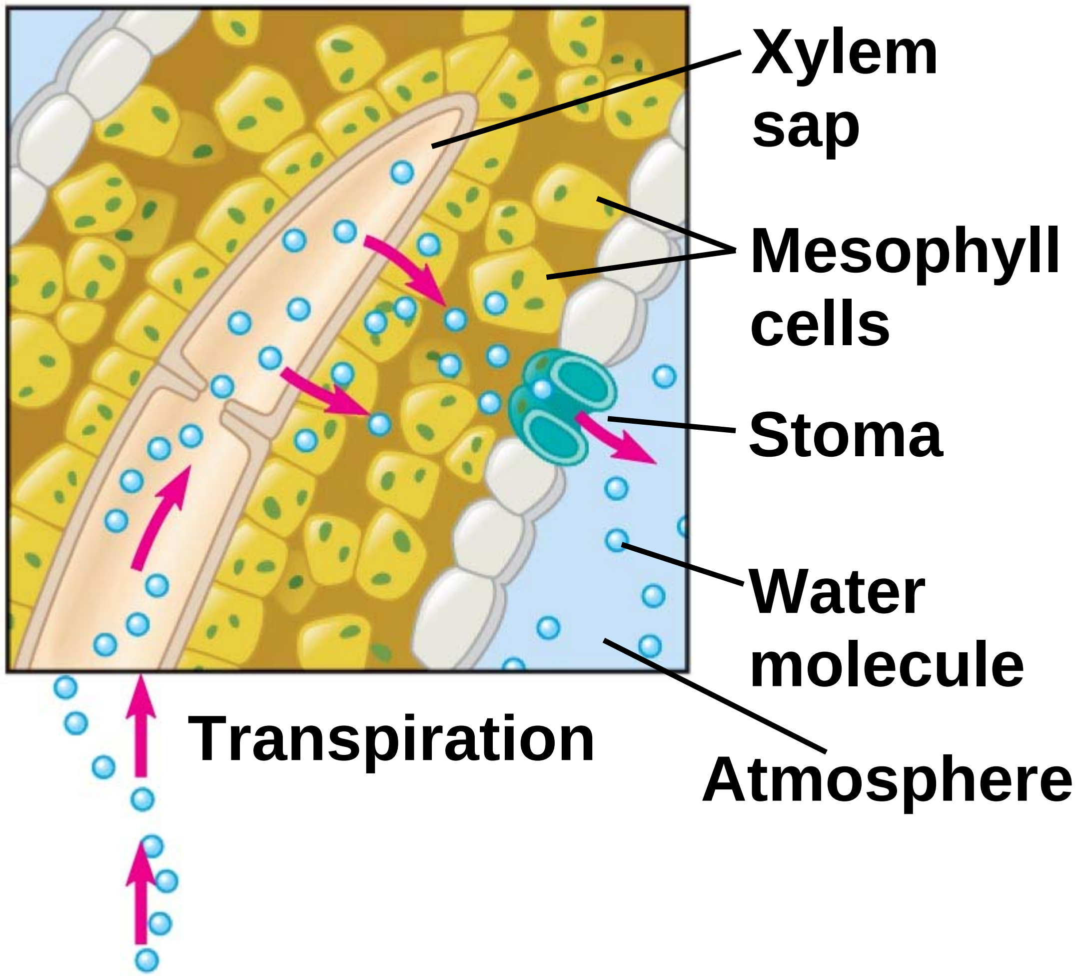
Water uptake
from soil

Fig. 36-15b



Cohesion and adhesion in the xylem

Fig. 36-15c



Xylem sap
Mesophyll cells
Stoma
Water molecule
Atmosphere
Transpiration

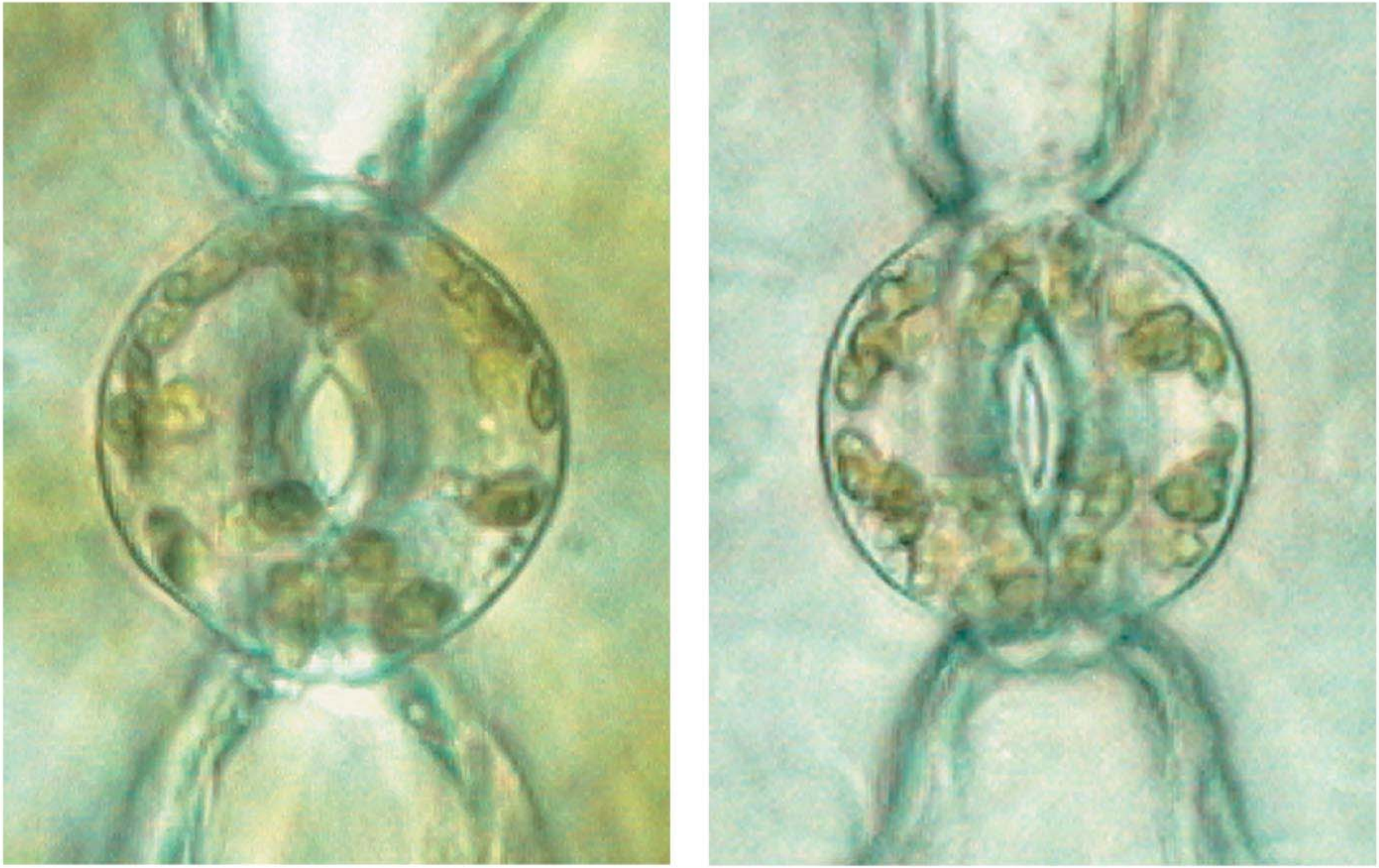
Xylem Sap Ascent by Bulk Flow: *A Review*

- The movement of xylem sap against gravity is maintained by the transpiration-cohesion-tension mechanism
- Transpiration lowers water potential in leaves, and this generates negative pressure (tension) that pulls water up through the xylem
- There is no energy cost to bulk flow of xylem sap

Concept 36.4: Stomata help regulate the rate of transpiration

- Leaves generally have broad surface areas and high surface-to-volume ratios
- These characteristics increase photosynthesis and increase water loss through stomata

