# Introduction to the Cell

# 4.1 Microscopes Reveal the World of the Cell (1 of 2)

- The **light microscope** can display living cells.
- The greater magnification and resolution of **scanning** and **transmission electron microscopes** reveal the ultrastructure of cells.
  - *Magnification* is the increase in an object's image size compared with its actual size.
  - *Resolution* is a measure of the clarity of an image. In other words, it is the ability of an instrument to show two nearby objects as separate.

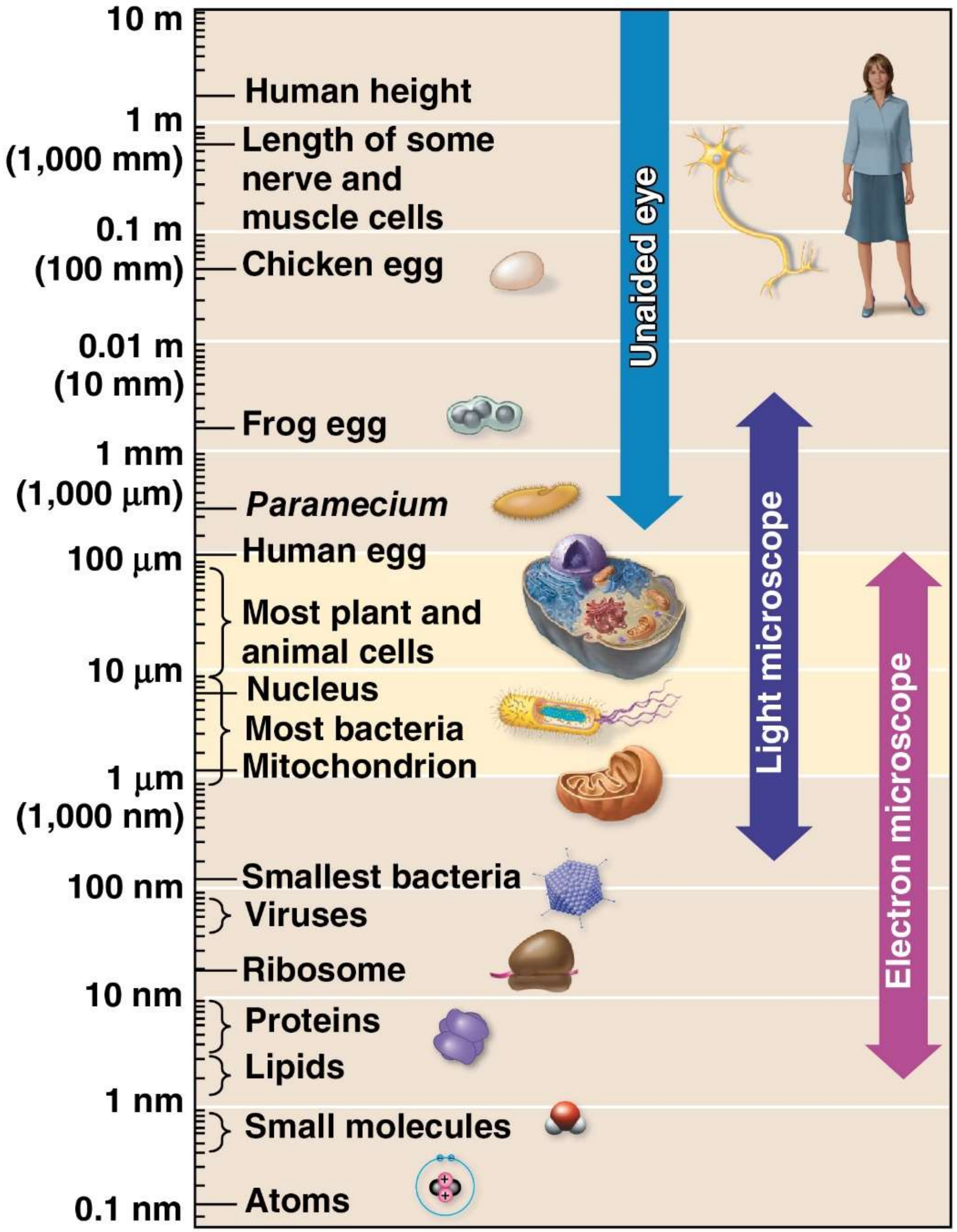
# 4.1 Microscopes Reveal the World of the Cell (2 of 2)

- In the mid-1800s, early studies of cells led to cell **theory**, which states that
  - all living things are composed of cells and
  - all cells come from other cells.

**Checkpoint question** Which type of microscope would you use to study (a) the changes in shape of a living human white blood cell; (b) the finest details of surface texture of a human hair; (c) the detailed structure of an organelle in a liver cell?

(a) Light microscope; (b) scanning electron microscope; (c) transmission electron microscope

# Figure 4.1e

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# 4.2 The Small Size of Cells Relates to the Need to Exchange Materials Across the Plasma Membrane (1 of 2)

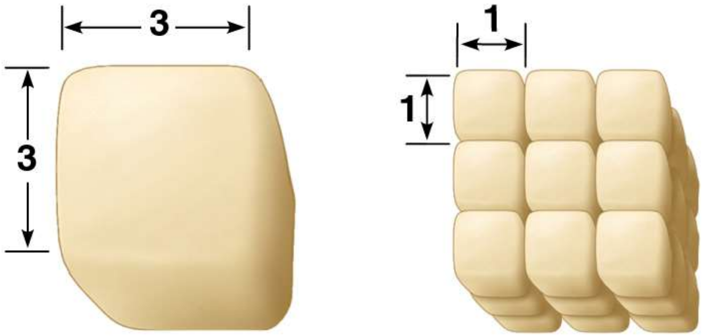
- The microscopic size of most cells provides a large surface-to-volume ratio.
- The **plasma membrane** is a phospholipid bilayer with embedded proteins.
  – Some proteins form channels (tunnels) that shield ions and other hydrophilic molecules as they pass through the hydrophobic center of the membrane.
  – Other proteins serve as pumps, using energy to actively transport molecules into or out of the cell.

# 4.2 The Small Size of Cells Relates to the Need to Exchange Materials Across the Plasma Membrane (2 of 2)

Large cube: 54/27 = 2; small cube: 6/1 = 6 (surface area is 1 × 1 × 6 sides = 6 units$^2$; volume is 1 × 1 × 1 unit$^3$)

Long Description:

Large cells have more surface area than small cells, but they have a much smaller surface area relative to their volume than small cells.




| | | |
|---|---|---|
| Total volume | 27 units$^3$ | 27 units$^3$ |
| Total surface area | 54 units$^2$ | 162 units$^2$ |
| Surface-to-volume ratio | 2 | 6 |

**Checkpoint question** To convince yourself that a small cell has a greater surface area relative to volume than a large cell, compare the surface-to-volume ratios of the large cube and one of the small cubes in Figure 4.2A.

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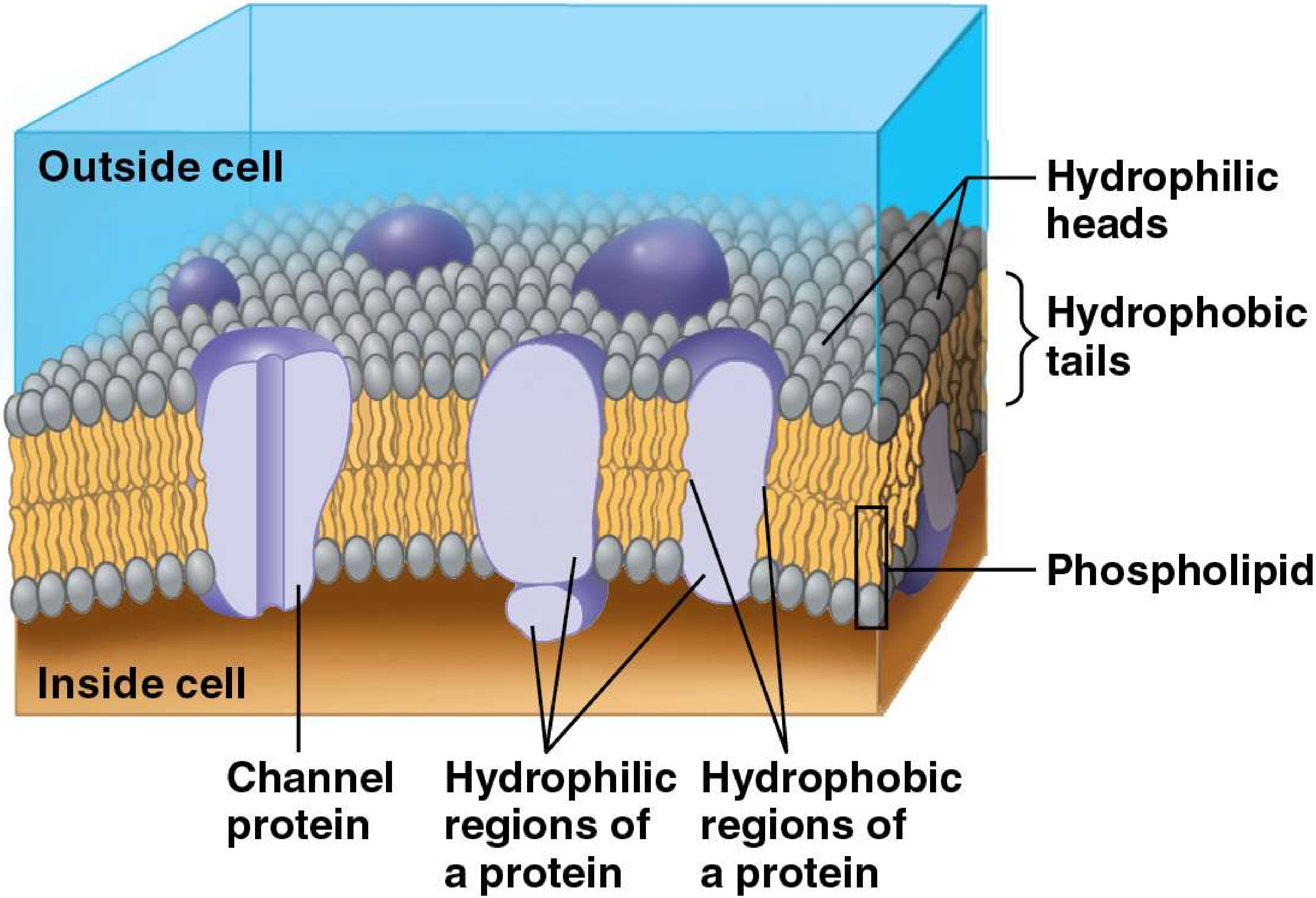
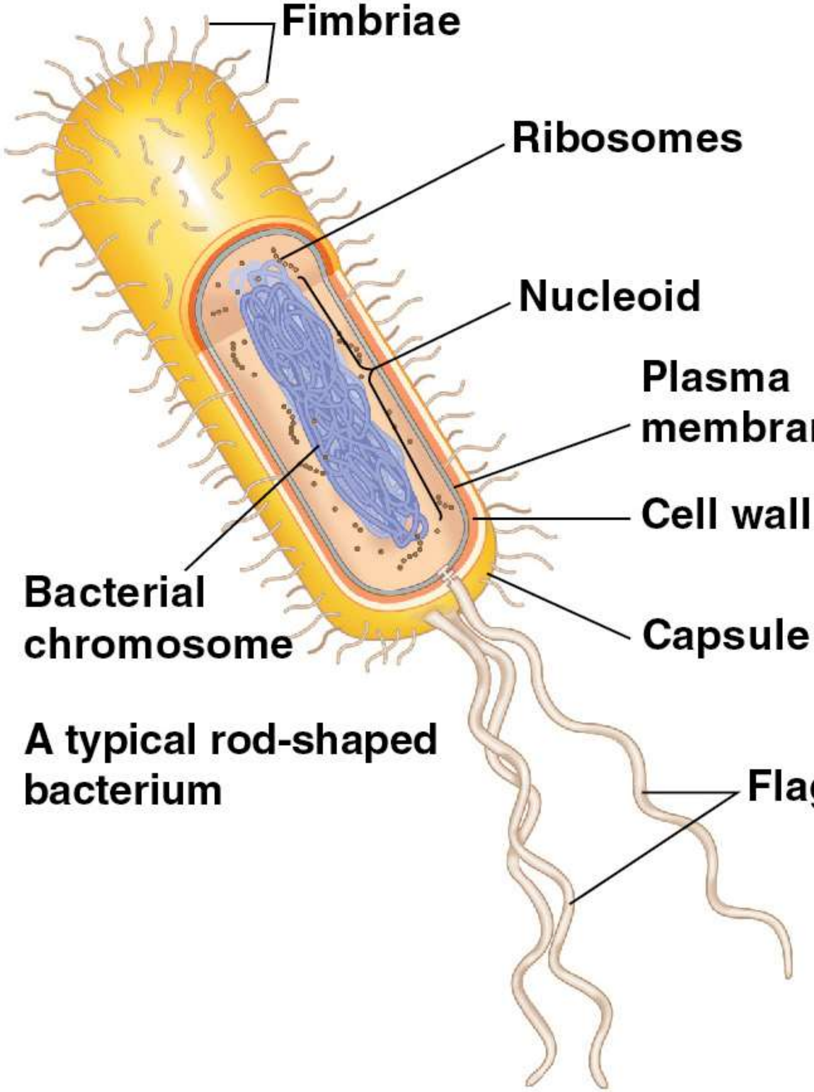
# Figure 4.2b


