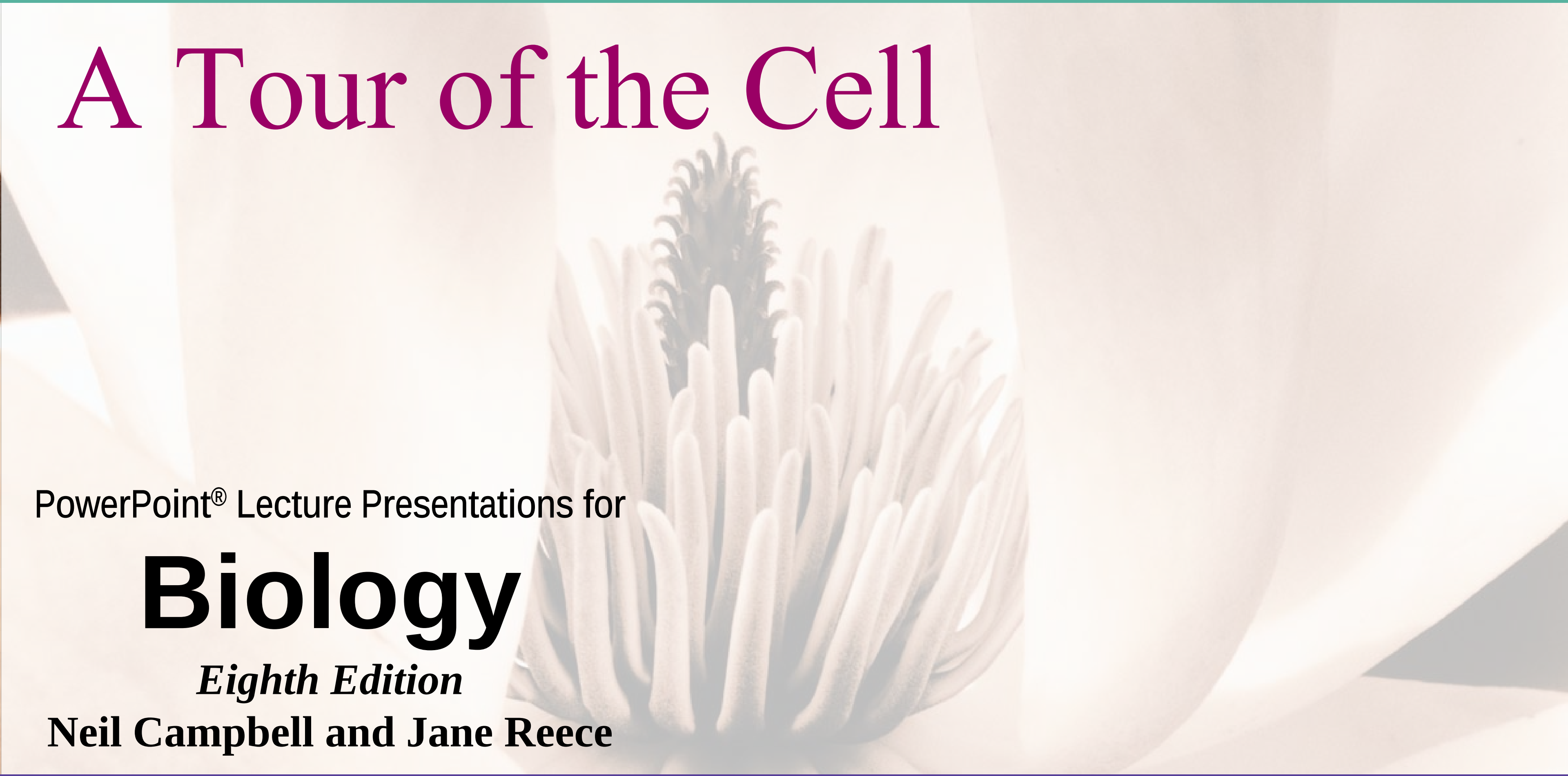
Chapter 6

A Tour of the Cell



PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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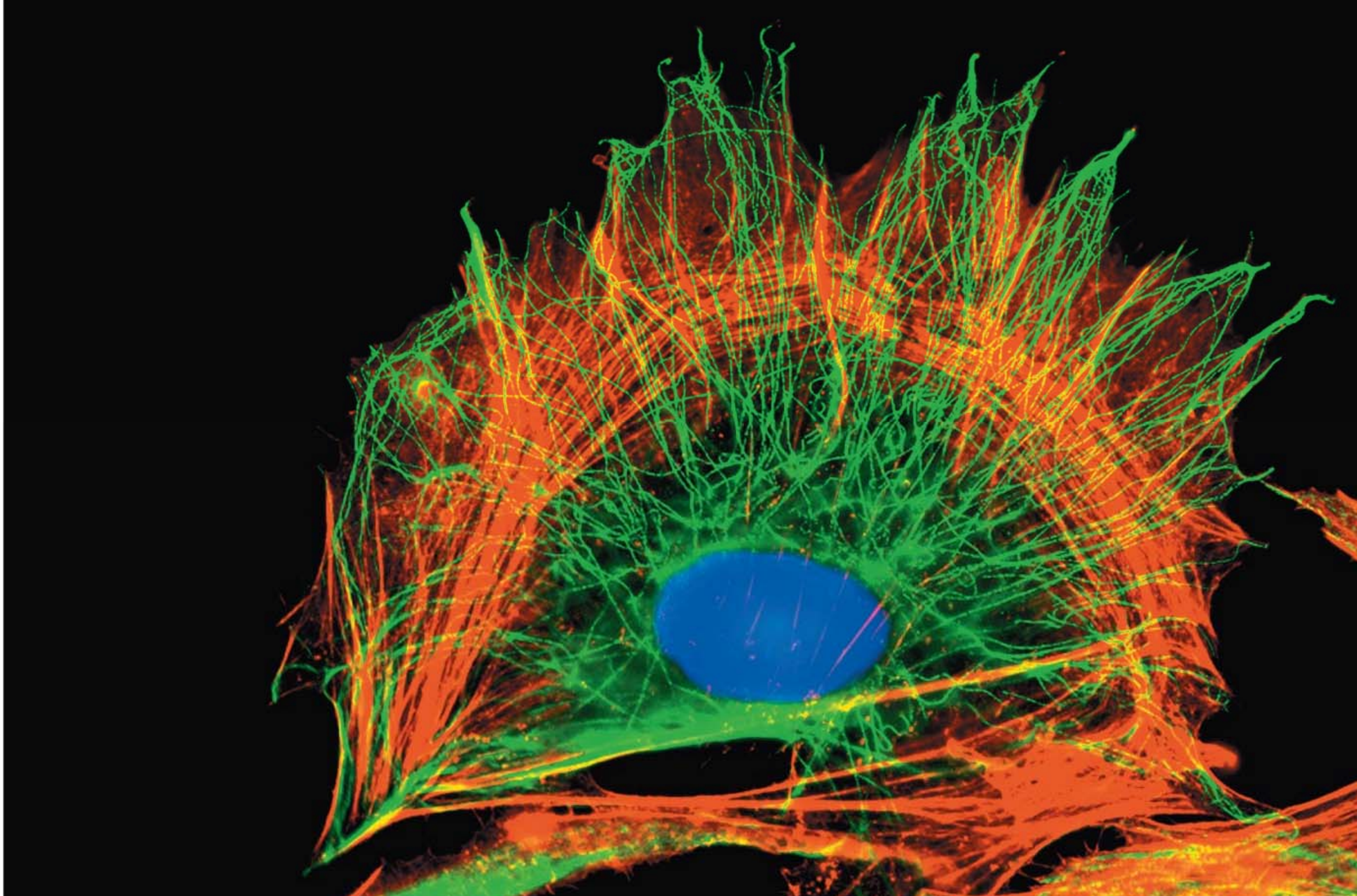
Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

Overview: The Fundamental Units of Life

- All organisms are made of cells
- The cell is the simplest collection of matter that can live
- Cell structure is correlated to cellular function
- All cells are related by their descent from earlier cells

Fig. 6-1

How do cellular components cooperate to help the cell function?



Concept 6.1: To study cells, biologists use microscopes and the tools of biochemistry