Fig. 36-16



Stomata: Major Pathways for Water Loss

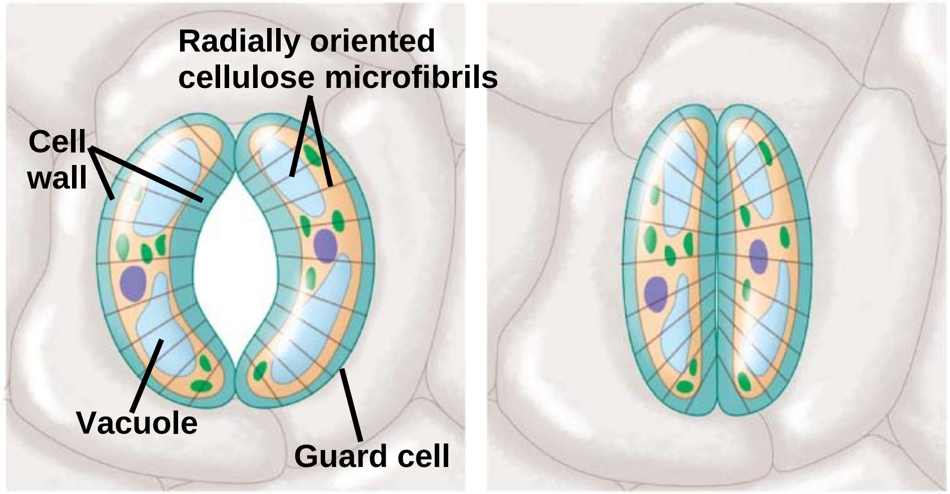
- About 95% of the water a plant loses escapes through stomata
- Each stoma is flanked by a pair of guard cells, which control the diameter of the stoma by changing shape

Mechanisms of Stomatal Opening and Closing

- Changes in turgor pressure open and close stomata
- These result primarily from the reversible uptake and loss of potassium ions by the guard cells

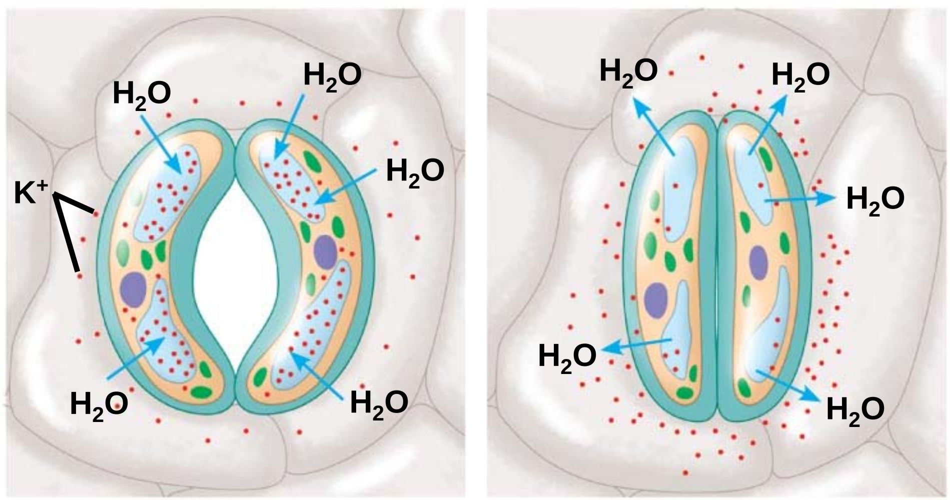
Fig. 36-17

Guard cells turgid/Stoma open Guard cells flaccid/Stoma closed



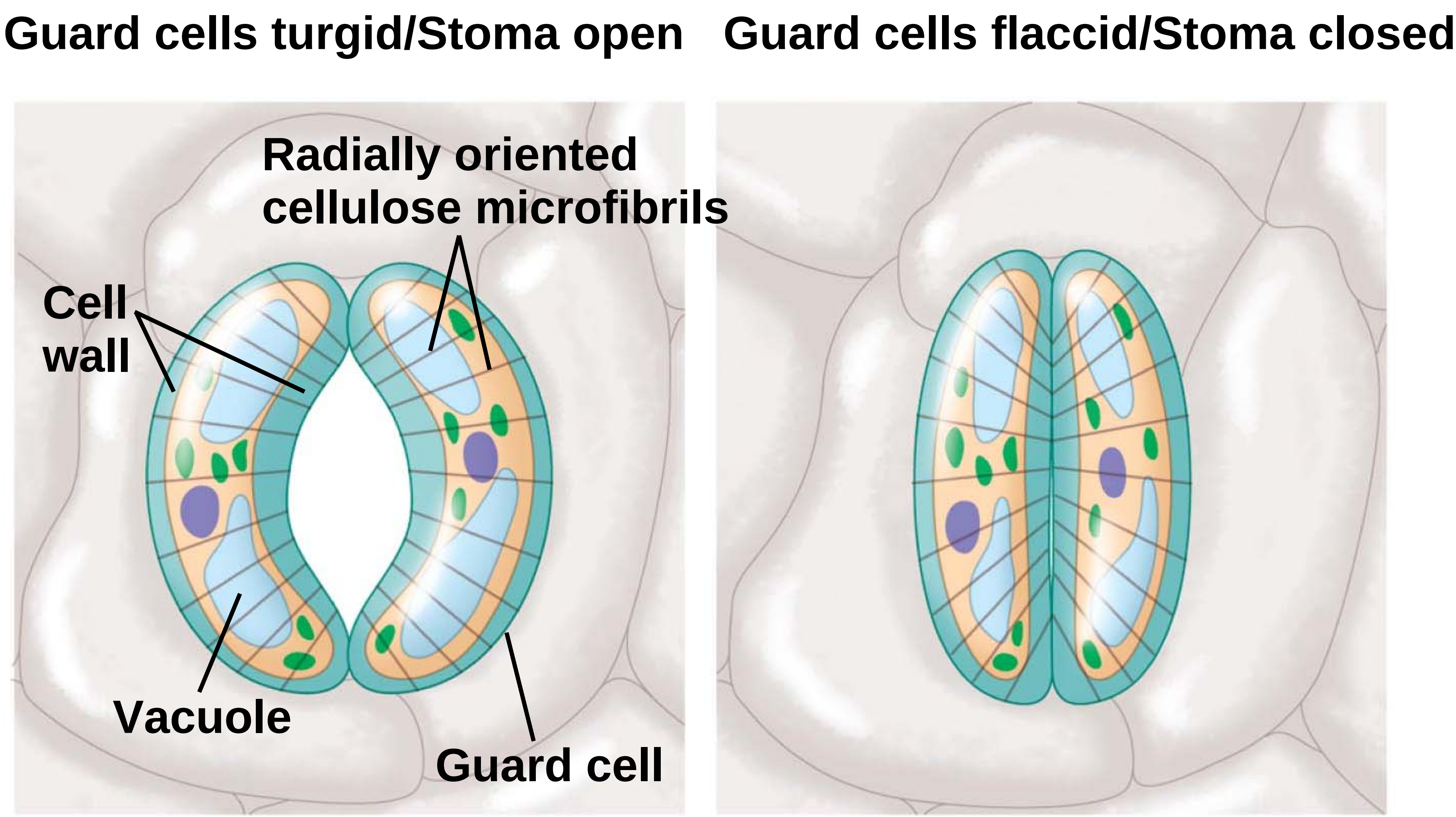
(a) Changes in guard cell shape and stomatal opening and closing (surface view)