Outside cell
Inside cell
Hydrophilic heads
Hydrophobic tails
Phospholipid
Channel protein
Hydrophilic regions of a protein
Hydrophobic regions of a protein

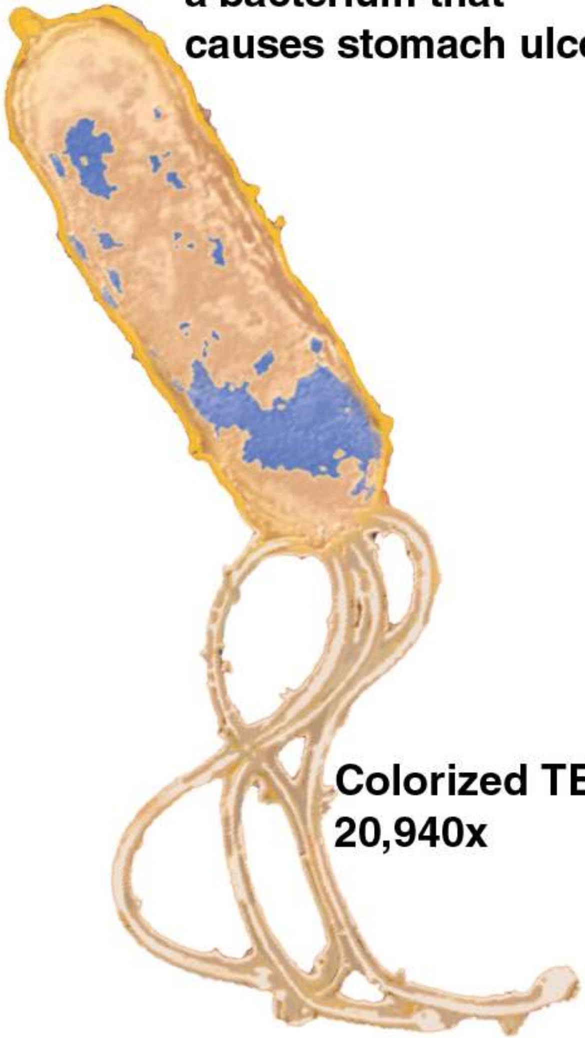
# 4.3 Prokaryotic Cells Are Structurally Simpler Than Eukaryotic Cells

- All cells have a plasma membrane, DNA, ribosomes, and **cytosol**.
- Bacteria and Archaea consist of **prokaryotic cells**.
- All other forms of life are  placed in domain Eukarya and have **eukaryotic cells**.
- Eukaryotic cells are distinguished by having
  – a membrane-enclosed nucleus and
  – many membrane-enclosed organelles that perform specific functions.
- Prokaryotic cells are smaller and simpler in structure.

# Figure 4.3




A typical rod-shaped bacterium



*Helicobactor pylori,* a bacterium that causes stomach ulcers

Colorized TEM 20,940x

# 4.4 Eukaryotic Cells Are Partitioned into Functional Compartments (1 of 2)

- Membrane-enclosed **organelles** compartmentalize a cell's activities.
- The organelles and other structures of eukaryotic cells can be organized into four basic functional groups:

  1. The nucleus and ribosomes carry out the genetic control of the cell.
  2. Organelles involved in the manufacture, distribution, and breakdown of molecules include the endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and peroxisomes.

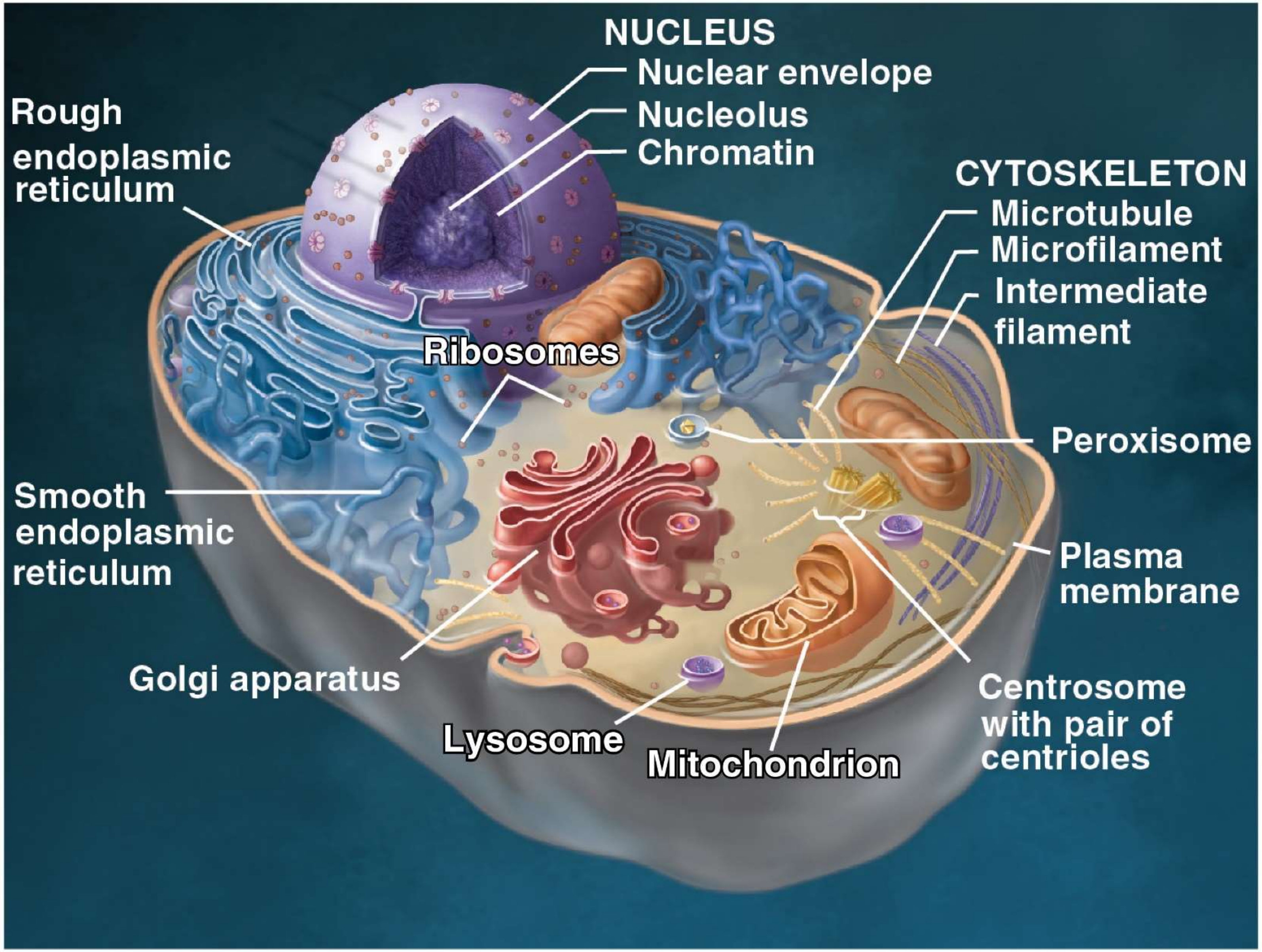
# 4.4 Eukaryotic Cells Are Partitioned into Functional Compartments (2 of 2)

3. Mitochondria in all cells and chloroplasts in plant cells function in energy processing.
4. Structural support, movement, and communication between cells are the functions of the cytoskeleton, plasma membrane, and plant cell wall.