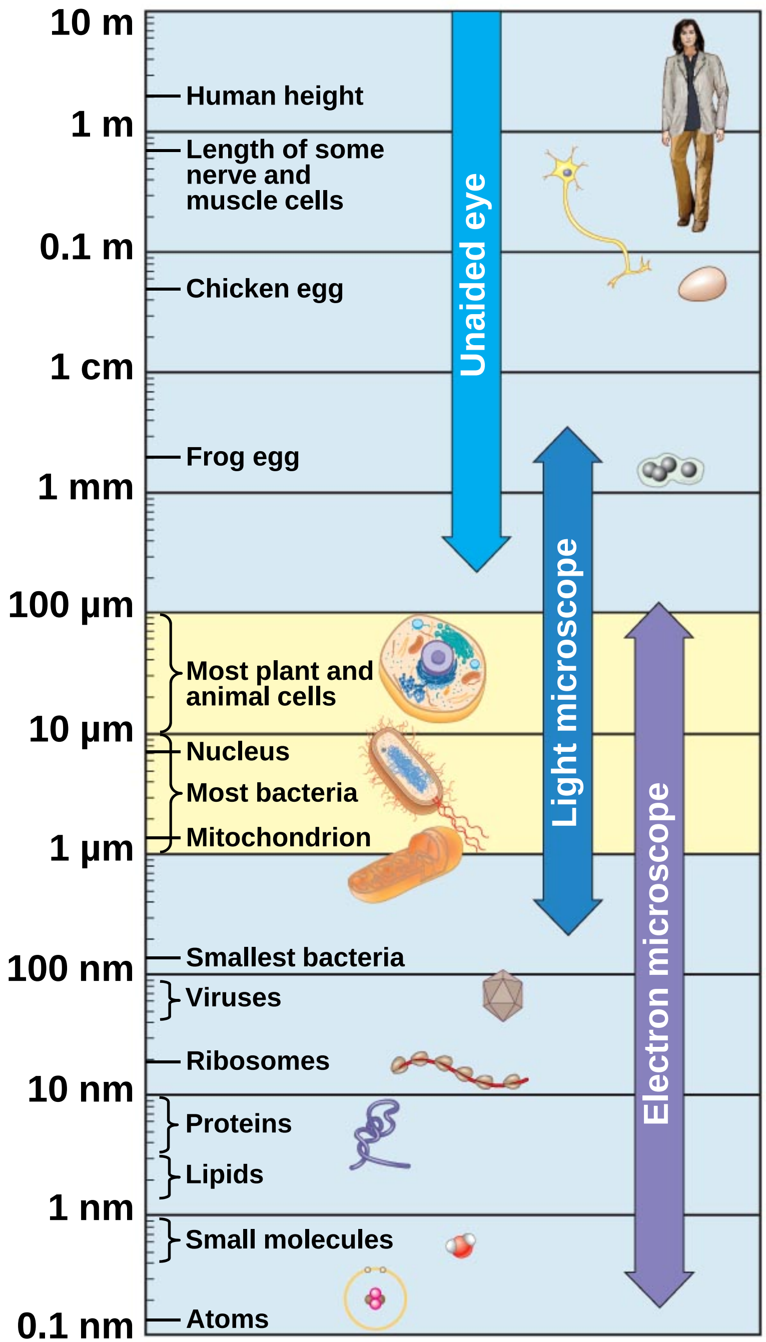
- Though usually too small to be seen by the unaided eye, cells can be complex

Microscopy

- Scientists use microscopes to visualize cells too small to see with the naked eye
- In a **light microscope (LM)**, visible light passes through a specimen and then through glass lenses, which magnify the image

- The quality of an image depends on
  - *Magnification*, the ratio of an object's image size to its real size
  - *Resolution*, the measure of the clarity of the image, or the minimum distance of two distinguishable points
  - *Contrast*, visible differences in parts of the sample

Fig. 6-2


10 m
1 m
0.1 m
1 cm
1 mm
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
0.1 nm
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Most plant and animal cells
Nucleus
Most bacteria
Mitochondrion
Smallest bacteria
Viruses
Ribosomes
Proteins
Lipids
Small molecules
Atoms
Unaided eye
Light microscope
Electron microscope

- LMs can magnify effectively to about 1,000 times the size of the actual specimen
- Various techniques enhance contrast and enable cell components to be stained or labeled
- Most subcellular structures, including **organelles** (membrane-enclosed compartments), are too small to be resolved by an LM

Fig. 6-3ab

TECHNIQUE | **RESULTS**

(a) Brightfield (unstained specimen)

50 µm

(b) Brightfield (stained specimen)

Fig. 6-3cd

TECHNIQUE

RESULTS

(c) Phase-contrast

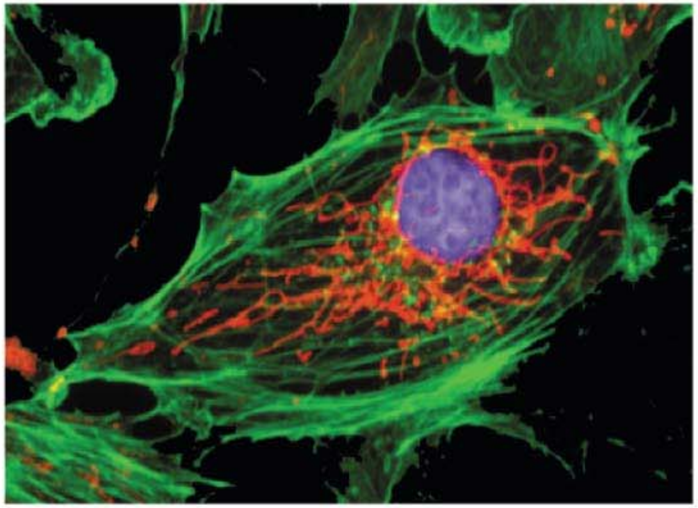
(d) Differential-interference-contrast (Nomarski)

Fig. 6-3e

TECHNIQUE

RESULTS

(e) Fluorescence



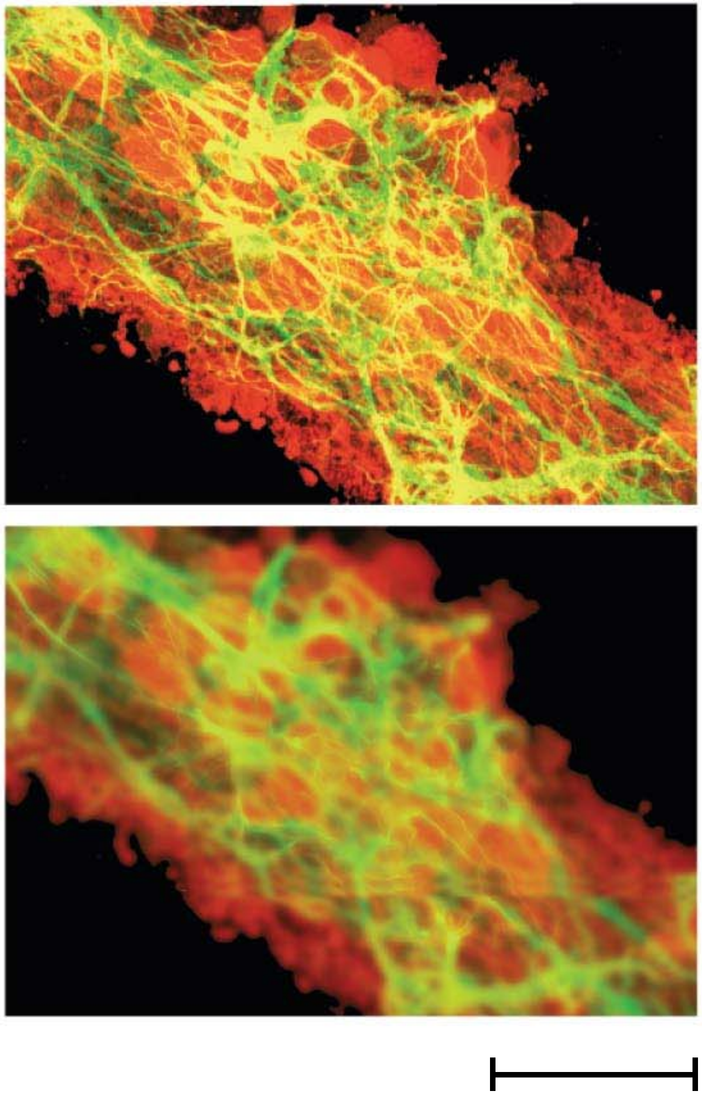
50 µm

Fig. 6-3f

TECHNIQUE

RESULTS

(f) Confocal

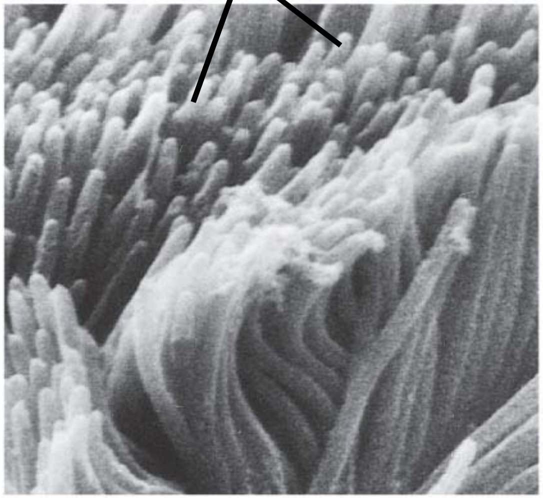


- Two basic types of **electron microscopes (EMs)** are used to study subcellular structures
- **Scanning electron microscopes (SEMs)** focus a beam of electrons onto the surface of a specimen, providing images that look 3-D
- **Transmission electron microscopes (TEMs)** focus a beam of electrons through a specimen
- TEMs are used mainly to study the internal structure of cells

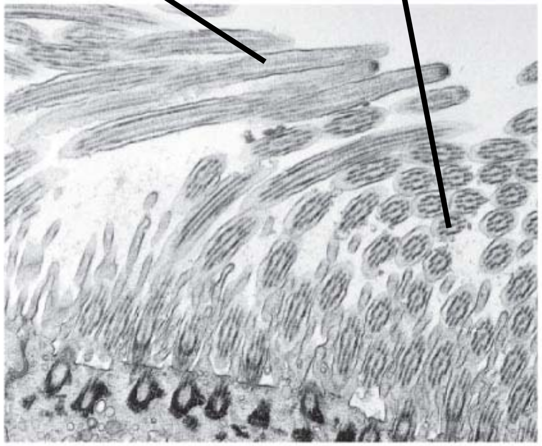
Fig. 6-4

TECHNIQUE | **RESULTS**

(a) Scanning electron microscopy (SEM)



(b) Transmission electron microscopy (TEM)