Guard cells turgid/Stoma open Guard cells flaccid/Stoma closed



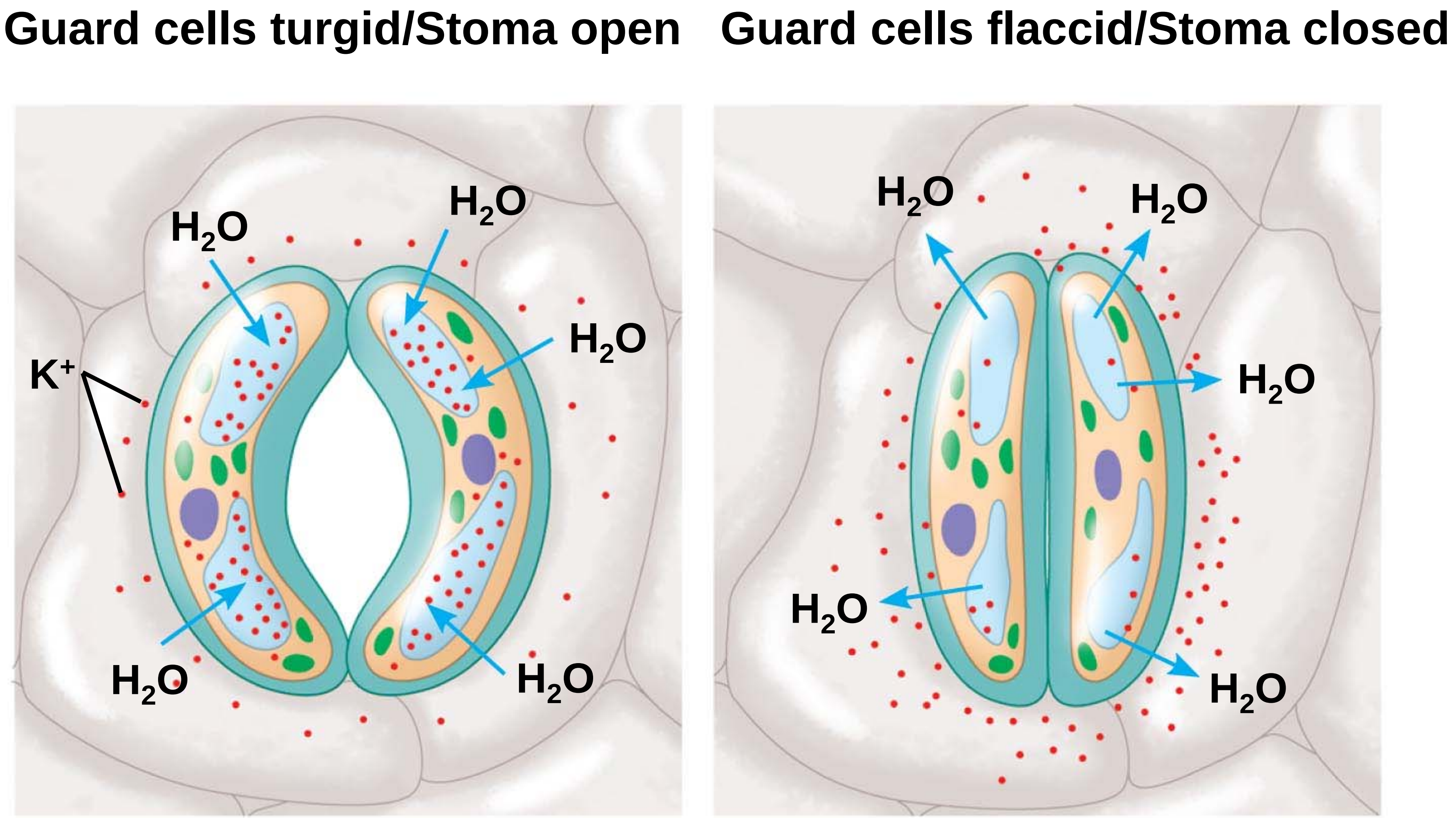
(b) Role of potassium in stomatal opening and closing

Fig. 36-17a



(a) Changes in guard cell shape and stomatal opening and closing (surface view)

Fig. 36-17b



(b) Role of potassium in stomatal opening and closing

Stimuli for Stomatal Opening and Closing

- Generally, stomata open during the day and close at night to minimize water loss
- Stomatal opening at dawn is triggered by light, CO_2 depletion, and an internal “clock” in guard cells
- All eukaryotic organisms have internal clocks; **circadian rhythms** are 24-hour cycles

Effects of Transpiration on Wilting and Leaf Temperature

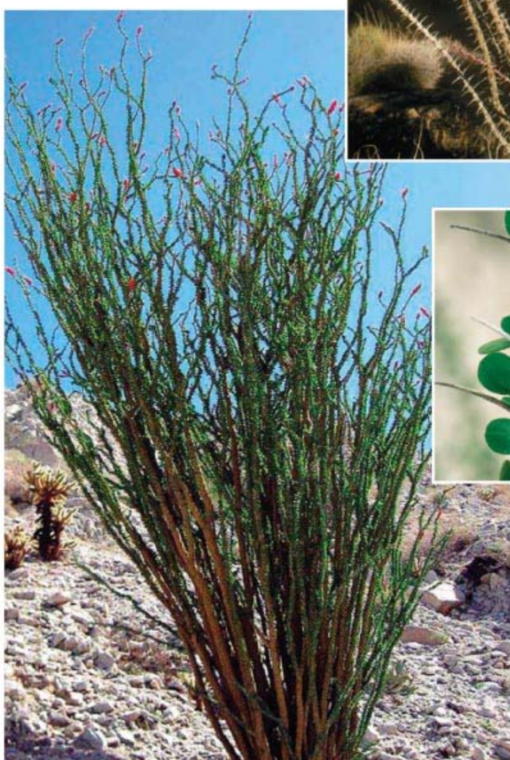
- Plants lose a large amount of water by transpiration
- If the lost water is not replaced by sufficient transport of water, the plant will lose water and wilt
- Transpiration also results in evaporative cooling, which can lower the temperature of a leaf and prevent denaturation of various enzymes involved in photosynthesis and other metabolic processes

Adaptations That Reduce Evaporative Water Loss

- **Xerophytes** are plants adapted to arid climates
- They have leaf modifications that reduce the rate of transpiration
- Some plants use a specialized form of photosynthesis called crassulacean acid metabolism (CAM) where stomatal gas exchange occurs at night

Fig. 36-18

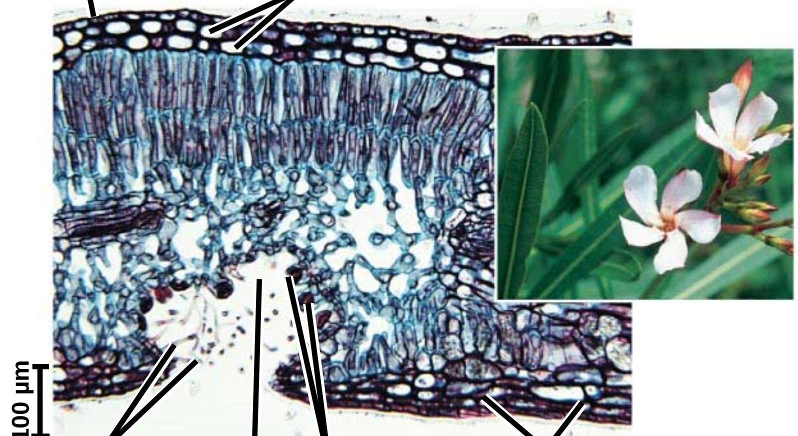
Ocotillo (leafless)



Ocotillo after heavy rain

Ocotillo leaves

Oleander leaf cross section and flowers



Old man cactus

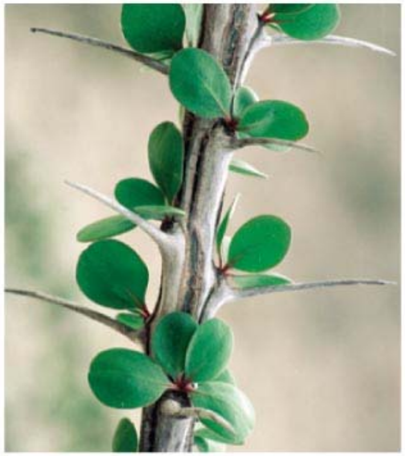
Fig. 36-18a

Ocotillo (leafless)