**Checkpoint question** Identify the structures in the plant cell that are not present in the animal cell.

Chloroplasts, central vacuole, cell wall, and plasmodesmata

# Figure 4.4a

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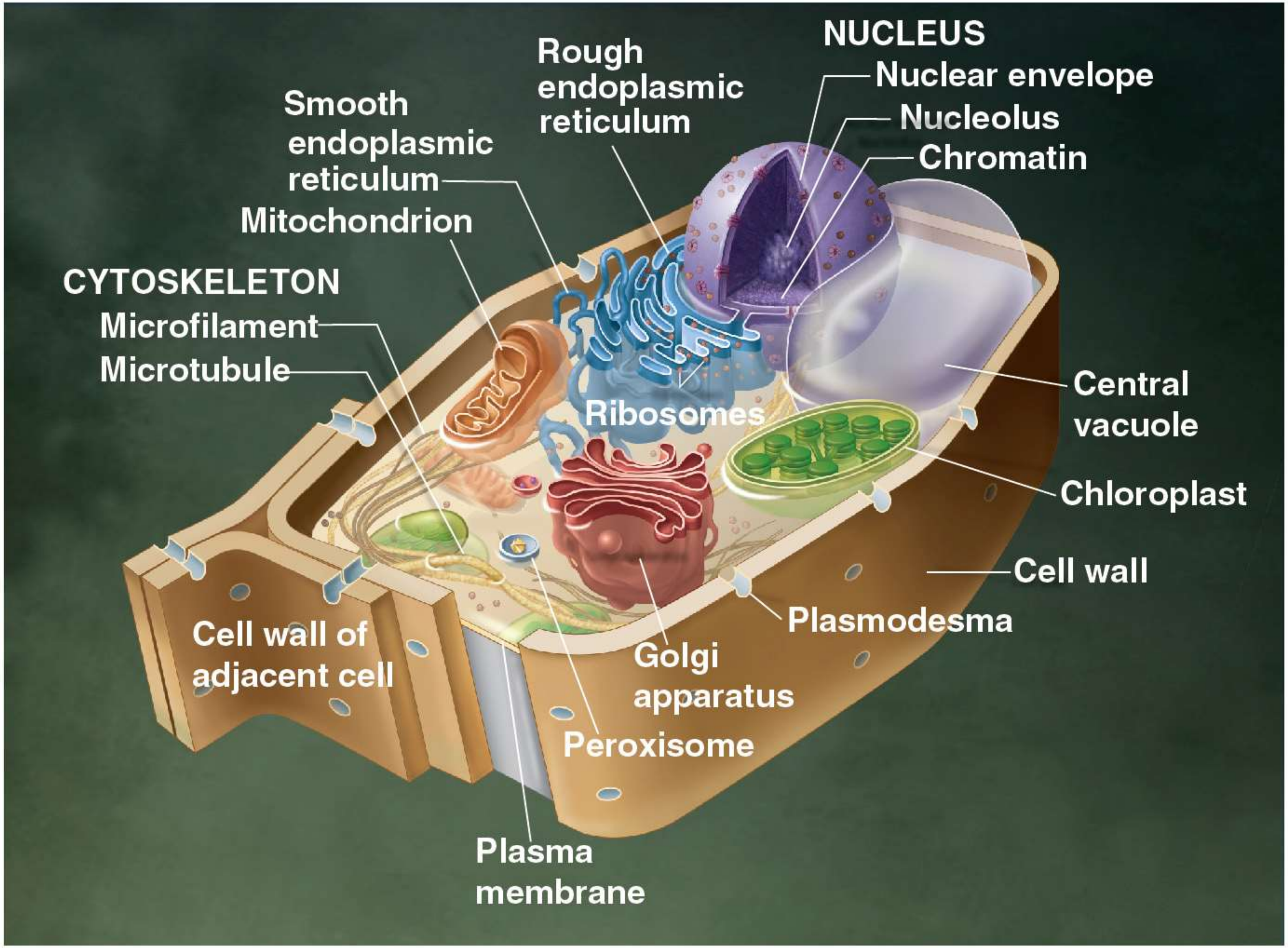
# Figure 4.4b


NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Mitochondrion
CYTOSKELETON
Microfilament
Microtubule
Ribosomes
Central vacuole
Chloroplast
Cell wall
Plasmodesma
Cell wall of adjacent cell
Golgi apparatus
Peroxisome
Plasma membrane

# The Nucleus and Ribosomes

# 4.5 The Nucleus Contains the Cell’s Genetic Instructions

- The **nucleus** houses the cell’s DNA, which directs protein synthesis via messenger RNA.
- Subunits of ribosomes are assembled in the **nucleolus**.

**Checkpoint question** Describe the processes that occur in the nucleus.

DNA is copied and passed on to daughter cells in cell division; rRNA is made and ribosomal subunits assembled; protein-making instructions in DNA are transcribed into mRNA.

# 4.6 Ribosomes Make Proteins for Use in the Cell and Export

- Ribosomes
  - are composed of ribosomal RNA and proteins and
  - synthesize proteins according to directions from DNA.
- Cells that make a lot of proteins have a large number of ribosomes.

# The Endomembrane System

# 4.7 Many Organelles Are Connected in the Endomembrane System

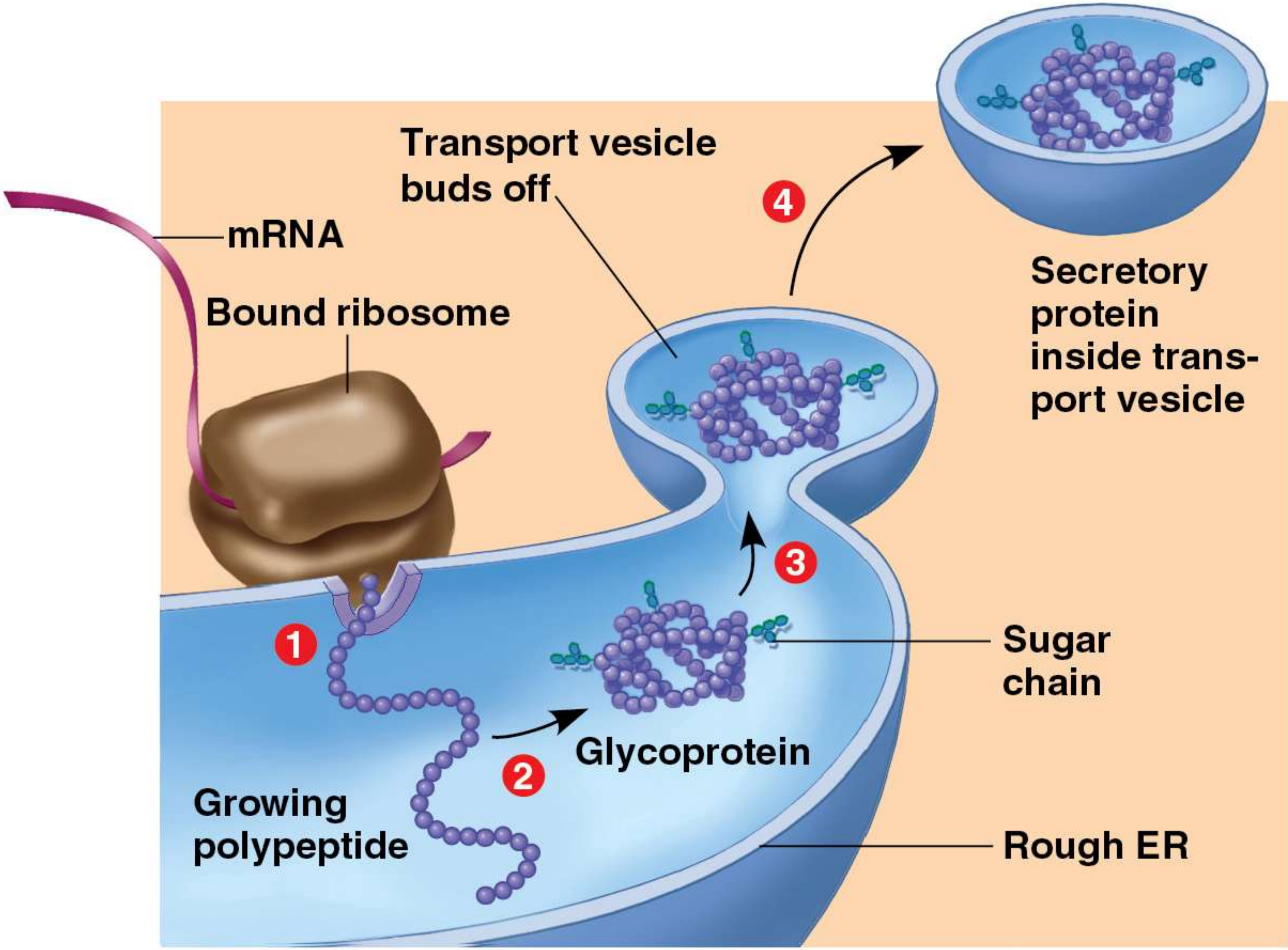
- Many of the membranes within a eukaryotic cell are part of the **endomembrane system**.
- Many of these organelles interact in the
  - synthesis,
  - distribution,
  - storage, and
  - export of molecules.

# 4.8 The Endoplasmic Reticulum is a Biosynthetic Workshop

- The ER is a membranous network of tubes and sacs.
  - **Smooth ER** synthesizes lipids and processes toxins.
  - **Rough ER** produces membranes, and ribosomes on its surface make membrane and secretory proteins.

**Checkpoint question** Explain why we say that the endoplasmic reticulum is a biosynthetic workshop.

# Figure 4.8b

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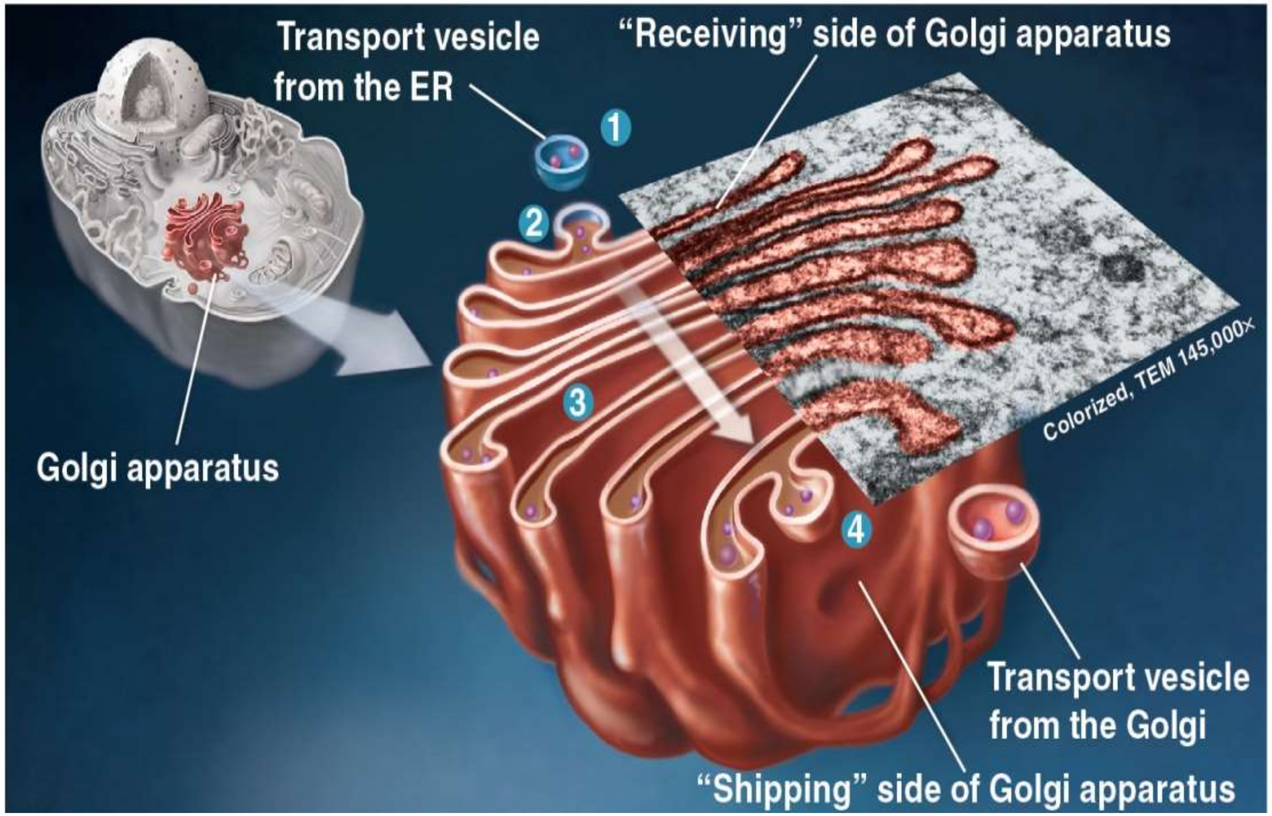
# 4.9 The Golgi Apparatus Modifies, Sorts, and Ships Cell Products (1 of 2)

- The **Golgi apparatus** consists of stacks of sacs in which products of the ER are processed and then sent to other organelles or to the cell surface.