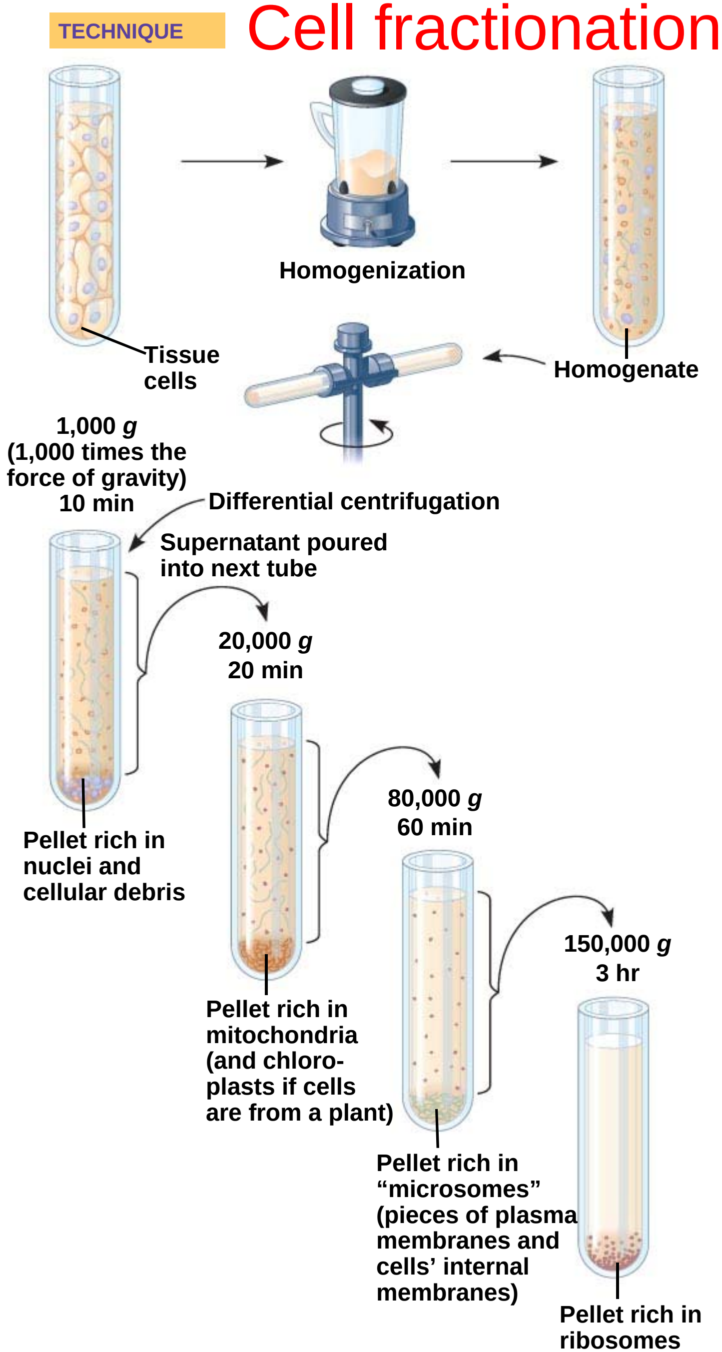


Cell Fractionation

- **Cell fractionation** takes cells apart and separates the major organelles from one another
- Ultracentrifuges fractionate cells into their component parts
- Cell fractionation enables scientists to determine the functions of organelles
- Biochemistry and cytology help correlate cell function with structure

Fig. 6-5

Cell fractionation



Concept 6.2: Eukaryotic cells have internal membranes that compartmentalize their functions

- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
- Only organisms of the domains Bacteria and Archaea consist of prokaryotic cells
- Protists, fungi, animals, and plants all consist of eukaryotic cells

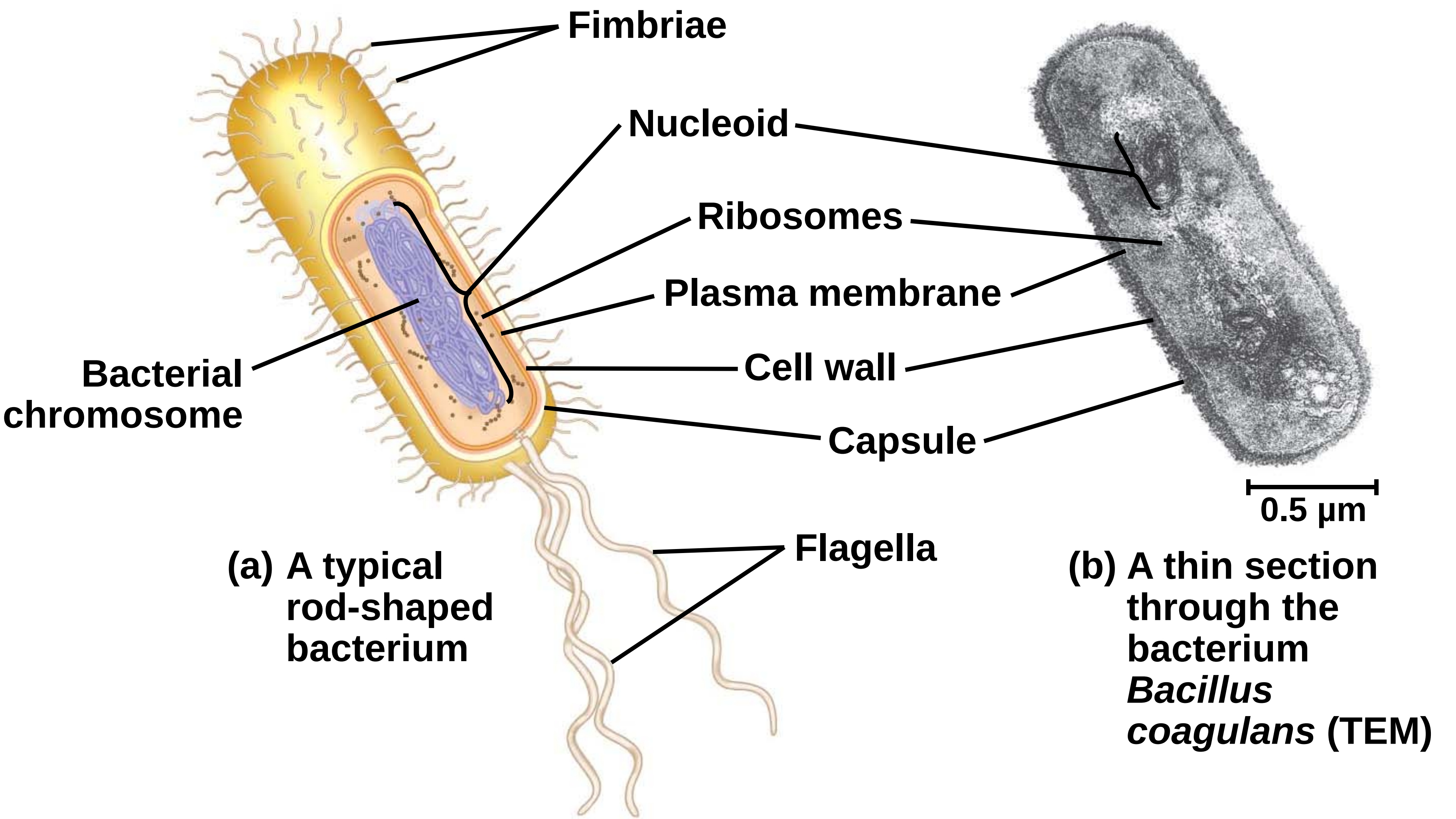
Comparing Prokaryotic and Eukaryotic Cells

- Basic features of all cells:
  – Plasma membrane
  – Semifluid substance called **cytosol**
  – Chromosomes (carry genes)
  – Ribosomes (make proteins)

- **Prokaryotic cells** are characterized by having
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
  - **Cytoplasm** bound by the plasma membrane

Fig. 6-6

A prokaryotic cell



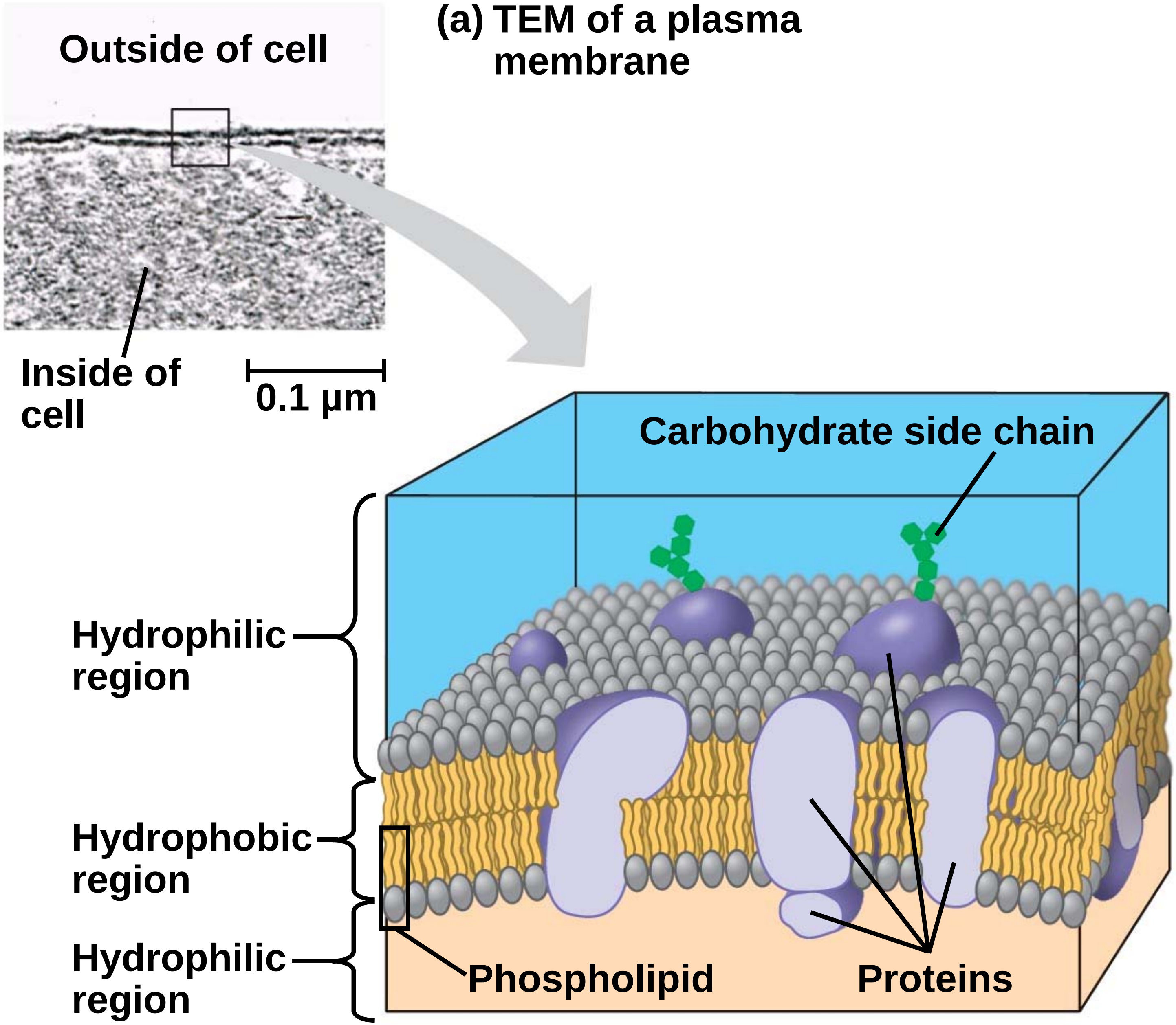
(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium *Bacillus coagulans* (TEM)