Fig. 36-18b

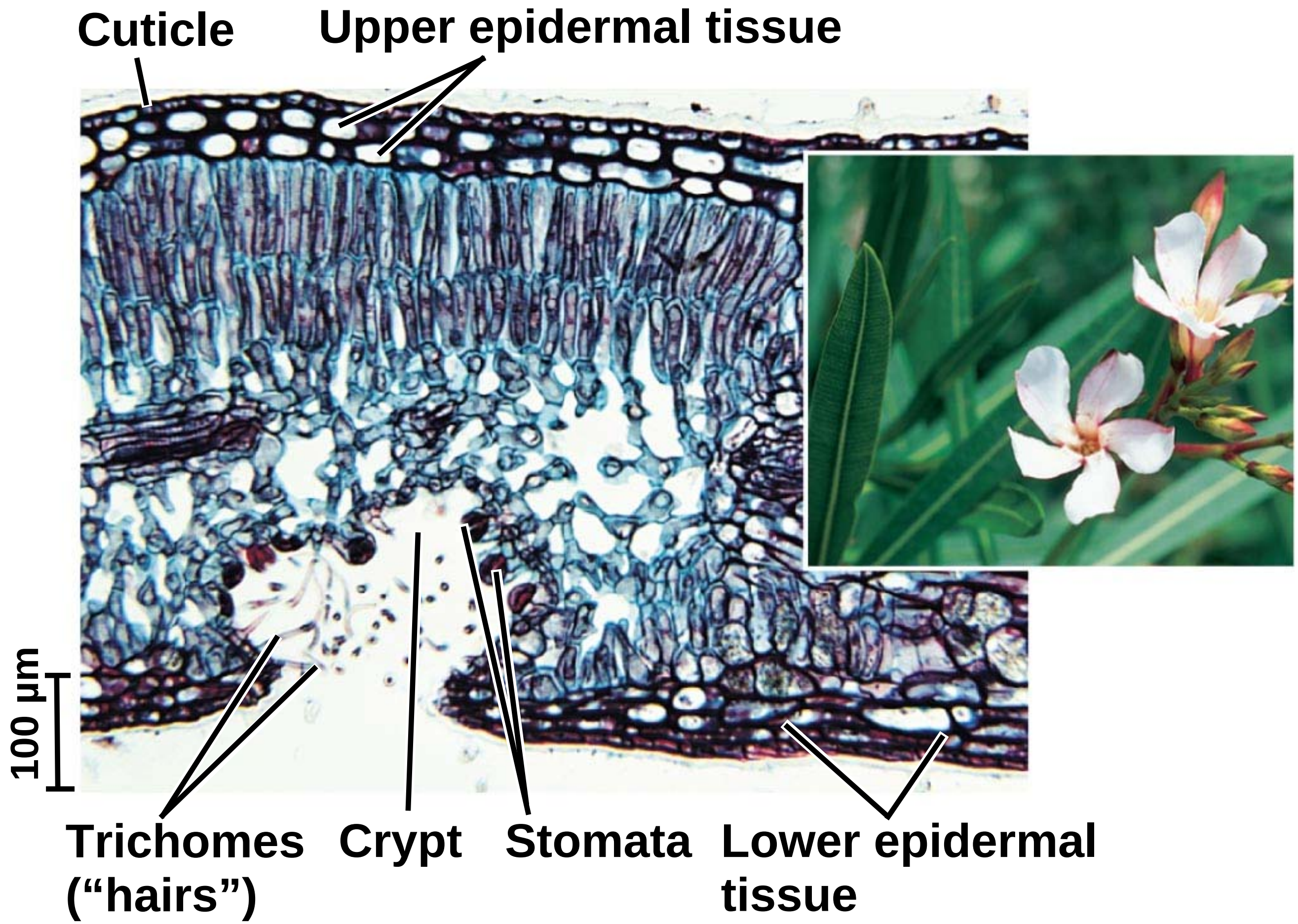
Ocotillo after heavy rain

Fig. 36-18c



Ocotillo leaves

Fig. 36-18d



Oleander leaf cross section and flowers

Fig. 36-18e

Old man cactus

Concept 36.5: Sugars are transported from leaves and other sources to sites of use or storage

- The products of photosynthesis are transported through phloem by the process of **translocation**

Movement from Sugar Sources to Sugar Sinks

- **Phloem sap** is an aqueous solution that is high in sucrose
- It travels from a sugar source to a sugar sink
- A **sugar source** is an organ that is a net producer of sugar, such as mature leaves
- A **sugar sink** is an organ that is a net consumer or storer of sugar, such as a tuber or bulb
- A storage organ can be both a sugar sink in summer and sugar source in winter

- Sugar must be loaded into sieve-tube elements before being exposed to sinks
- Depending on the species, sugar may move by symplastic or both symplastic and apoplastic pathways
- **Transfer cells** are modified companion cells that enhance solute movement between the apoplast and symplast

Fig. 36-19

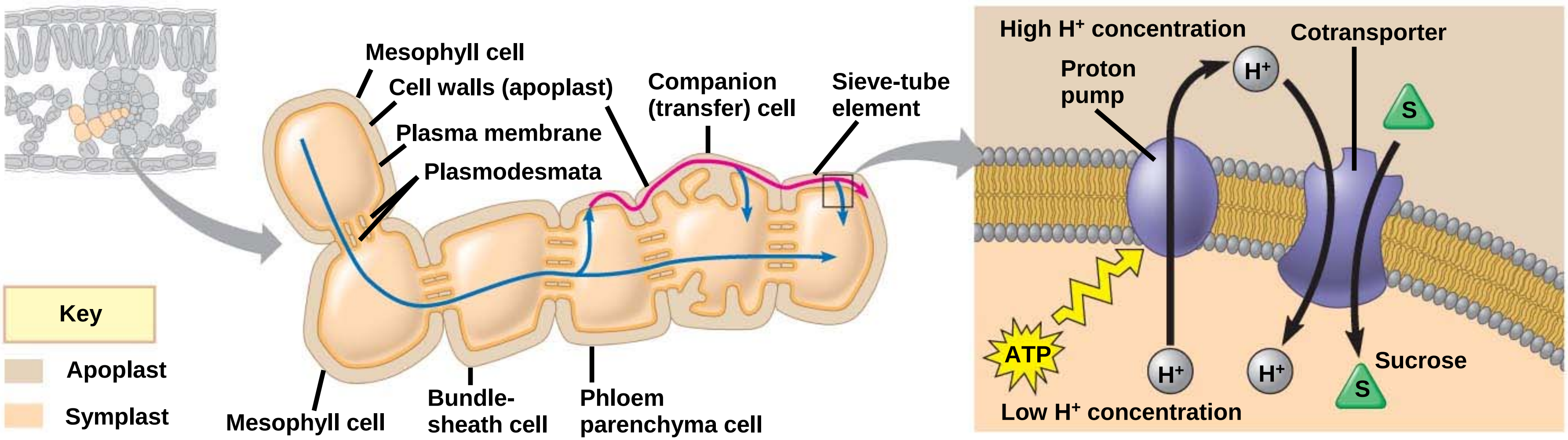
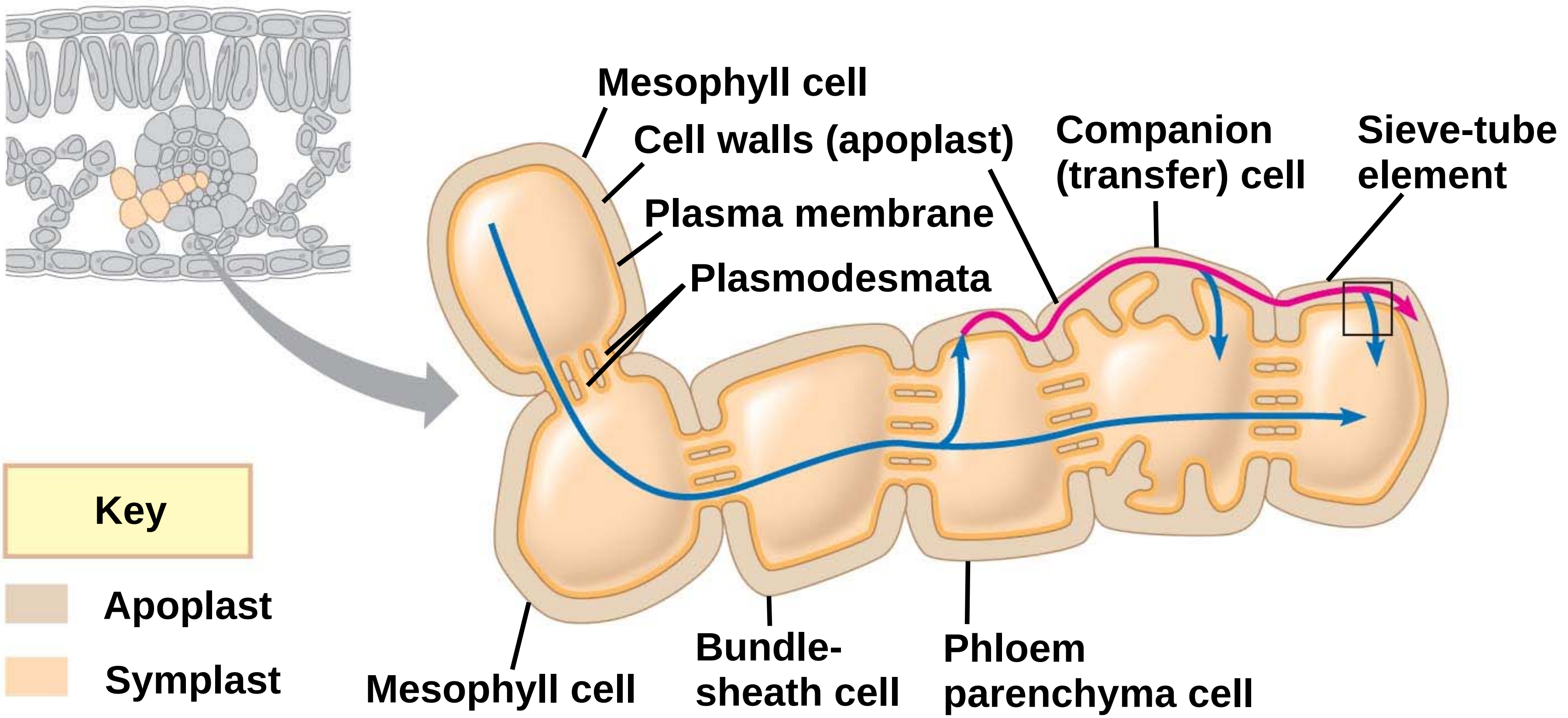