# 4.9 The Golgi Apparatus Modifies, Sorts, and Ships Cell Products (2 of 2)




The Golgi receives transport vesicles budded from the ER that contain proteins synthesized by bound ribosomes. The Golgi finishes processing the proteins and dispatches transport vesicles to the plasma membrane, where the proteins are secreted.

**Checkpoint question** What is the relationship of the Golgi apparatus to the ER in a protein-secreting cell?

# 4.10 Lysosomes Are Digestive Compartments Within a Cell (1 of 2)

3. Mitochondria in all cells and chloroplasts in plant cells function in energy processing.
4. Structural support, movement, and communication between cells are the functions of the cytoskeleton, plasma membrane, and plant cell wall.

**Checkpoint question** Identify the structures in the plant cell that are not present in the animal cell.

Chloroplasts, central vacuole, cell wall, and plasmodesmata

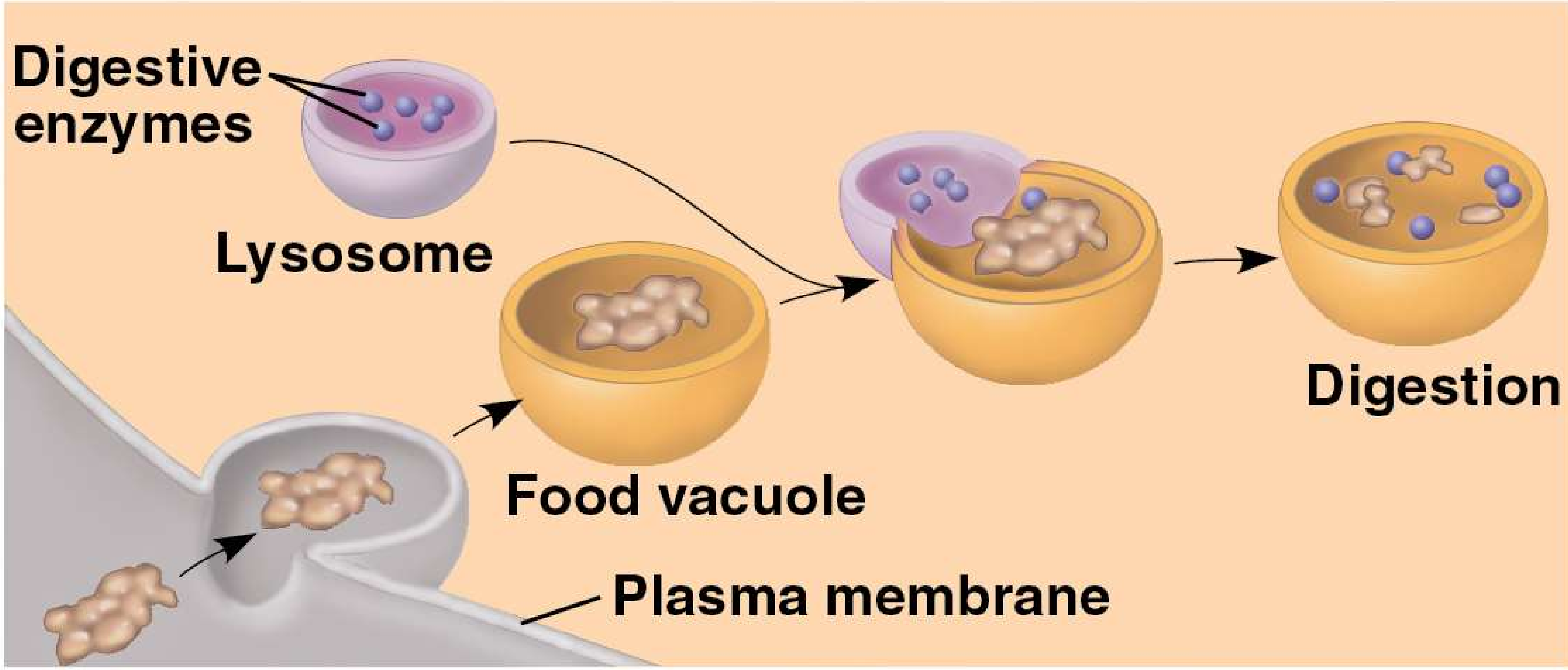
# 4.10 Lysosomes Are Digestive Compartments Within a Cell (2 of 2)

- Lysosomes house enzymes that break down ingested substances and damaged organelles.

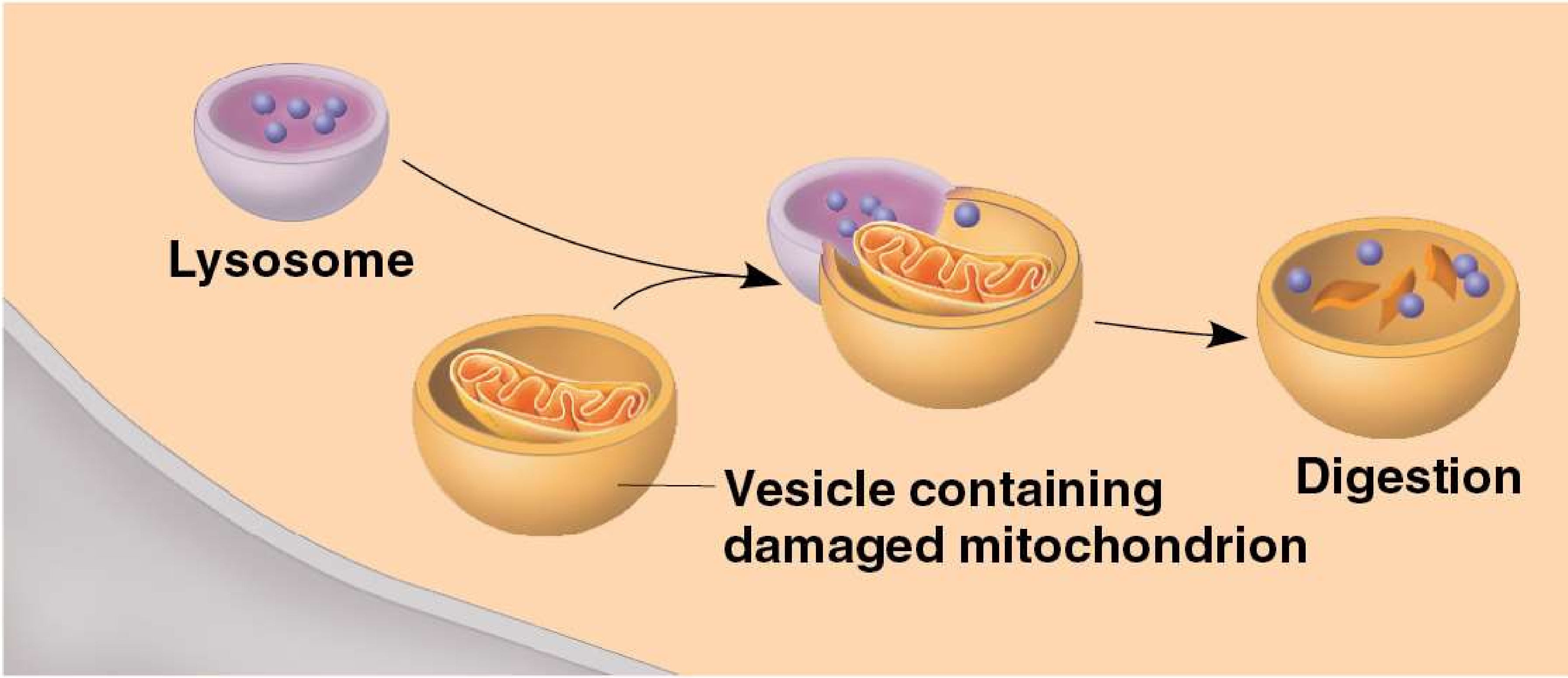
**Checkpoint question** How is a lysosome like a recycling center?

It breaks down damaged organelles and recycles their molecules.

# Figure 4.10a_4



# Figure 4.10b_3



# 4.11 Vacuoles Function in the General Maintenance of the Cell

- **Vacuoles** are large vesicles that have a variety of functions.
  - Some protists have contractile vacuoles.
  - Plant cells contain a large **central vacuole** that stores molecules and wastes and facilitates growth.

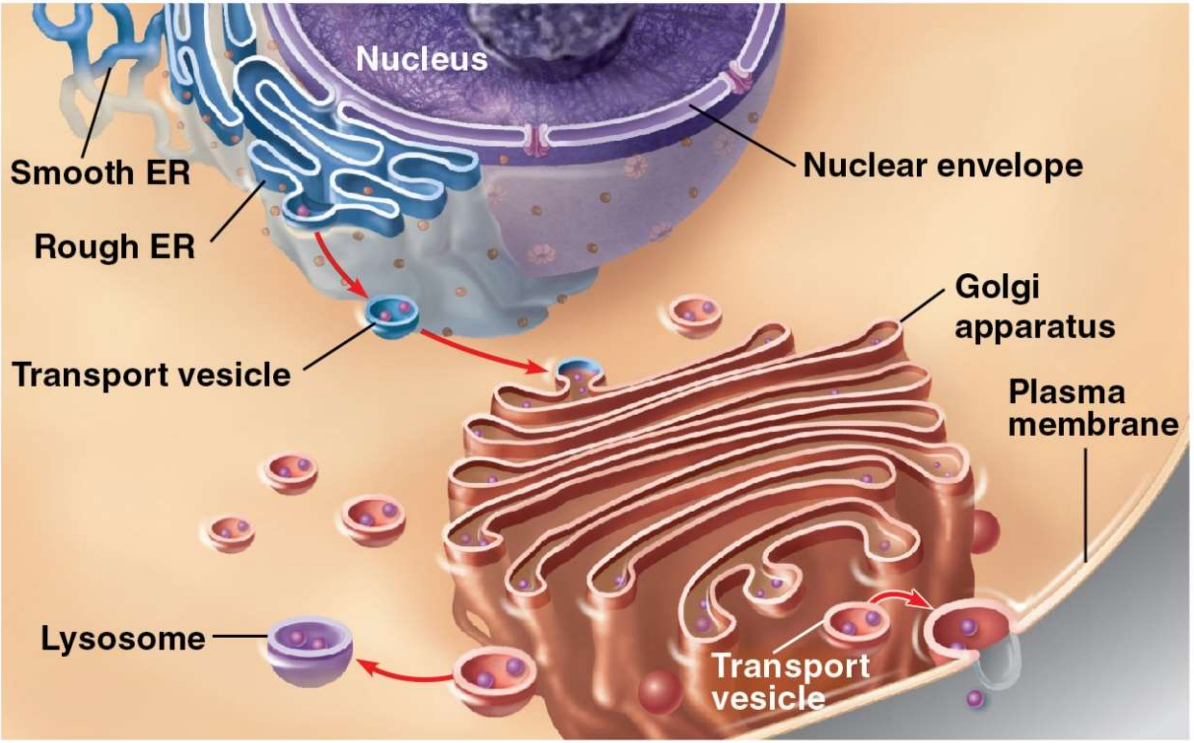
**Checkpoint question** Is a food vacuole part of the endomembrane system? Explain.