- **Eukaryotic cells** are characterized by having
  - DNA in a nucleus that is bounded by a membranous nuclear envelope
  - Membrane-bound organelles
  - Cytoplasm in the region between the plasma membrane and nucleus
- Eukaryotic cells are generally much larger than prokaryotic cells

- The **plasma membrane** is a selective barrier that allows sufficient passage of oxygen, nutrients, and waste to service the volume of every cell
- The general structure of a biological membrane is a double layer of phospholipids

Fig. 6-7



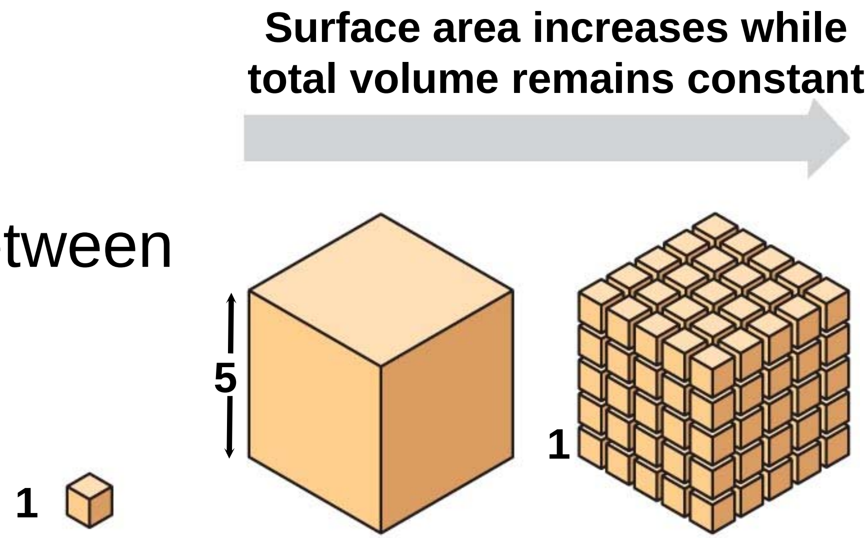
(a) TEM of a plasma membrane

(b) Structure of the plasma membrane

- The logistics of carrying out cellular metabolism sets limits on the size of cells
- The surface area to volume ratio of a cell is critical
- As the surface area increases by a factor of n^2, the volume increases by a factor of n^3
- Small cells have a greater surface area relative to volume

Fig. 6-8

Geometric relationships between surface area and volume



Total surface area [Sum of the surface areas (height × width) of all boxes sides × number of boxes]	**6**	**150**	**750**
Total volume [height × width × length × number of boxes]	**1**	**125**	**125**
Surface-to-volume (S-to-V) ratio [surface area ÷ volume]	**6**	**1.2**	**6**

A Panoramic View of the Eukaryotic Cell

- A eukaryotic cell has internal membranes that partition the cell into organelles
- Plant and animal cells have most of the same organelles

PLAY BioFlix: Tour Of An Animal Cell

PLAY BioFlix: Tour Of A Plant Cell

Fig. 6-9a

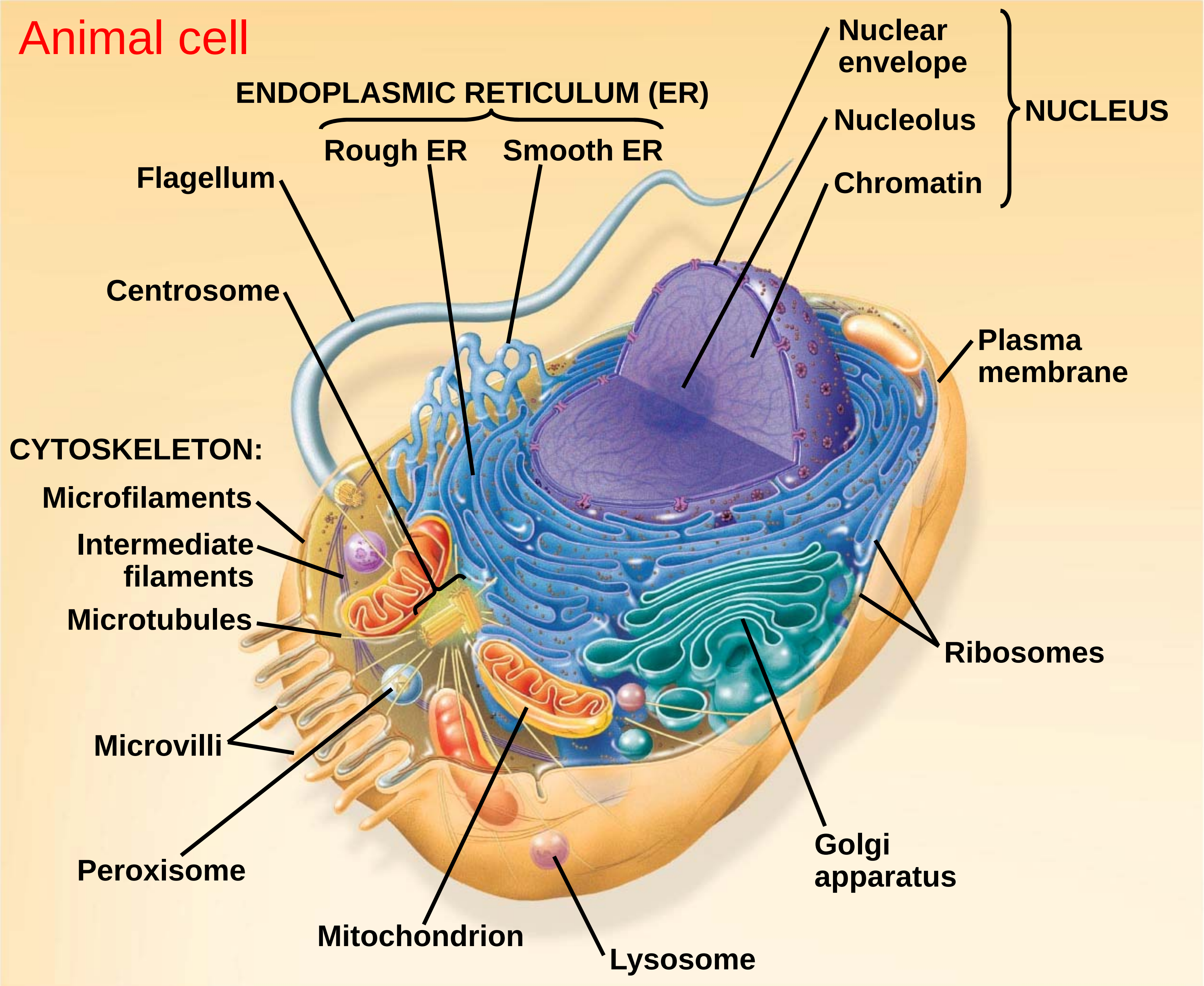
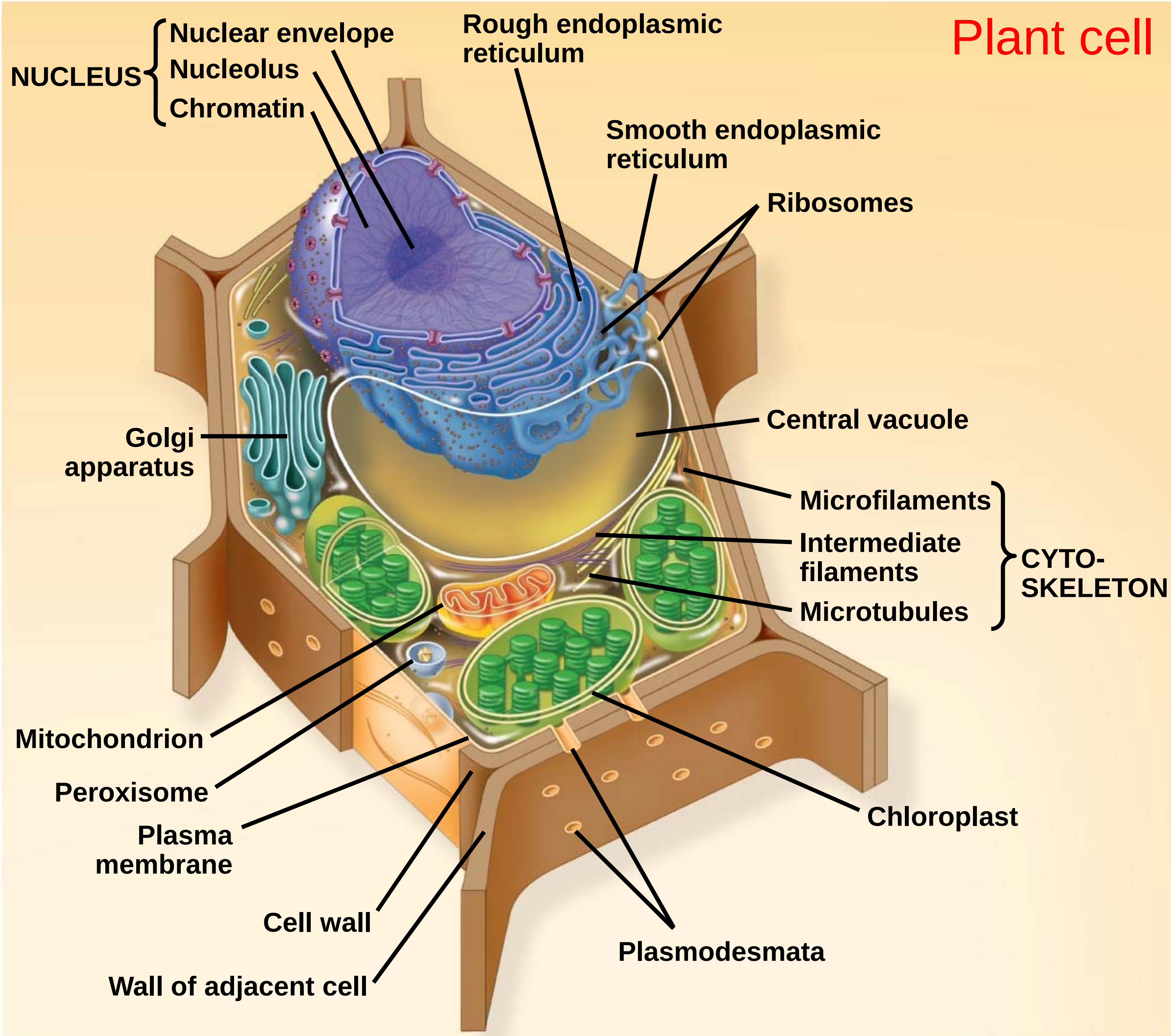