Mesophyll cell
Cell walls (apoplast)
Plasma membrane
Plasmodesmata
Companion (transfer) cell
Sieve-tube element
Key
Apoplast
Symplast
Mesophyll cell
Bundle-sheath cell
Phloem parenchyma cell
High H+ concentration
Cotransporter
Proton pump
H+
S
ATP
H+
H+
Sucrose
S
Low H+ concentration

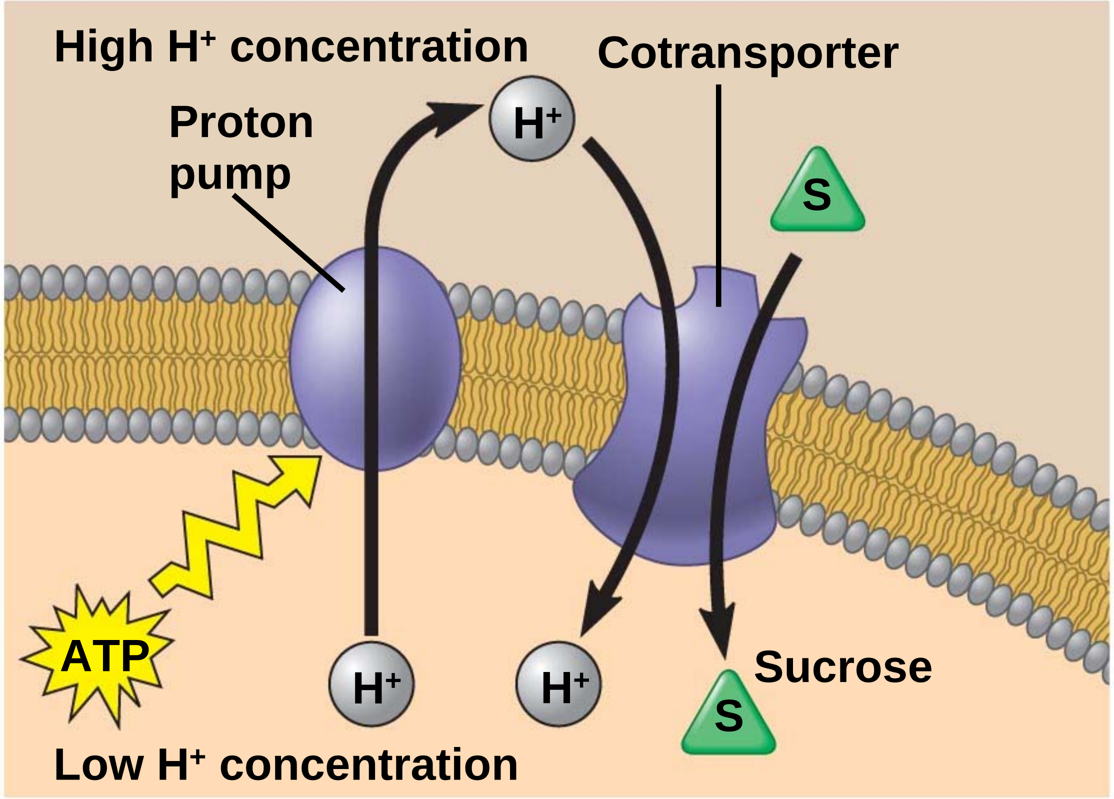
Fig. 36-19a



Mesophyll cell
Cell walls (apoplast)
Plasma membrane
Plasmodesmata
Companion (transfer) cell
Sieve-tube element
Key
Apoplast
Symplast
Mesophyll cell
Bundle-sheath cell
Phloem parenchyma cell

- In many plants, phloem loading requires active transport
- Proton pumping and cotransport of sucrose and H^+ enable the cells to accumulate sucrose
- At the sink, sugar molecules diffuse from the phloem to sink tissues and are followed by water

Fig. 36-19b



High H+ concentration
Cotransporter
Proton
pump
H+
S
ATP
H+
H+
Sucrose
S
Low H+ concentration

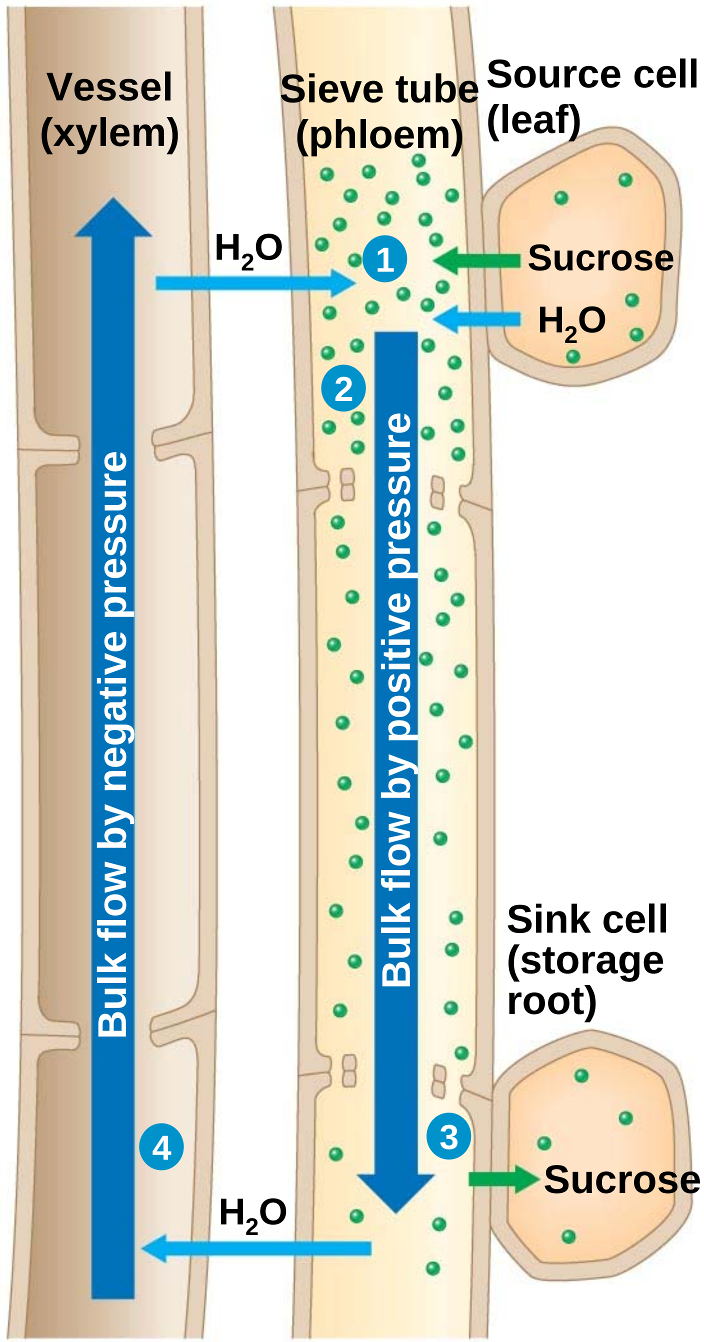
Bulk Flow by Positive Pressure: The Mechanism of Translocation in Angiosperms