Yes; it forms by pinching in from the plasma membrane, which is part of the endomembrane system.

# 4.12 A Review of the Structures Involved in Manufacturing and Breakdown (1 of 3)

- The organelles of the endomembrane system are interconnected structurally and functionally.
- Figure 4.12 summarizes the relationships among the major organelles of the endomembrane system.

# 4.12 A Review of the Structures Involved in Manufacturing and Breakdown (2 of 3)




Transport vesicles move membranes and the substances they enclose between components of the endomembrane system.
Long Description:

**Checkpoint question** How do transport vesicles help tie together the endomembrane system?

# 4.12 A Review of the Structures Involved in Manufacturing and Breakdown (3 of 3)

- **Peroxisomes** are metabolic compartments that do not originate from the endomembrane system.

# Energy-Converting Organelles

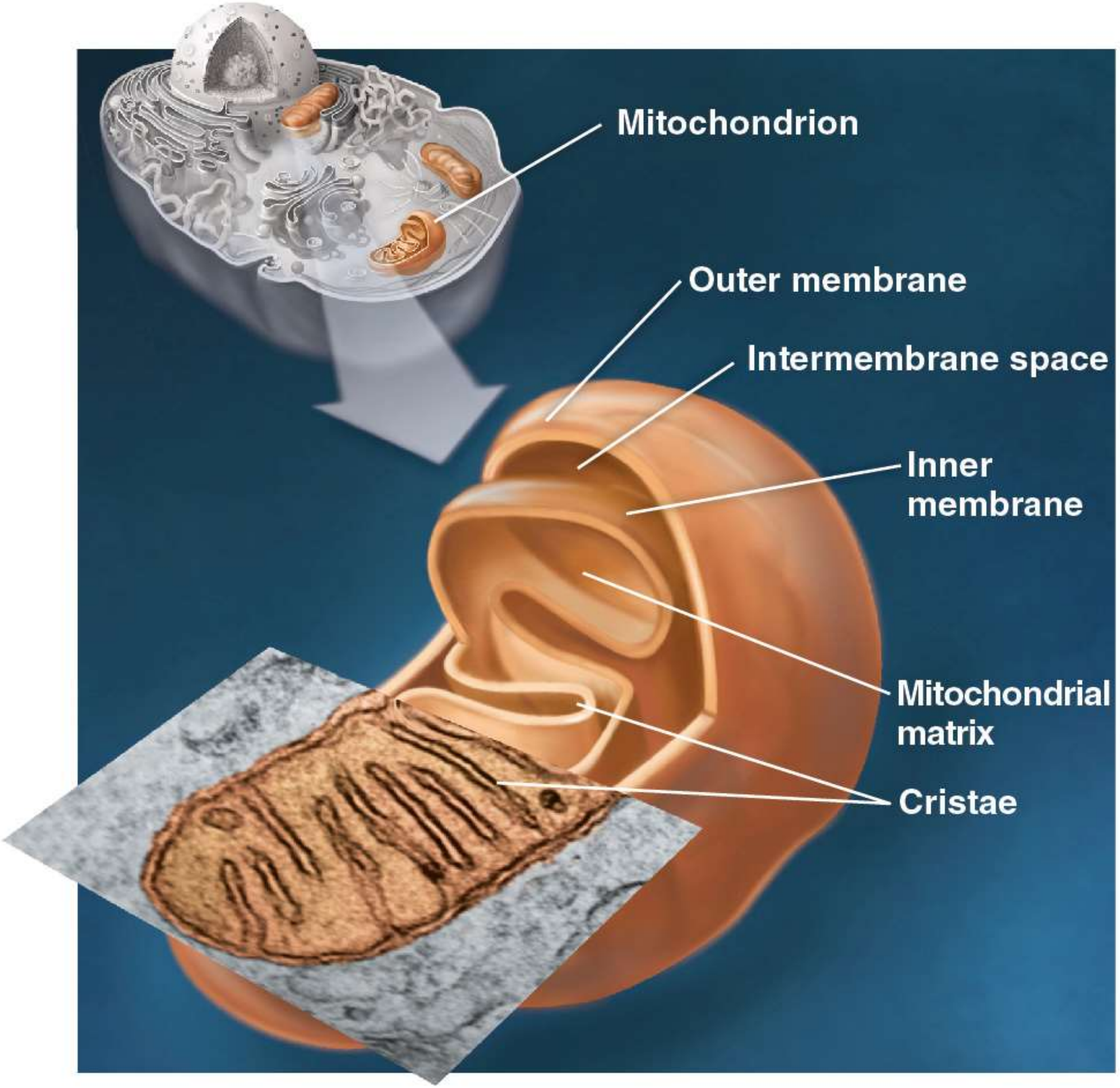
# 4.13 Mitochondria Harvest Chemical Energy from Food

- **Mitochondria** are organelles that carry out cellular respiration in nearly all eukaryotic cells.
- Mitochondria have two internal compartments.
  1. The intermembrane space is the narrow region between the inner and outer membranes.
  2. The **mitochondrial matrix** contains the mitochondrial DNA, ribosomes, and many enzymes that catalyze some of the reactions of cellular respiration.

**Checkpoint question** What is cellular respiration?

A process that converts the chemical energy of food molecules to the chemical energy of ATP.

# Figure 4.13


Mitochondrion
Outer membrane
Intermembrane space
Inner membrane
Mitochondrial matrix
Cristae

# 4.14 Chloroplasts Convert Solar Energy to Chemical Energy (1 of 2)

- Photosynthesis is the conversion of light energy from the sun to the chemical energy of sugar molecules.
- **Chloroplasts** are the photosynthesizing organelles of plants and algae.

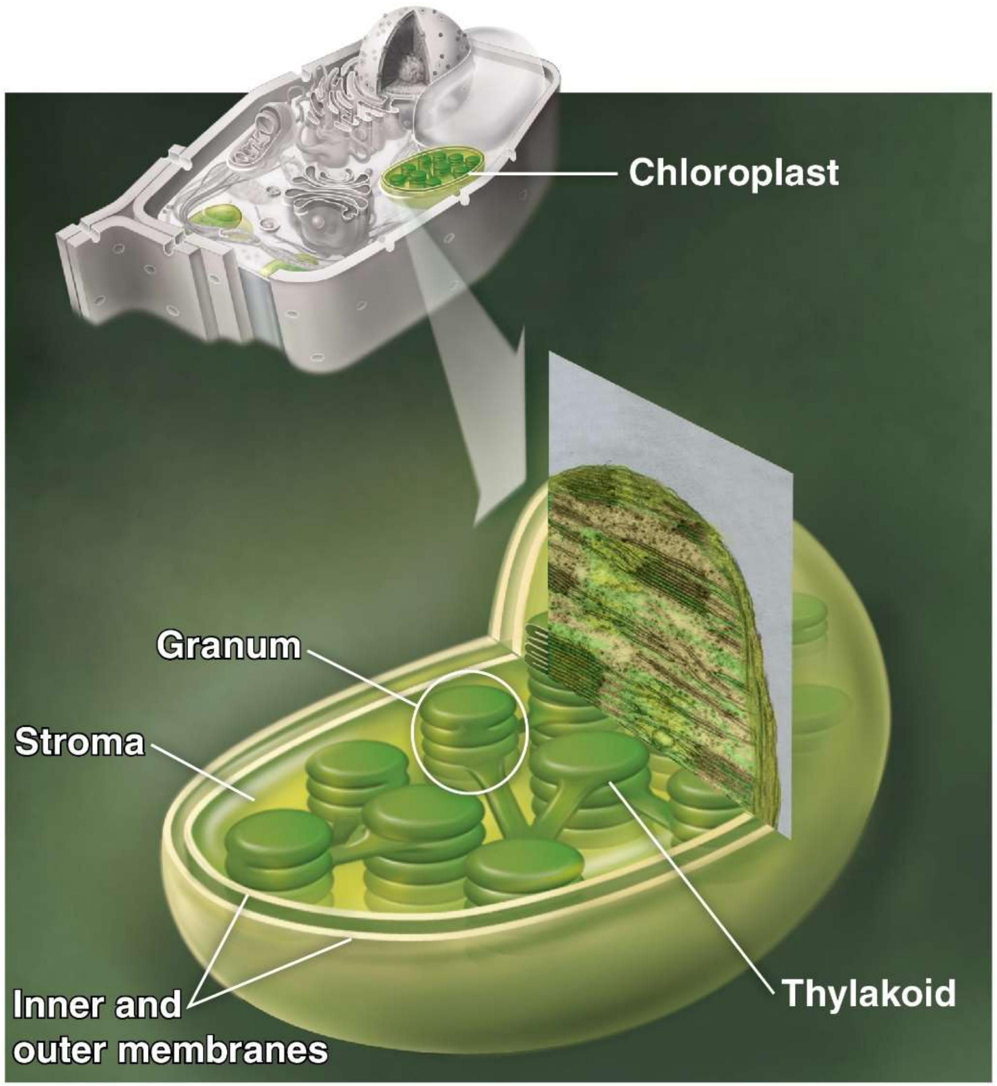
# 4.14 Chloroplasts Convert Solar Energy to Chemical Energy (2 of 2)

**Checkpoint question**

Which membrane in a chloroplast appears to be the most extensive?

Why might this be so?

The thylakoids are the most extensive. The chlorophyll molecules that trap solar energy are embedded in them.