Animal cell
ENDOPLASMIC RETICULUM (ER)
Rough ER
Smooth ER
Flagellum
Centrosome
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Microvilli
Peroxisome
Mitochondrion
Lysosome
Golgi apparatus
Ribosomes
Plasma membrane
Nuclear envelope
Nucleolus
Chromatin
NUCLEUS

Fig. 6-9b


Plant cell
NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Ribosomes
Golgi apparatus
Central vacuole
Microfilaments
Intermediate filaments
Microtubules
CYTO-SKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Plasmodesmata
Chloroplast

Concept 6.3: The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes

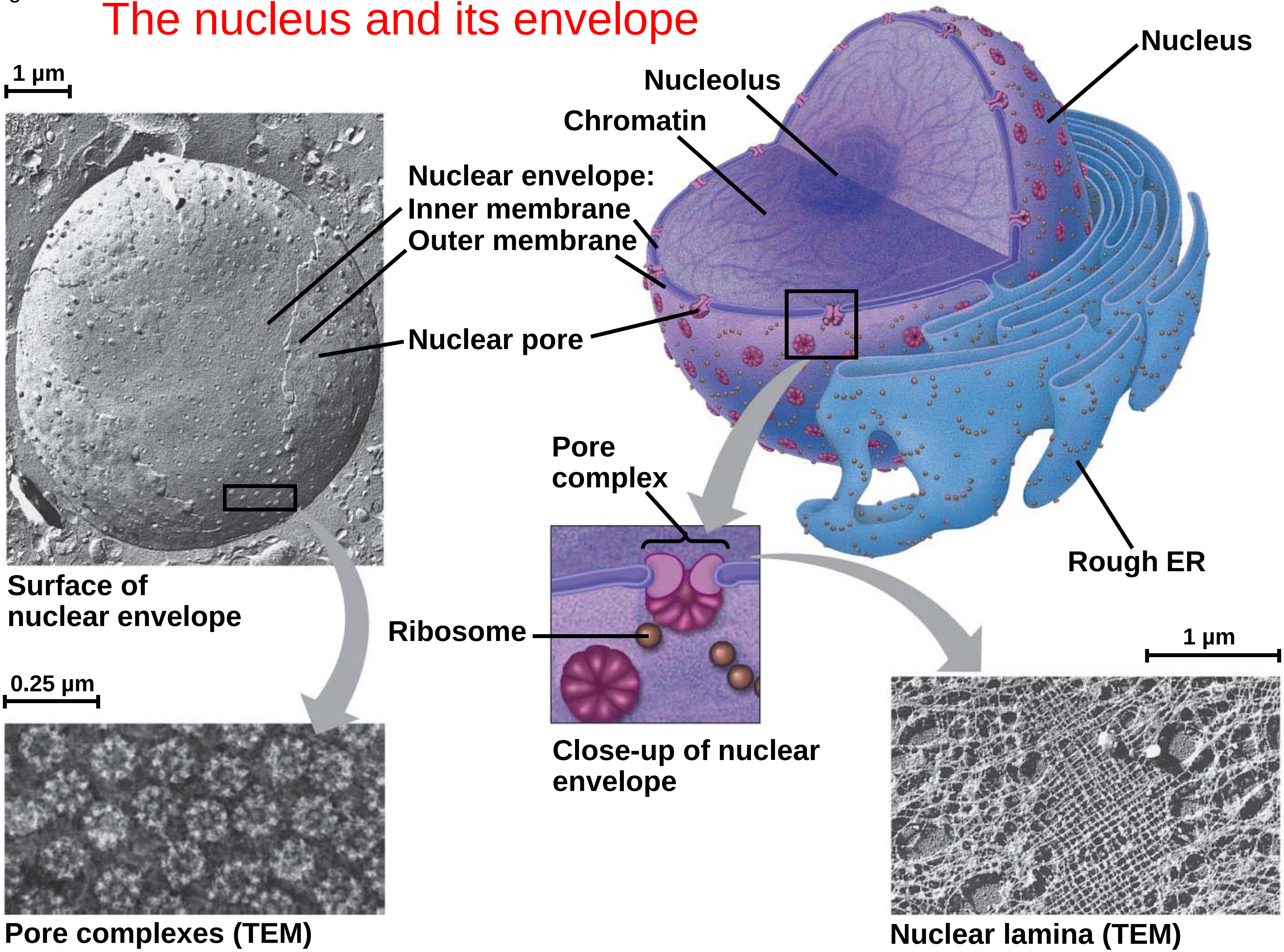
- The nucleus contains most of the DNA in a eukaryotic cell
- Ribosomes use the information from the DNA to make proteins

The Nucleus: Information Central

- The **nucleus** contains most of the cell’s genes and is usually the most conspicuous organelle
- The **nuclear envelope** encloses the nucleus, separating it from the cytoplasm
- The nuclear membrane is a double membrane; each membrane consists of a lipid bilayer

Fig. 6-10

The nucleus and its envelope



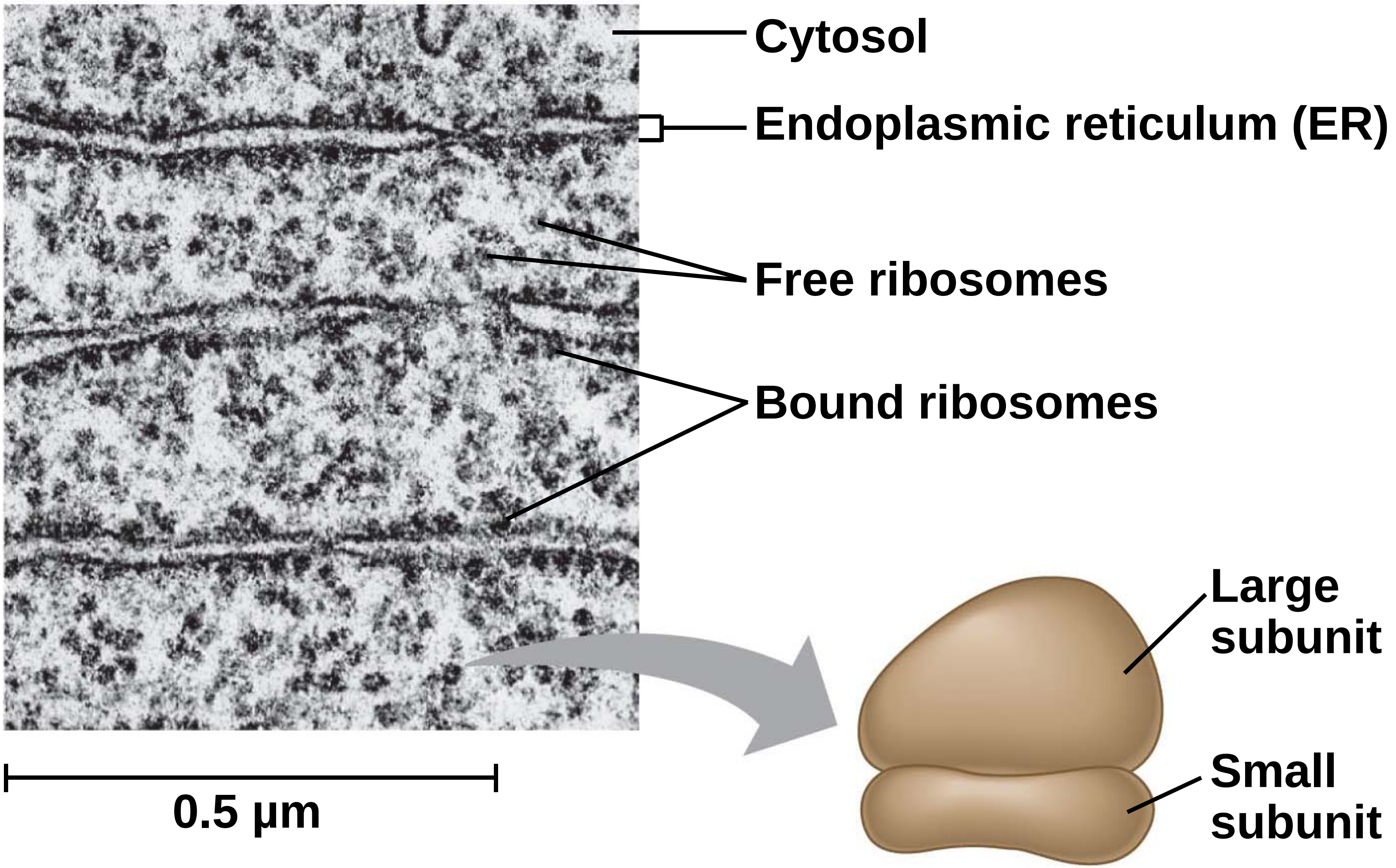
- Pores regulate the entry and exit of molecules from the nucleus
- The shape of the nucleus is maintained by the **nuclear lamina**, which is composed of protein