- In studying angiosperms, researchers have concluded that sap moves through a sieve tube by bulk flow driven by positive pressure

PLAY Animation: Translocation of Phloem Sap in Summer

PLAY Animation: Translocation of Phloem Sap in Spring

Fig. 36-20



1 Loading of sugar

2 Uptake of water

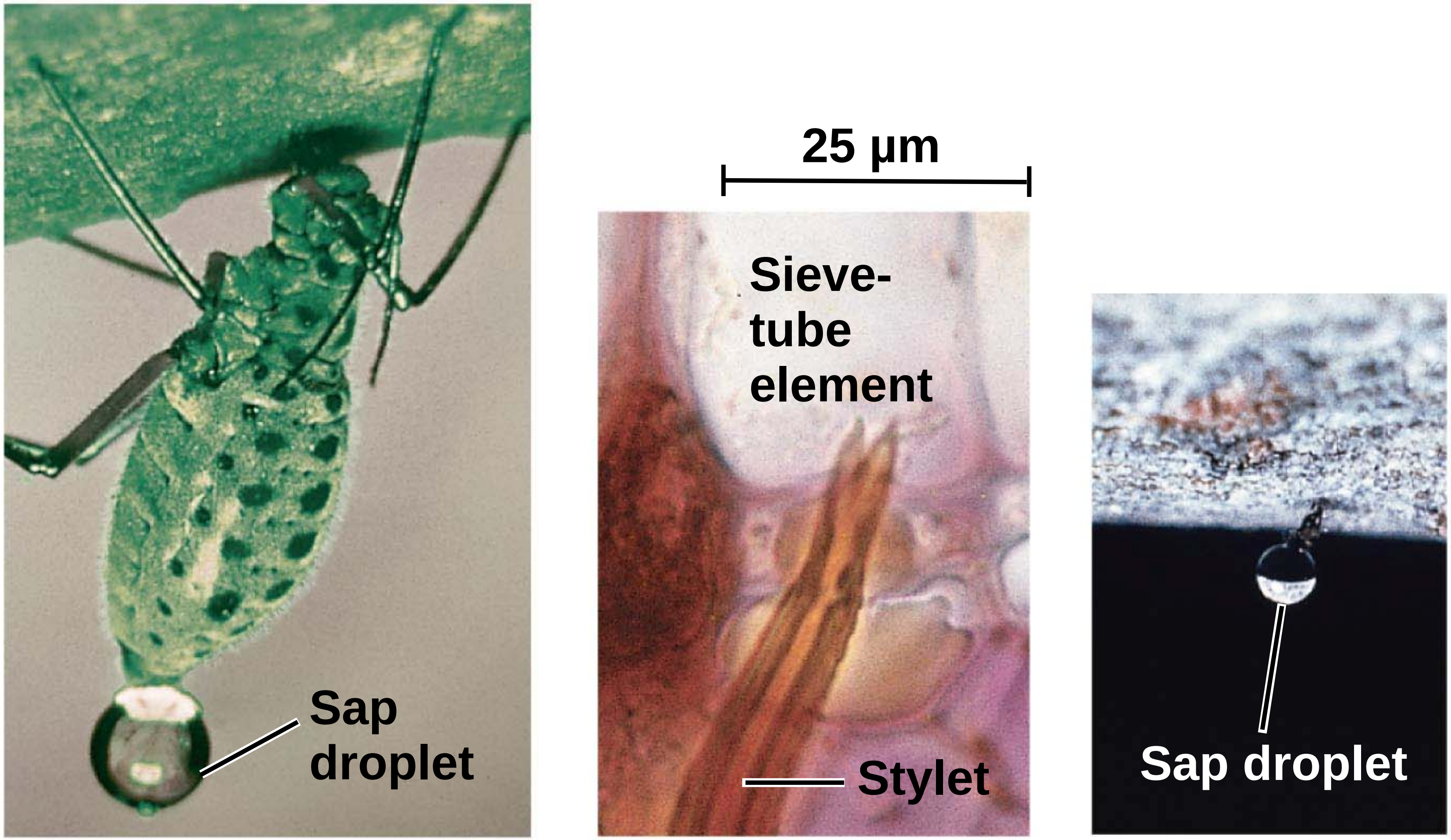
3 Unloading of sugar

4 Water recycled

- The pressure flow hypothesis explains why phloem sap always flows from source to sink
- Experiments have built a strong case for pressure flow as the mechanism of translocation in angiosperms

Fig. 36-21

EXPERIMENT



Aphid feeding

Stylet in sieve-tube element

Separated stylet exuding sap

Concept 36.6: The symplast is highly dynamic

- The symplast is a living tissue and is responsible for dynamic changes in plant transport processes

Plasmodesmata: Continuously Changing Structures

- Plasmodesmata can change in permeability in response to turgor pressure, cytoplasmic calcium levels, or cytoplasmic pH
- Plant viruses can cause plasmodesmata to dilate
- Mutations that change communication within the symplast can lead to changes in development