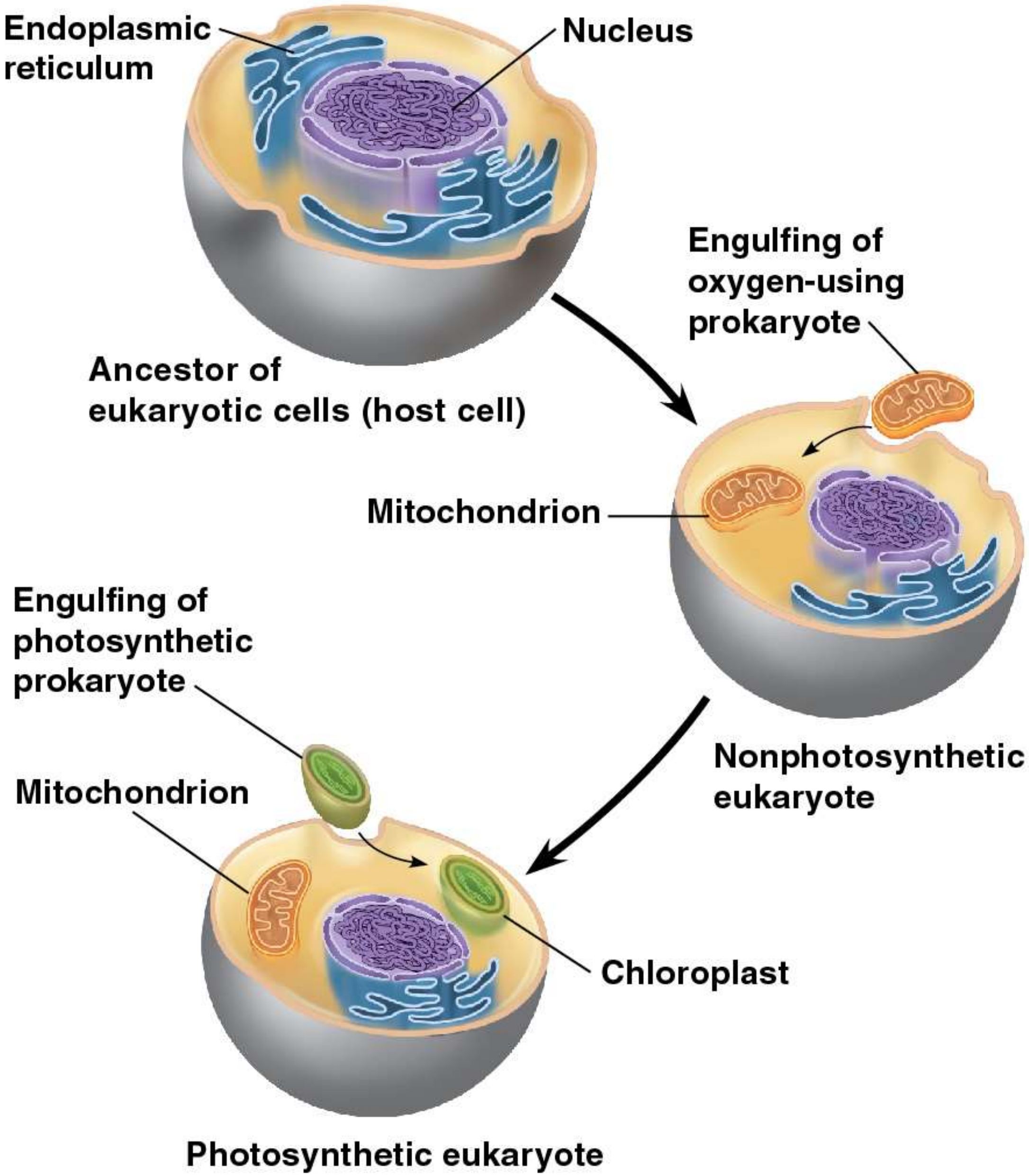
# 4.15 Evolution Connection: Mitochondria and Chloroplasts Evolved by Endosymbiosis

- The **endosymbiont theory** states that mitochondria and chloroplasts were formerly small prokaryotes that began living within larger cells.

**Checkpoint question** All eukaryotes have mitochondria, but not all have chloroplasts. What is the evolutionary explanation?

The first endosymbiosis would have given rise to eukaryotic cells containing mitochondria. A second endosymbiotic event gave rise to cells containing chloroplasts as well as mitochondria.

# Figure 4.15



Endoplasmic reticulum
Nucleus
Ancestor of eukaryotic cells (host cell)
Engulfing of oxygen-using prokaryote
Mitochondrion
Nonphotosynthetic eukaryote
Engulfing of photosynthetic prokaryote
Mitochondrion
Chloroplast
Photosynthetic eukaryote

# The Cytoskeleton and Cell Surfaces

# 4.16 The Cell's Internal Skeleton Helps Organize Its Structure and Activities (1 of 2)

- The **cytoskeleton** includes **microfilaments**, **intermediate filaments**, and **microtubules**. Their functions include
  - maintenance of cell shape,
  - anchorage and movement of organelles,
  - amoeboid movement, and
  - muscle contraction.

# 4.16 The Cell’s Internal Skeleton Helps Organize Its Structure and Activities (2 of 2)

**Checkpoint question** Which component of the cytoskeleton is most important in

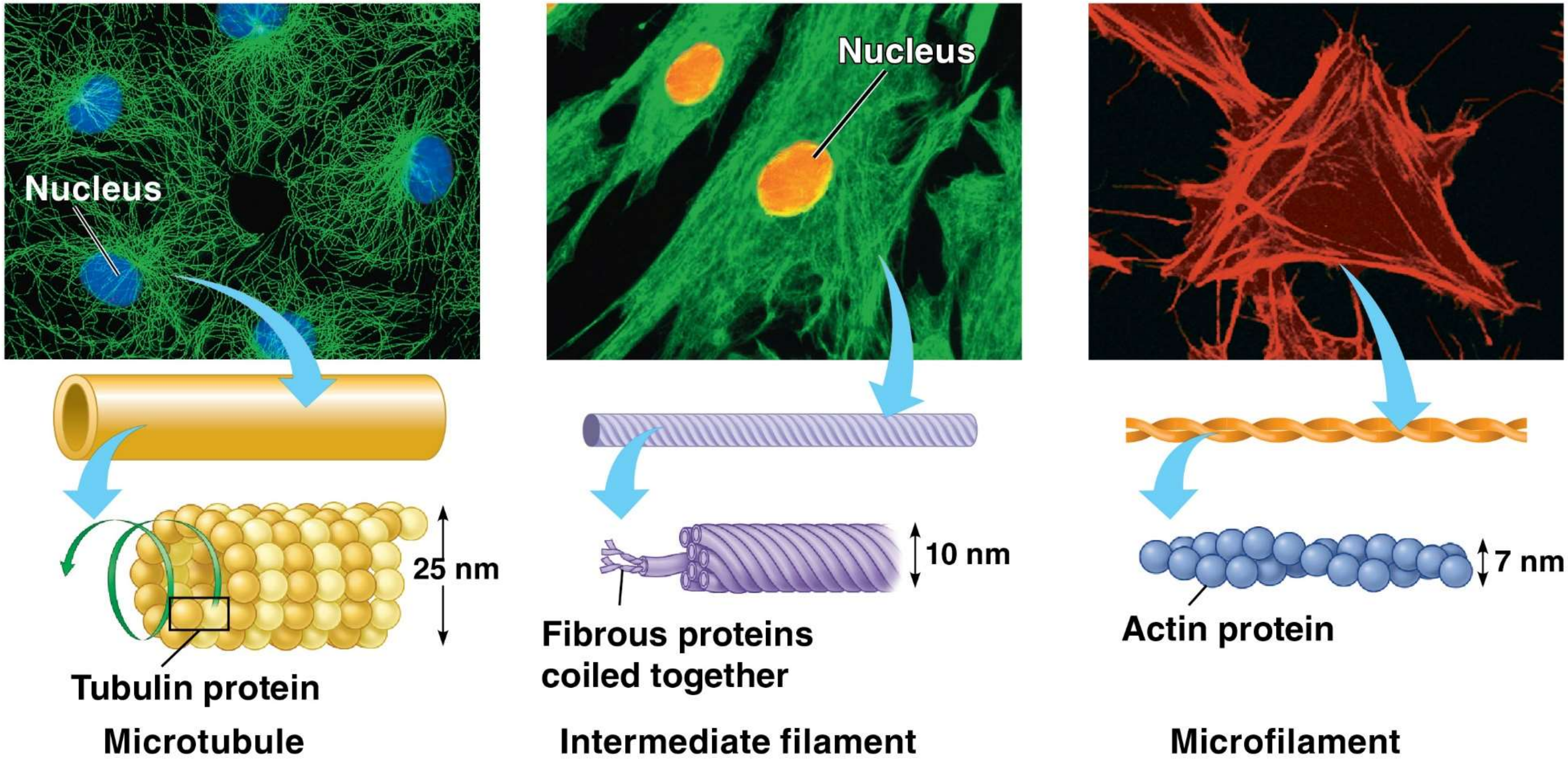
a. holding the nucleus in place within an animal cell;

b. guiding transport vesicles from the Golgi to the plasma membrane;

c. contracting muscle cells?

a) Intermediate filaments; b) microtubules;
c) microfilaments

# Figure 4.16


Nucleus
Nucleus
25 nm
Tubulin protein
Microtubule
10 nm
Fibrous proteins coiled together
Intermediate filament
7 nm
Actin protein
Microfilament

# 4.17 Scientific Thinking: Scientists Discovered the Cytoskeleton Using the Tools of Biochemistry and Microscopy (1 of 2)

- In the 1940s, biochemists first isolated and identified the proteins actin and myosin from muscle cells.
- In 1954, scientists, using newly developed techniques of microscopy, established how filaments of actin and myosin interact in muscle contraction.
- In the next decade, researchers identified actin filaments in all types of cells.

# 4.17 Scientific Thinking: Scientists Discovered the Cytoskeleton Using the Tools of Biochemistry and Microscopy (2 of 2)

- Researchers then tagged actin proteins with fluorescent molecules and injected them into living cells.
- This technique enabled scientists to visualize the dynamic behavior of cytoskeletal proteins in living cells.