- In the nucleus, DNA and proteins form genetic material called **chromatin**
- Chromatin condenses to form discrete **chromosomes**
- The **nucleolus** is located within the nucleus and is the site of ribosomal RNA (rRNA) synthesis

Ribosomes: Protein Factories

- **Ribosomes** are particles made of ribosomal RNA and protein
- Ribosomes carry out protein synthesis in two locations:
  - In the cytosol (free ribosomes)
  - On the outside of the endoplasmic reticulum or the nuclear envelope (bound ribosomes)

Fig. 6-11



TEM showing ER and ribosomes

Diagram of a ribosome

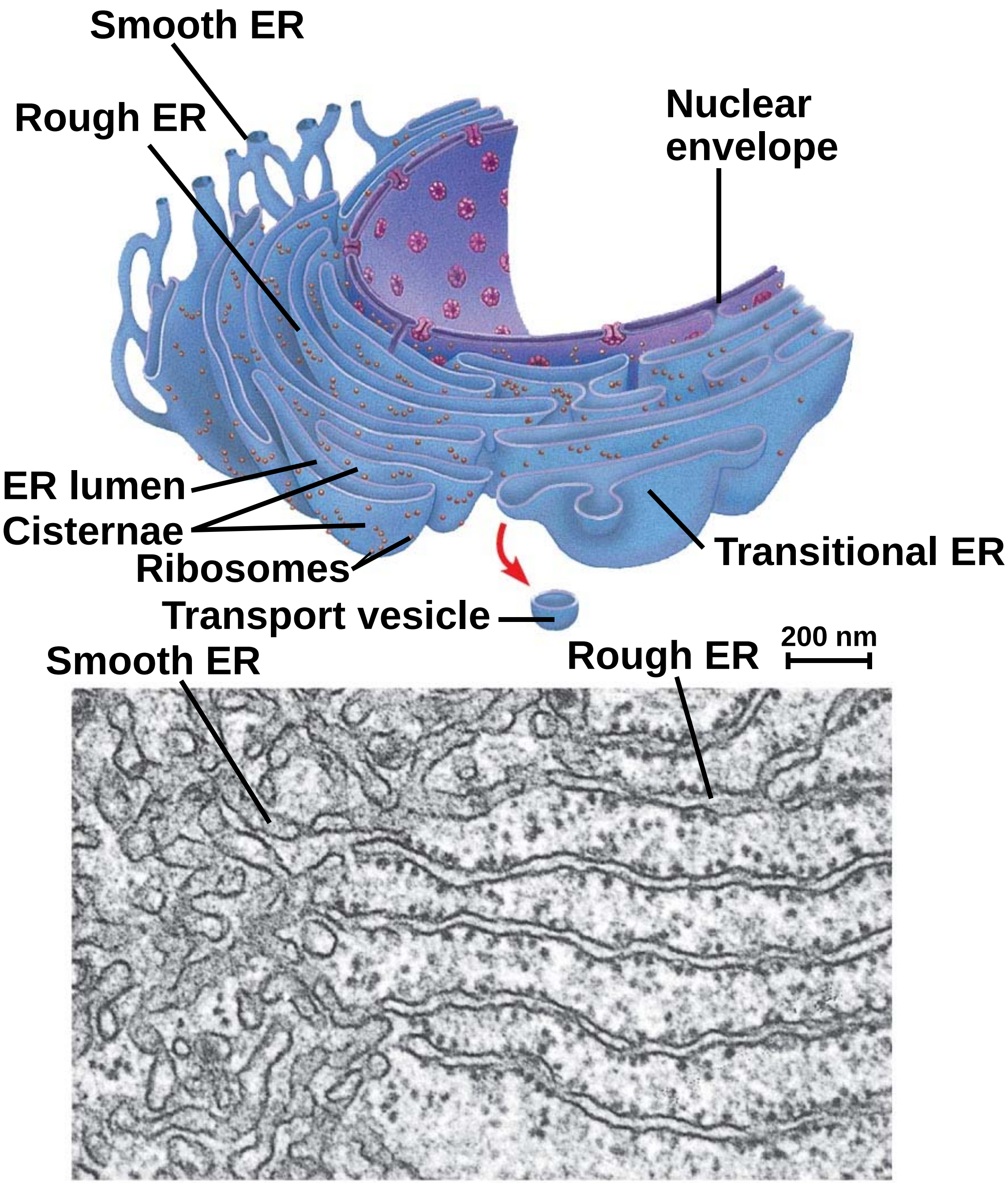
Concept 6.4: The endomembrane system regulates protein traffic and performs metabolic functions in the cell

- Components of the **endomembrane system**:
  - Nuclear envelope
  - Endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vacuoles
  - Plasma membrane
- These components are either continuous or connected via transfer by **vesicles**

The Endoplasmic Reticulum: Biosynthetic Factory

- The **endoplasmic reticulum (ER)** accounts for more than half of the total membrane in many eukaryotic cells
- The ER membrane is continuous with the nuclear envelope
- There are two distinct regions of ER:
  - **Smooth ER**, which lacks ribosomes
  - **Rough ER**, with ribosomes studding its surface

Fig. 6-12


Smooth ER
Rough ER
Nuclear envelope
ER lumen
Cisternae
Ribosomes
Transport vesicle
Transitional ER
Smooth ER
Rough ER
200 nm

Functions of Smooth ER

- The smooth ER
  - Synthesizes lipids
  - Metabolizes carbohydrates
  - Detoxifies poison
  - Stores calcium