Fig. 36-22

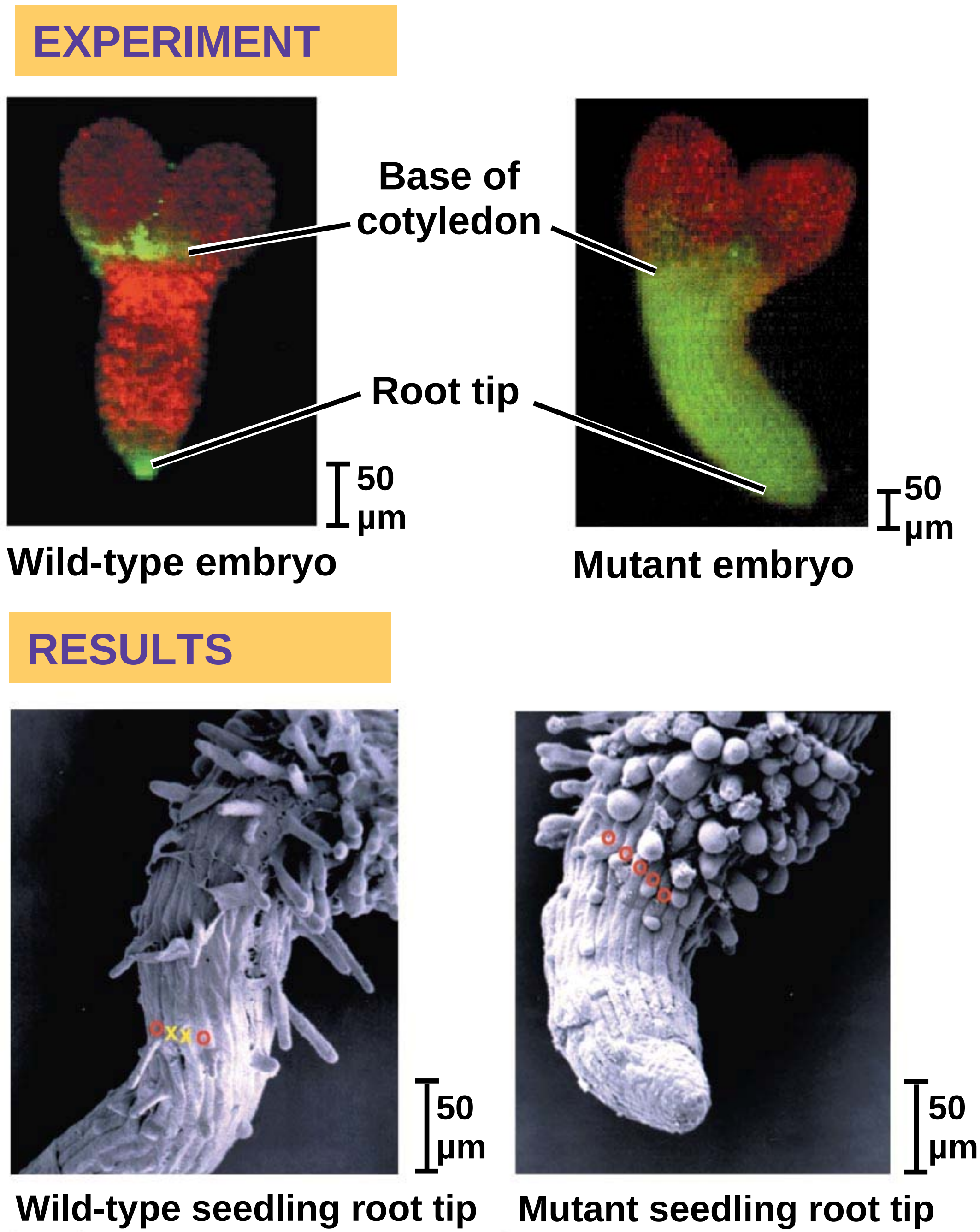
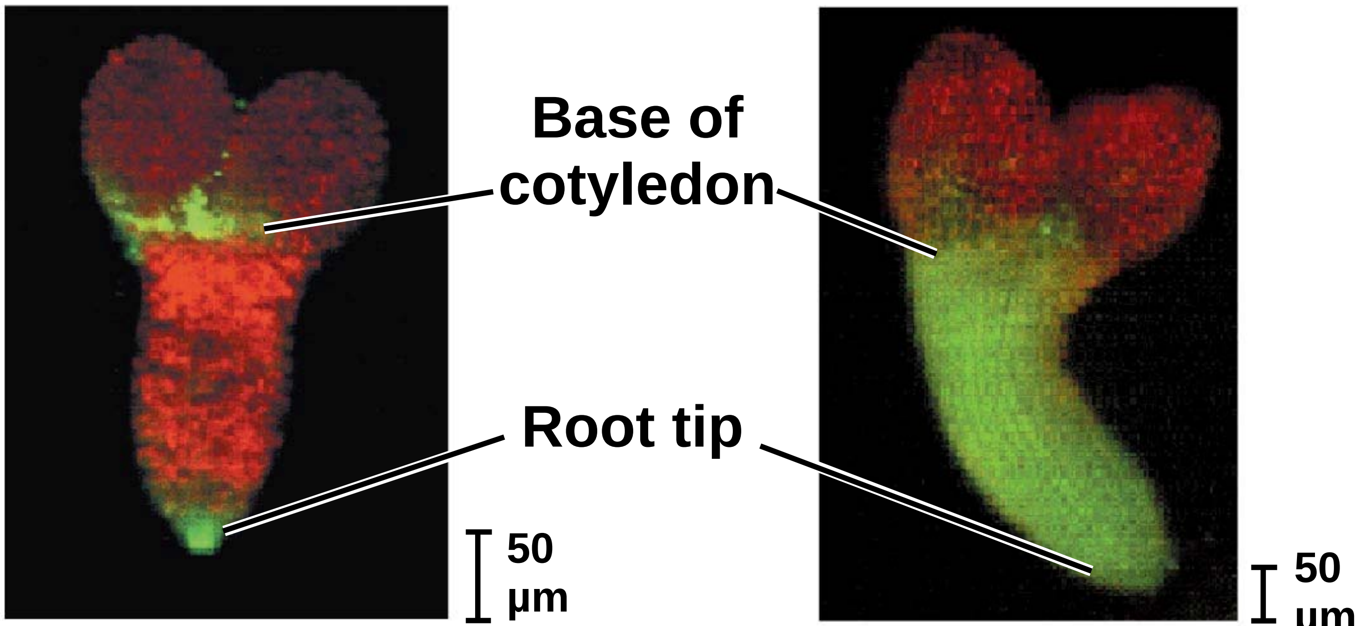

EXPERIMENT
Base of cotyledon
Root tip
50 µm
50 µm
Wild-type embryo
Mutant embryo
RESULTS
50 µm
50 µm
Wild-type seedling root tip
Mutant seedling root tip

Fig. 36-22a

EXPERIMENT



Wild-type embryo **Mutant embryo**

Fig. 36-22b

RESULTS

50 µm

Wild-type seedling root tip

50 µm

Mutant seedling root tip

Electrical Signaling in the Phloem

- The phloem allows for rapid electrical communication between widely separated organs

Phloem: An Information Superhighway

- Phloem is a “superhighway” for systemic transport of macromolecules and viruses
- **Systemic** communication helps integrate functions of the whole plant