# 4.18 Cilia and Flagella Move When Microtubules Bend (1 of 2)

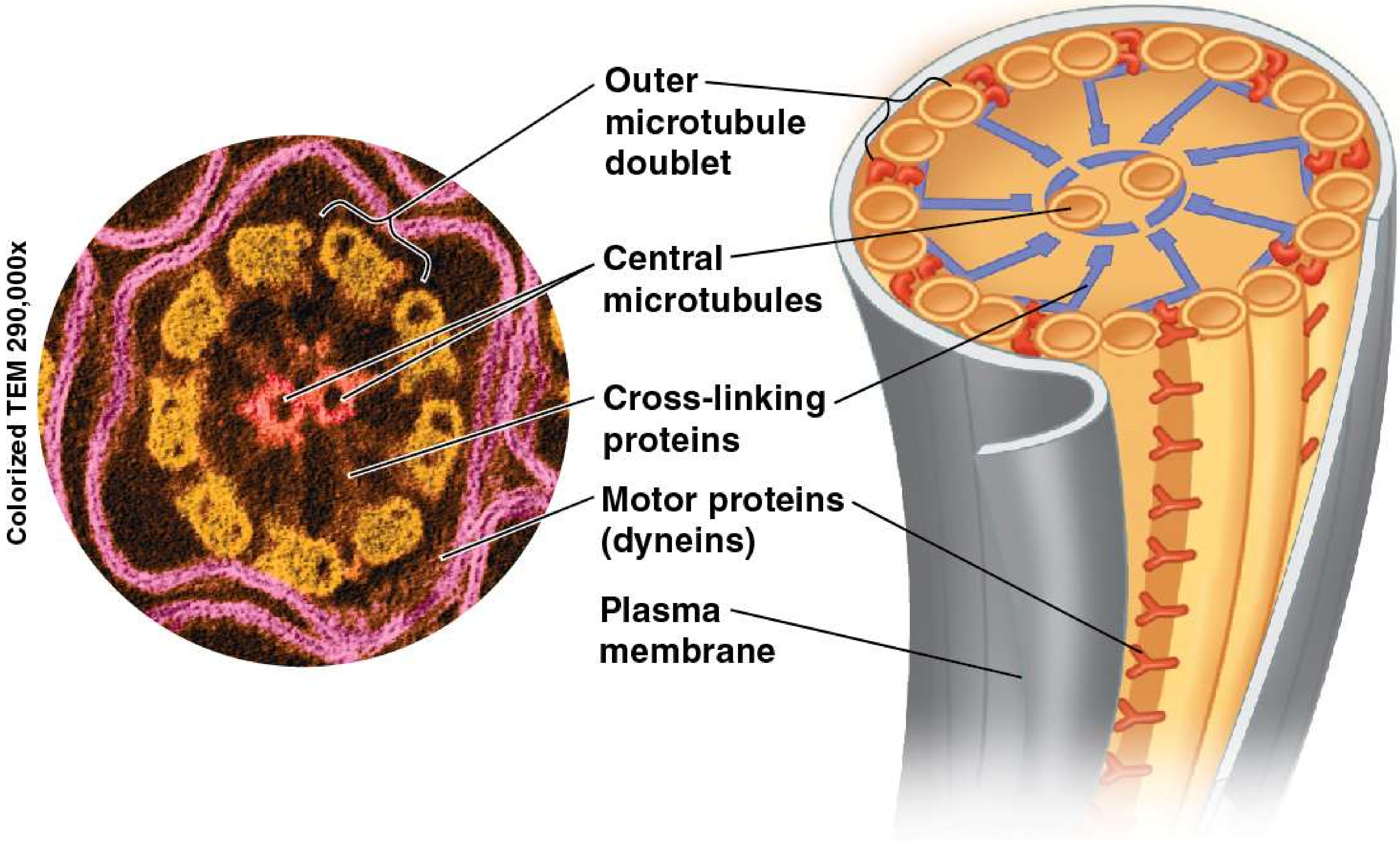
- Eukaryotic **cilia** and flagella are locomotor appendages made of microtubules in a “9 + 2” arrangement.
  - Flagella, longer than cilia, propel a cell by an undulating, whiplike motion.
- Cilia work more like the coordinated oars of a rowing team.
  - Though different in length and beating pattern, cilia and flagella have a common structure and mechanism of movement.

# 4.18 Cilia and Flagella Move When Microtubules Bend (2 of 2)

**Checkpoint question** Primary ciliary dyskinesia (PCD), also known as immotile cilia syndrome, is a fairly rare disease in which cilia and flagella are lacking motor proteins. PCD is characterized by recurrent respiratory tract infections and immotile sperm. How would you explain these seemingly unrelated symptoms?

Without motor proteins, microtubules cannot bend. Thus cilia cannot cleanse the respiratory tract, and sperm cannot swim.

# Figure 4.18c

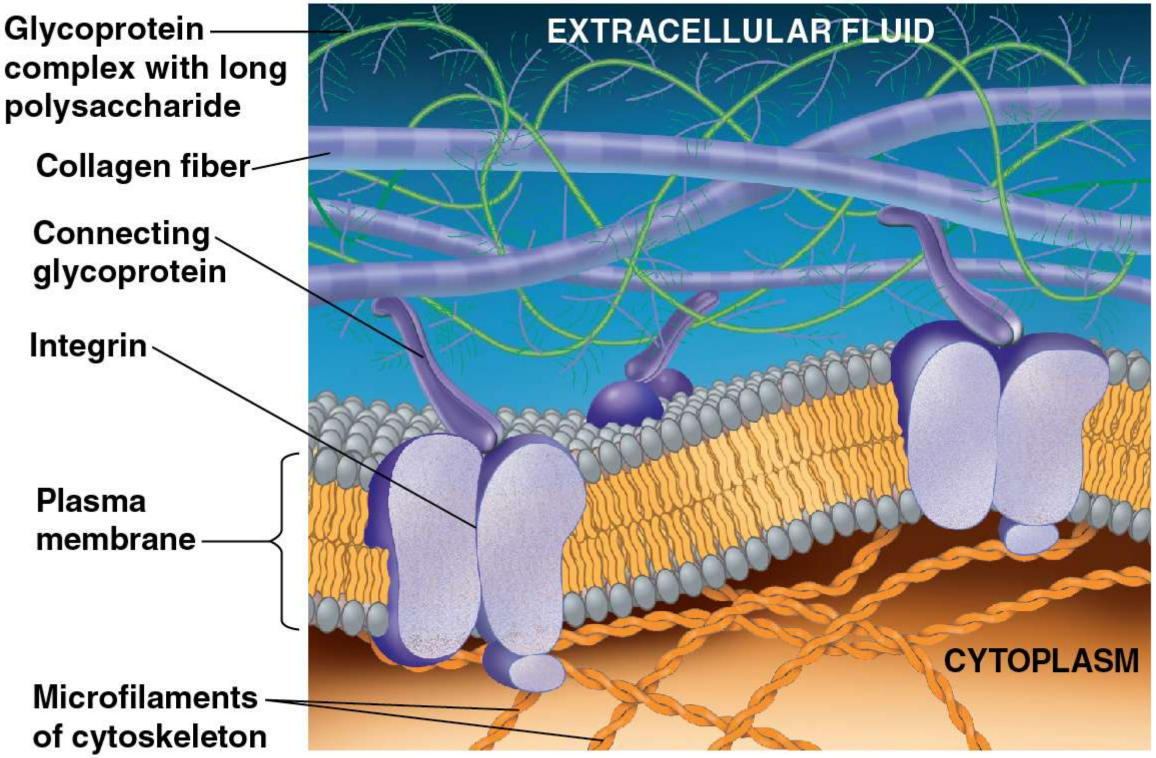


Colorized TEM 290,000x
Outer microtubule doublet
Central microtubules
Cross-linking proteins
Motor proteins (dyneins)
Plasma membrane

# 4.19 The Extracellular Matrix of Animal Cells Functions in Support and Regulation (1 of 2)

- Animal cells synthesize and secrete an elaborate **extracellular matrix** (**ECM**), which
  - binds tissue cells together,
  - supports the plasma membrane, and
  - communicates with the cytoskeleton.
- The ECM may attach to the cell through other glycoproteins that then bind to membrane proteins called **integrins**.

# 4.19 The Extracellular Matrix of Animal Cells Functions in Support and Regulation (2 of 2)




The membrane is attached through membrane proteins to microfilaments of the cytoskeleton and to connecting glycoproteins and collagen fibers of the ECM.

**Checkpoint question** Referring to Figure 4.19, describe the structures that provide support to the plasma membrane.

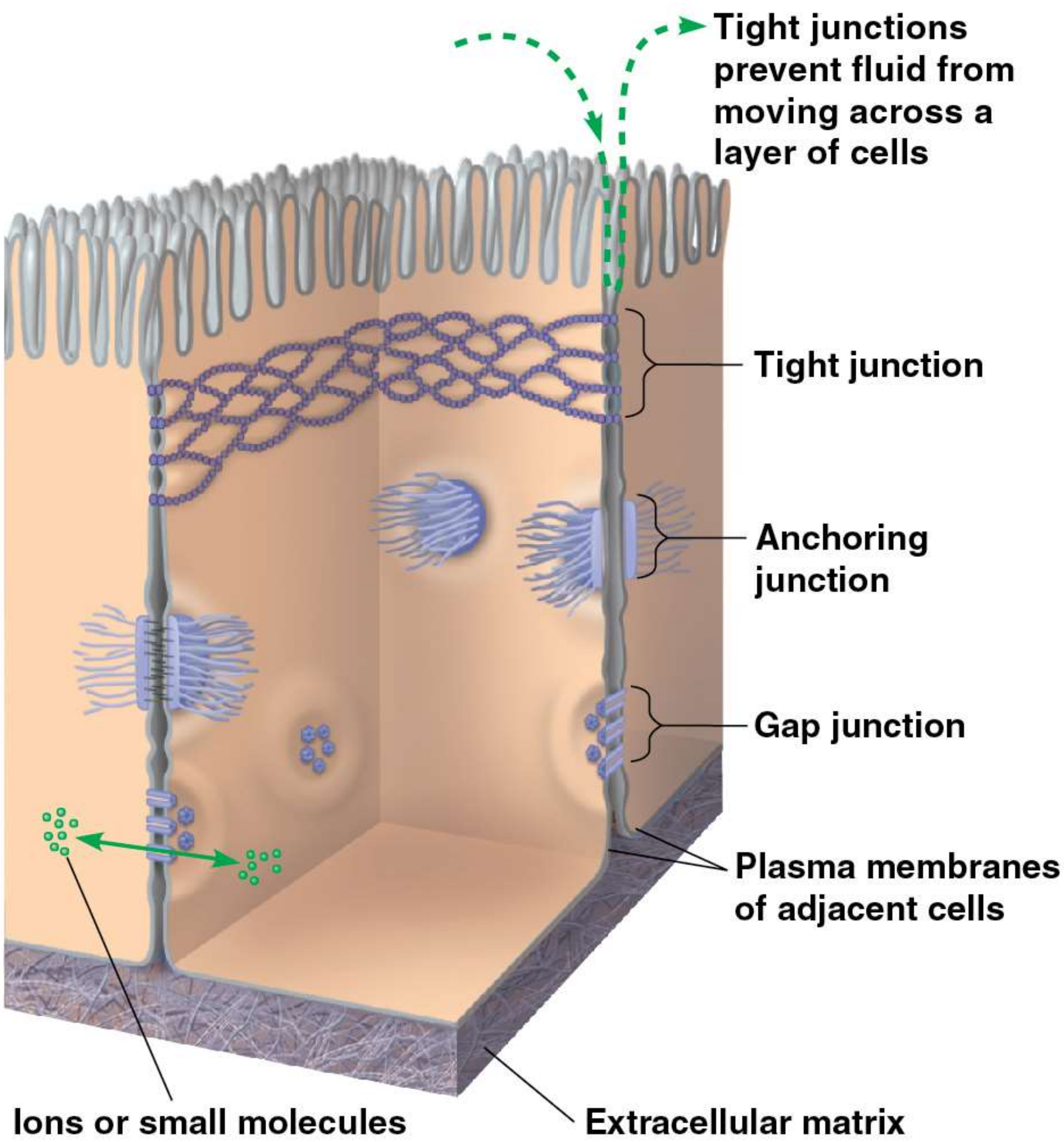
# 4.20 Three Types of Cell Junctions Are Found in Animal Tissues

- Neighboring cells often adhere, interact, and communicate through specialized junctions between them.
  - Tight junctions bind cells to form leakproof sheets.
  - Anchoring junctions rivet cells into strong tissues.
  - Gap junctions allow ions and small molecules to flow from cell to cell.