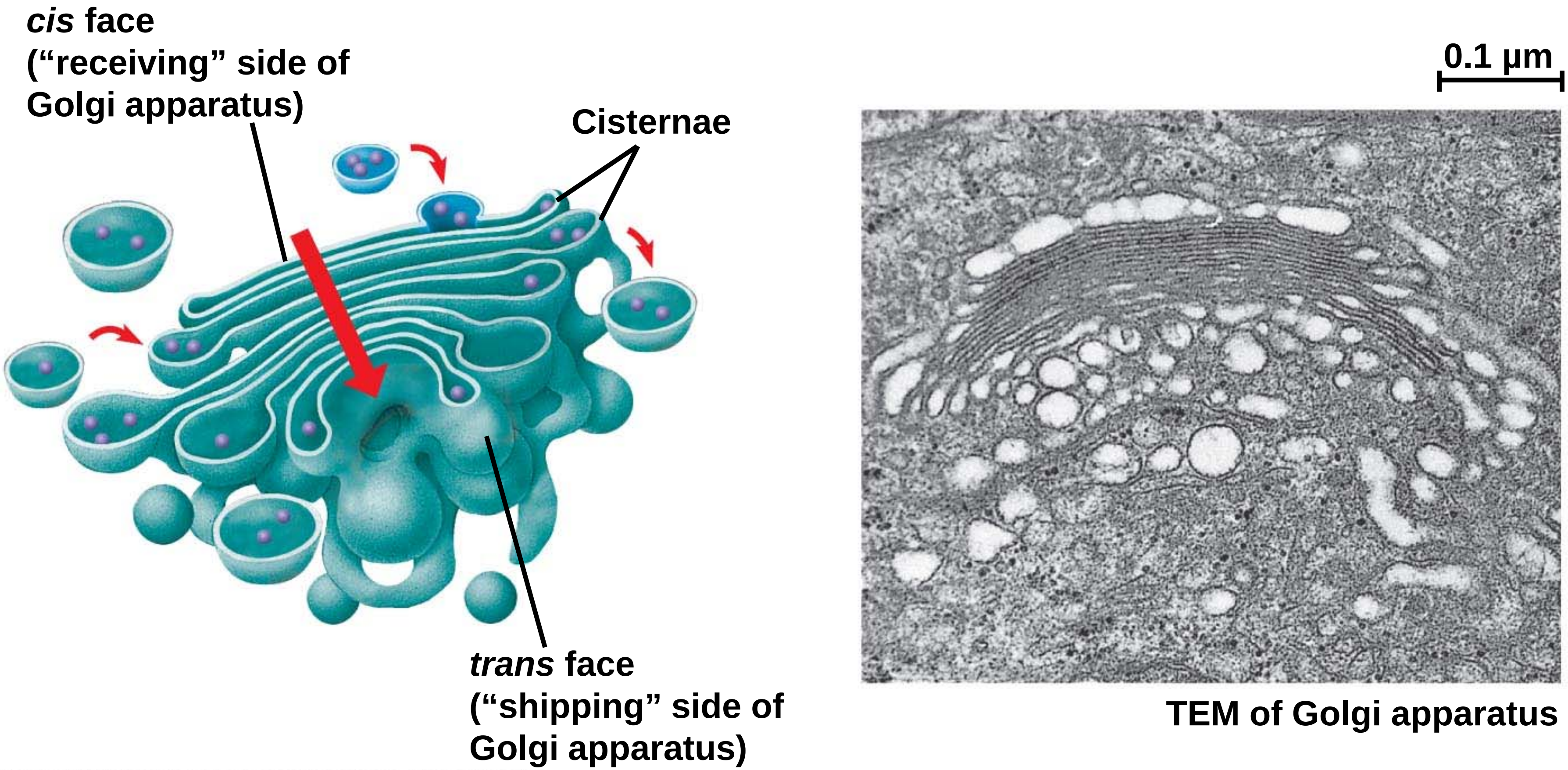
Functions of Rough ER

- The rough ER
  - Has bound ribosomes, which secrete **glycoproteins** (proteins covalently bonded to carbohydrates)
  - Distributes **transport vesicles,** proteins surrounded by membranes
  - Is a membrane factory for the cell

The Golgi Apparatus: Shipping and Receiving Center

- The **Golgi apparatus** consists of flattened membranous sacs called cisternae
- Functions of the Golgi apparatus:
  - Modifies products of the ER
  - Manufactures certain macromolecules
  - Sorts and packages materials into transport vesicles

Fig. 6-13



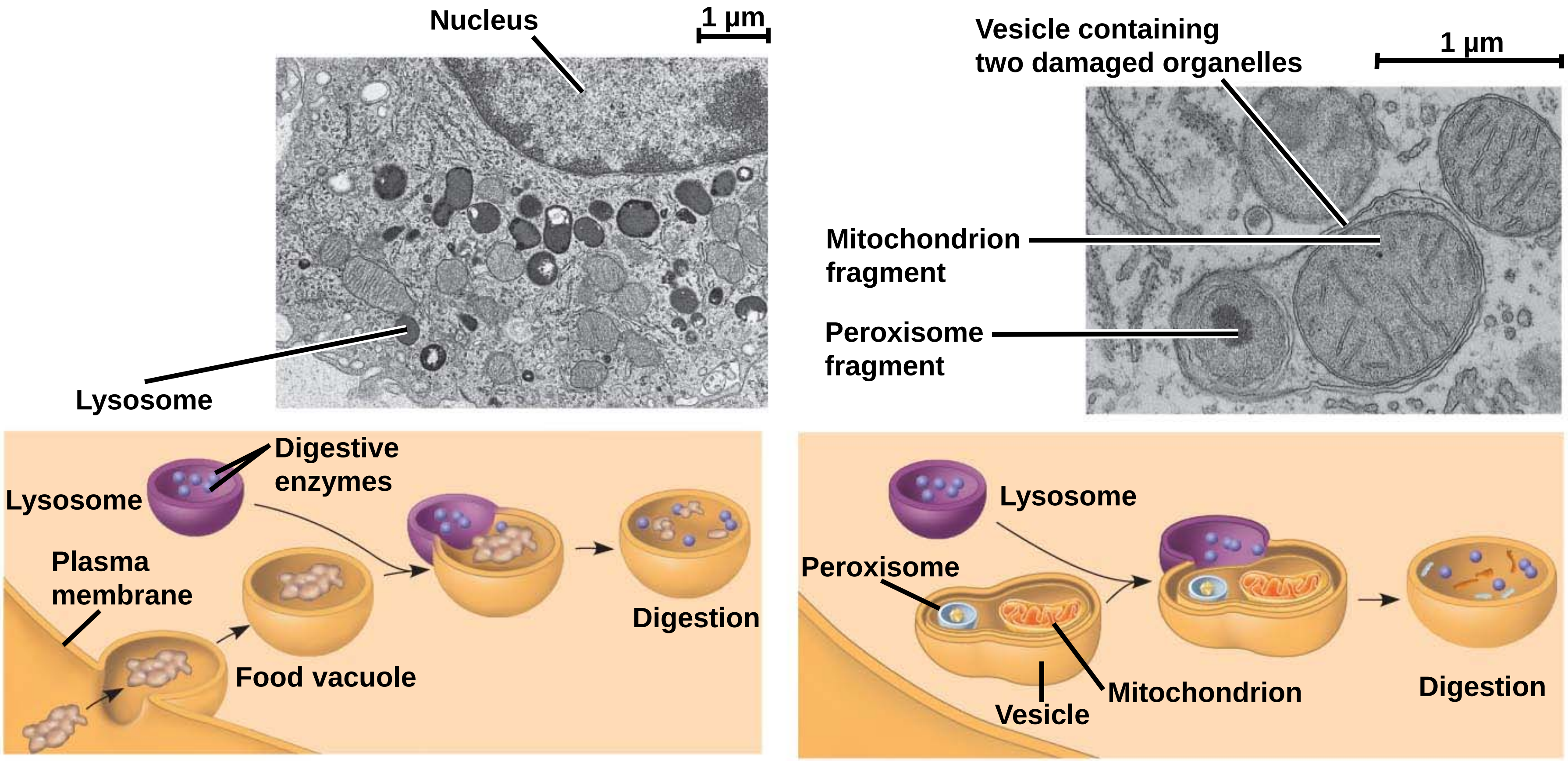
cis face
("receiving" side of
Golgi apparatus)
Cisternae
trans face
("shipping" side of
Golgi apparatus)
0.1 µm
TEM of Golgi apparatus

Lysosomes: Digestive Compartments

- A **lysosome** is a membranous sac of hydrolytic enzymes that can digest macromolecules
- Lysosomal enzymes can hydrolyze proteins, fats, polysaccharides, and nucleic acids

- Some types of cell can engulf another cell by **phagocytosis**; this forms a food vacuole
- A lysosome fuses with the food vacuole and digests the molecules
- Lysosomes also use enzymes to recycle the cell’s own organelles and macromolecules, a process called autophagy

Fig. 6-14



(a) Phagocytosis

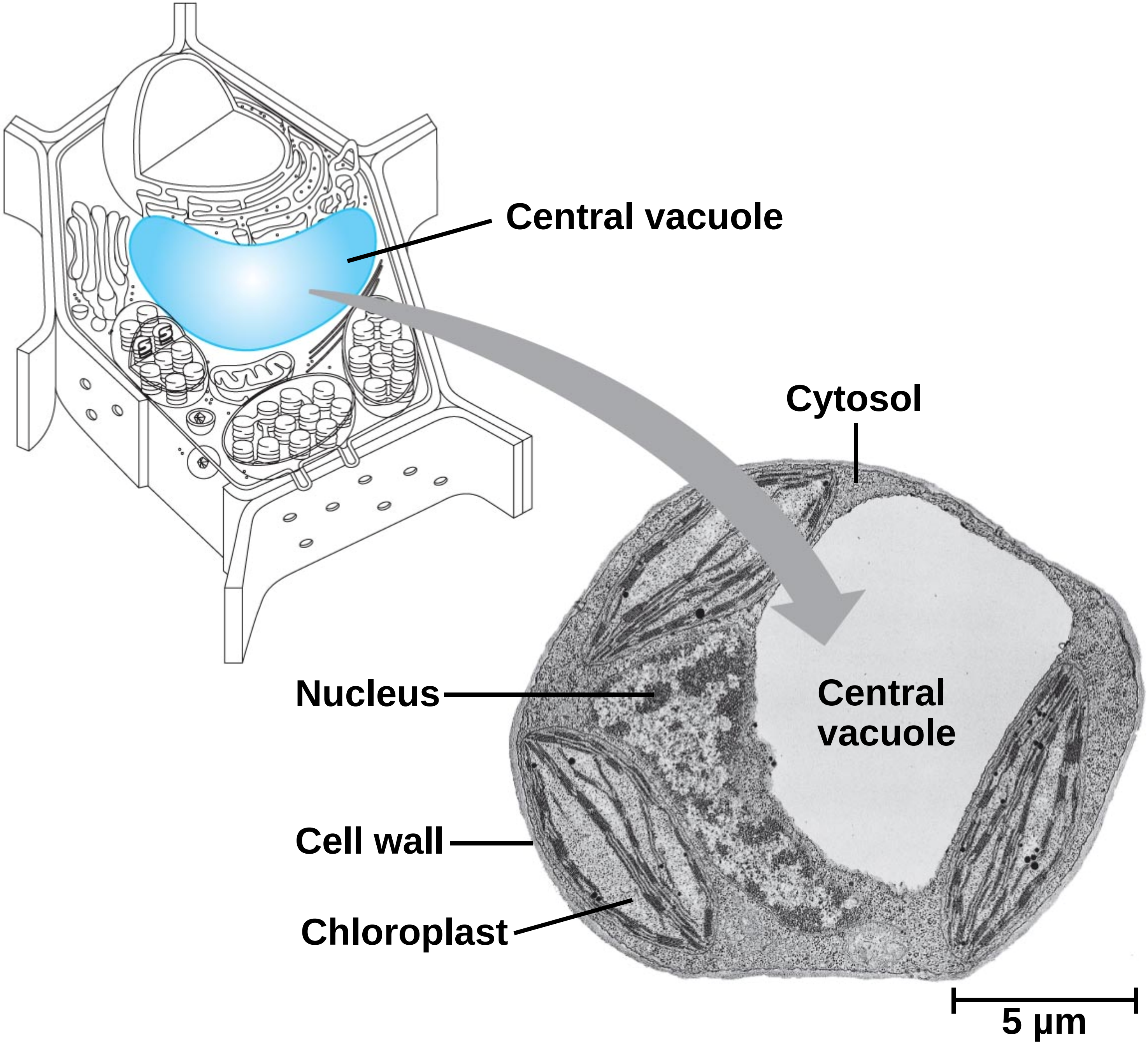
(b) Autophagy

Vacuoles: Diverse Maintenance Compartments

- A plant cell or fungal cell may have one or several vacuoles

- **Food vacuoles** are formed by phagocytosis
- **Contractile vacuoles**, found in many freshwater protists, pump excess water out of cells
- **Central vacuoles**, found in many mature plant cells, hold organic compounds and water