Fig. 36-UN1

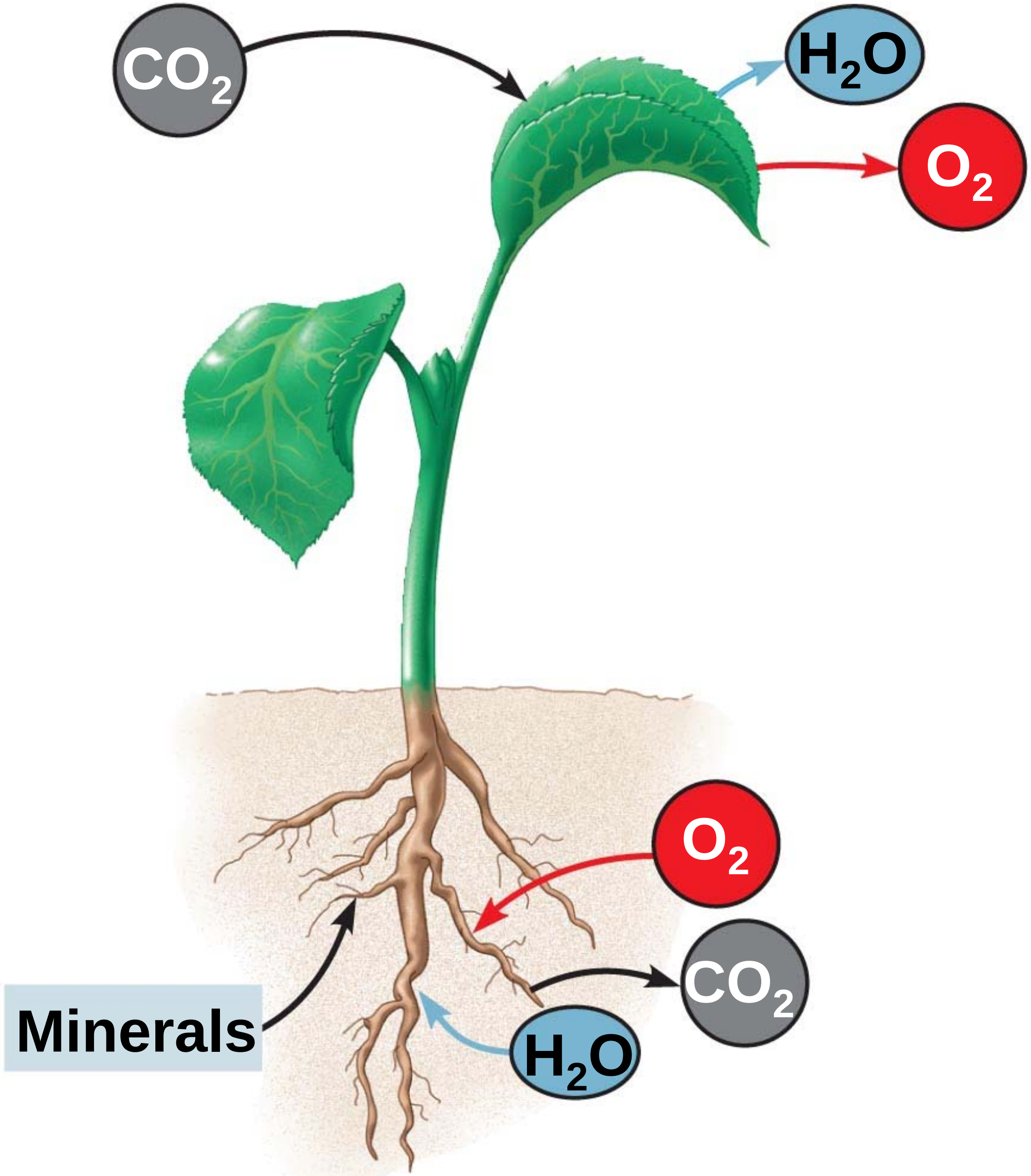


Fig. 36-UN2

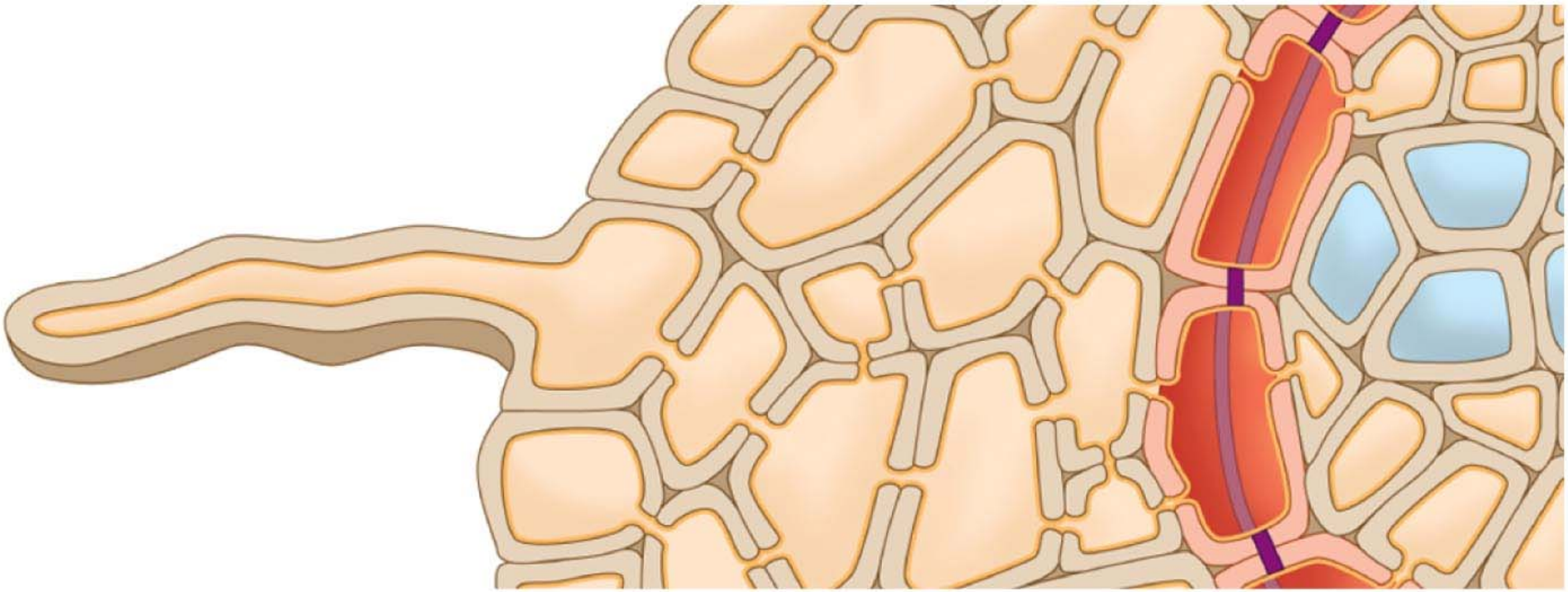
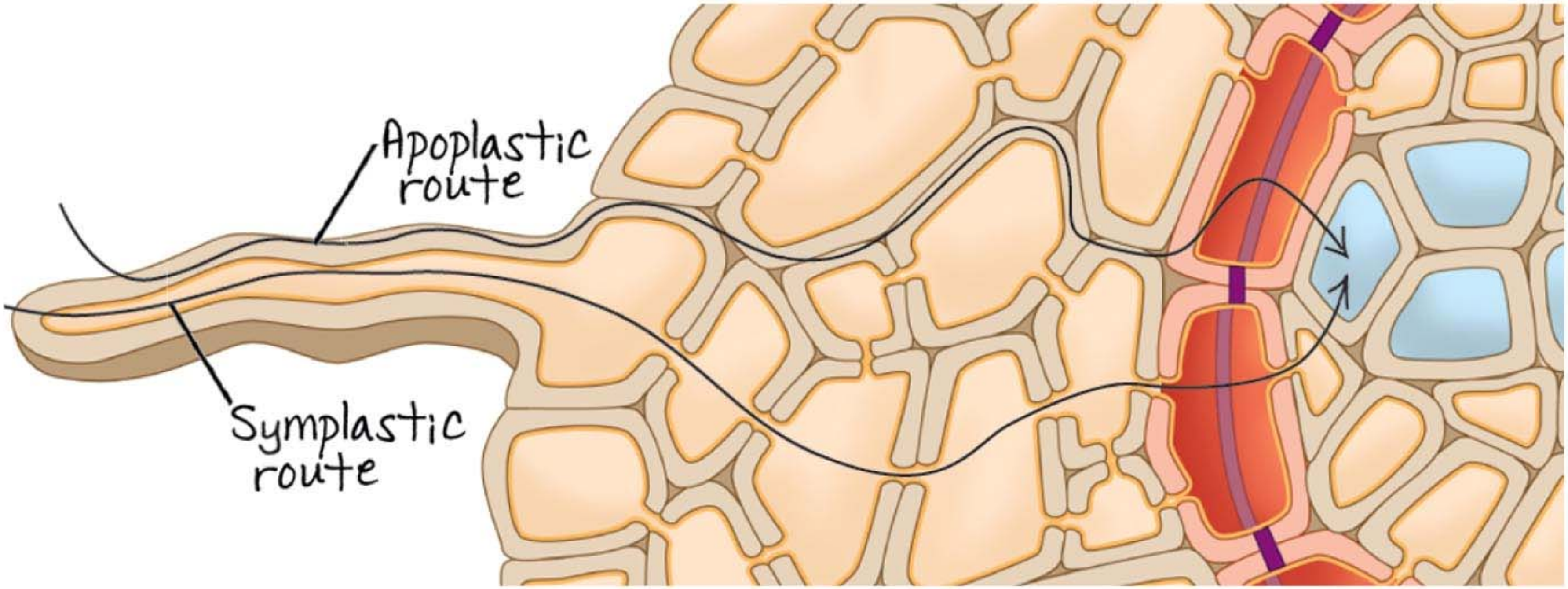


Fig. 36-UN3



You should now be able to:

1. Describe how proton pumps function in transport of materials across membranes
2. Define the following terms: osmosis, water potential, flaccid, turgor pressure, turgid
3. Explain how aquaporins affect the rate of water transport across membranes
4. Describe three routes available for short-distance transport in plants

5. Relate structure to function in sieve-tube cells, vessel cells, and tracheid cells
6. Explain how the endodermis functions as a selective barrier between the root cortex and vascular cylinder
7. Define and explain guttation
8. Explain this statement: “The ascent of xylem sap is ultimately solar powered”

9. Describe the role of stomata and discuss factors that might affect their density and behavior

10. Trace the path of phloem sap from sugar source to sugar sink; describe sugar loading and unloading