**Checkpoint question** A muscle tear injury would probably involve the rupture of which type of cell junction?

Anchoring junction

# Figure 4.20



Tight junctions prevent fluid from moving across a layer of cells
Tight junction
Anchoring junction
Gap junction
Plasma membranes of adjacent cells
Ions or small molecules
Extracellular matrix

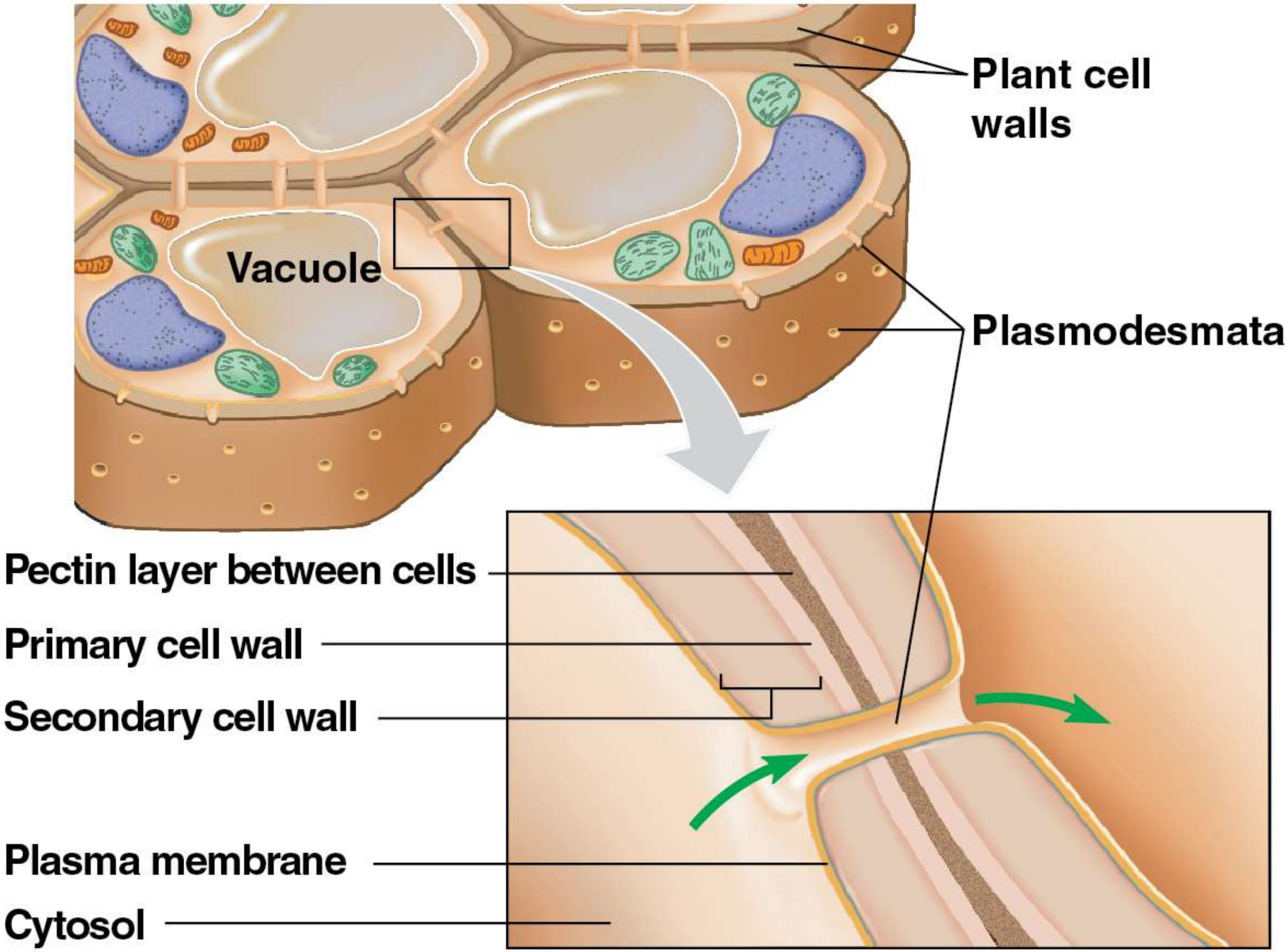
# 4.21 Cell Walls Enclose and Support Plant Cells

- A plant cell, but not an animal cell, has a rigid **cell wall** that
  - protects and provides skeletal support that helps keep the plant upright on land and
  - is primarily composed of cellulose.
- Plant cells have cell junctions called **plasmodesmata** that allow plant tissues to share water, nourishment, and chemical messages.

**Checkpoint question** Which animal cell junction is analogous to a plasmodesma?

A gap junction

# Figure 4.21



Plant cell walls
Vacuole
Plasmodesmata
Pectin layer between cells
Primary cell wall
Secondary cell wall
Plasma membrane
Cytosol

# 4.22 Review: Eukaryotic Cell Structures Can Be Grouped on the Basis of Four Main Functions (1 of 2)

- Eukaryotic cell structures can be grouped on the basis of four functions:
  1. genetic control,
  2. manufacturing, distribution, and breakdown of materials,
  3. energy processing, and
  4. structural support, movement, and intercellular communication.

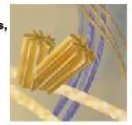
# 4.22 Review: Eukaryotic Cell Structures Can Be Grouped on the Basis of Four Main Functions (2 of 2)

**Checkpoint question** How do mitochondria, smooth ER, and the cytoskeleton all contribute to the contraction of a muscle cell?

Mitochondria supply energy in the form of ATP. The smooth ER helps regulate contraction by the uptake and release of calcium ions. Microfilaments function in the actual contractile apparatus.

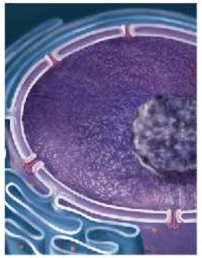
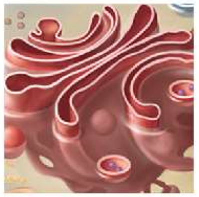
# Table 4.22 Eukaryotic Cell Structures and Their Functions (1 of 3)

TABLE 4.22 Eukaryotic Cell Structures and Their Functions

| | | |
|---|---|---|
| **1. Genetic Control** | | |
| Nucleus |  | DNA replication, RNA synthesis; assembly of ribosomal subunits (in nucleolus) |
| Ribosomes | | Polypeptide (protein) synthesis |
| **2. Manufacturing, Distribution, and Breakdown** | | |
| Rough ER | | Synthesis of membrane lipids and proteins, secretory proteins, and hydrolytic enzymes; formation of transport vesicles |
| Smooth ER | | Lipid synthesis; detoxification in liver cells; calcium ion storage in muscle cells |
| Golgi apparatus |  | Modification and sorting of ER products; formation of lysosomes and transport vesicles |
| Lysosomes (in animal cells and some protists) | | Digestion of ingested food or bacteria and recycling of a cell's damaged organelles and macromolecules |
| Vacuoles | | Digestion (food vacuole); water balance (contractile vacuole); storage of chemicals and cell enlargement (central vacuole in plant cells) |
| Peroxisomes (not part of endomembrane system) | | Diverse metabolic processes, with breakdown of toxic hydrogen peroxide by-product |
| **3. Energy Processing** | | |
| Mitochondria |  | Cellular respiration: conversion of chemical energy in food to chemical energy of ATP |
| Chloroplasts (in plants and algae) | | Photosynthesis: conversion of light energy to chemical energy of sugars |
| **4. Structural Support, Movement, and Communication Between Cells** | | |
| Cytoskeleton (microfilaments, intermediate filaments, and microtubules) |  | Maintenance of cell shape; anchorage for organelles; movement of organelles within cells; cell movement (crawling, muscle contraction, bending of cilia and flagella) |
| Plasma membrane | | Regulate traffic in and out of cell |
| Extracellular matrix (in animals) | | Support; regulation of cellular activities |
| Cell junctions |  | Communication between cells; binding of cells in tissues |
| Cell walls (in plants) | | Support and protection; binding of cells in tissues |

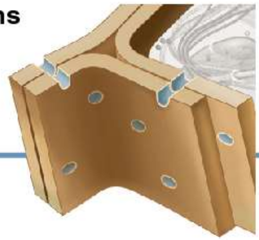
# Table 4.22 Eukaryotic Cell Structures and Their Functions (2 of 3)

**TABLE 4.22 Eukaryotic Cell Structures and Their Functions**

| | | |
|---|---|---|
| **1. Genetic Control** | | |
| Nucleus |  | DNA replication, RNA synthesis; assembly of ribosomal subunits (in nucleolus) |
| Ribosomes | | Polypeptide (protein) synthesis |
| **2. Manufacturing, Distribution, and Breakdown** | | |
| Rough ER | | Synthesis of membrane lipids and proteins, secretory proteins, and hydrolytic enzymes; formation of transport vesicles |
| Smooth ER | | Lipid synthesis; detoxification in liver cells; calcium ion storage in muscle cells |
| Golgi apparatus |  | Modification and sorting of ER products; formation of lysosomes and transport vesicles |
| Lysosomes (in animal cells and some protists) | | Digestion of ingested food or bacteria and recycling of a cell's damaged organelles and macromolecules |
| Vacuoles | | Digestion (food vacuole); water balance (contractile vacuole); storage of chemicals and cell enlargement (central vacuole in plant cells) |
| Peroxisomes (not part of endomembrane system) | | Diverse metabolic processes, with breakdown of toxic hydrogen peroxide by-product |

# Table 4.22 Eukaryotic Cell Structures and Their Functions (3 of 3)

**TABLE 4.22 Eukaryotic Cell Structures and Their Functions**

| | | |
|---|---|---|
| **3. Energy Processing** | | |
| Mitochondria |  | Cellular respiration: conversion of chemical energy in food to chemical energy of ATP |
| Chloroplasts (in plants and algae) | | Photosynthesis: conversion of light energy to chemical energy of sugars |
| **4. Structural Support, Movement, and Communication Between Cells** | | |
| Cytoskeleton (microfilaments, intermediate filaments, and microtubules) |  | Maintenance of cell shape; anchorage for organelles; movement of organelles within cells; cell movement (crawling, muscle contraction, bending of cilia and flagella) |
| Plasma membrane | | Regulate traffic in and out of cell |
| Extracellular matrix (in animals) | | Support; regulation of cellular activities |
| Cell junctions |  | Communication between cells; binding of cells in tissues |
| Cell walls (in plants) | | Support and protection; binding of cells in tissues |

# Table 4.1 Metric Measurement Equivalents

$$1\text{ meter}(\text{m}) = 100\text{ cm} = 1,000\text{ mm} = 39.4\text{ inches}$$

$$1\text{ centimeter}(\text{cm}) = 10^{-2}\text{ m}\left(0.01\text{ or }1/100\text{ m}\right) = 0.4\text{ inch}$$

$$1\text{ millimeter}(\text{mm}) = 10^{-3}\text{ m}\left(0.001\text{ or }1/1,000\text{ m}\right)$$

$$1\text{ micrometer}(\mu\text{m}) = 10^{-6}\text{ m}\left(0.000001\text{ m}\right) = 10^{-3}\text{ mm}$$

$$1\text{ nanometer}(\text{nm}) = 10^{-9}\text{ m} = 10^{-3}\,\mu\text{m}$$