Fig. 6-15

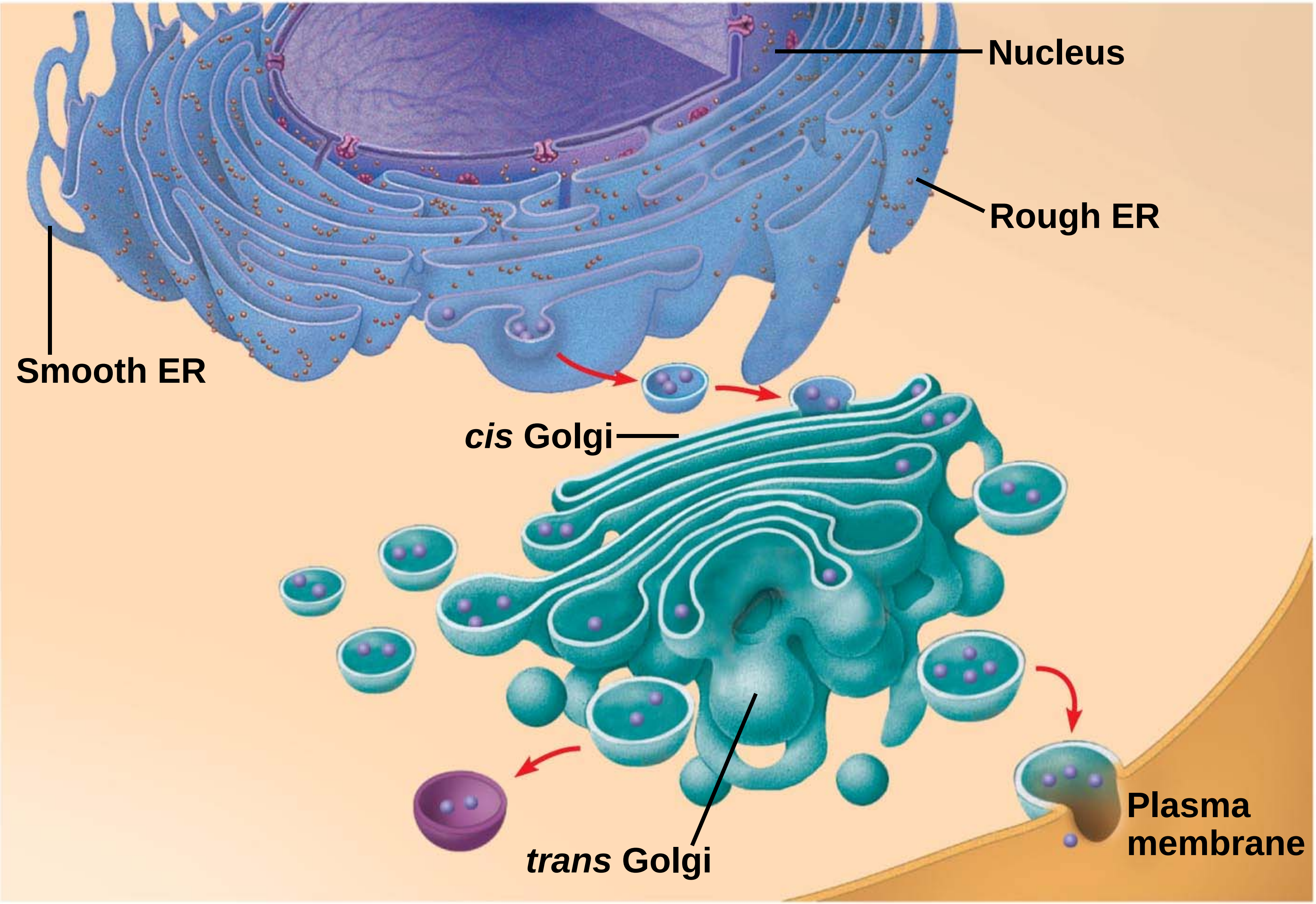


Central vacuole
Cytosol
Nucleus
Central
vacuole
Cell wall
Chloroplast
5 µm

The Endomembrane System: *A Review*

- The endomembrane system is a complex and dynamic player in the cell's compartmental organization

Fig. 6-16-3


Nucleus
Rough ER
Smooth ER
cis Golgi
trans Golgi
Plasma
membrane

Concept 6.5: Mitochondria and chloroplasts change energy from one form to another

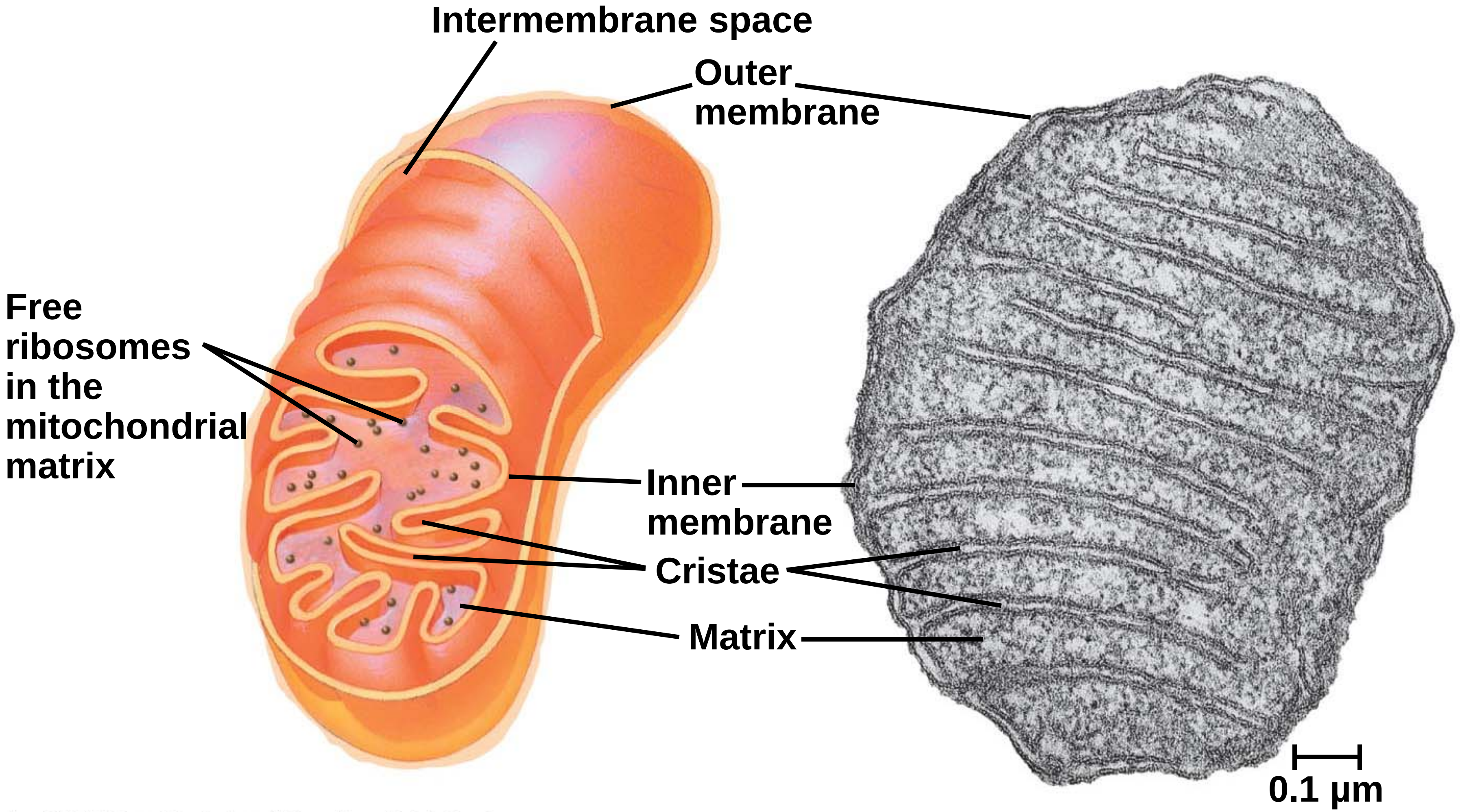
- **Mitochondria** are the sites of cellular respiration, a metabolic process that generates ATP
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis
- **Peroxisomes** are oxidative organelles

- Mitochondria and chloroplasts
  - Are not part of the endomembrane system
  - Have a double membrane
  - Have proteins made by free ribosomes
  - Contain their own DNA

Mitochondria: Chemical Energy Conversion

- Mitochondria are in nearly all eukaryotic cells
- They have a smooth outer membrane and an inner membrane folded into **cristae**
- The inner membrane creates two compartments: intermembrane space and **mitochondrial matrix**
- Some metabolic steps of cellular respiration are catalyzed in the mitochondrial matrix
- Cristae present a large surface area for enzymes that synthesize ATP

Fig. 6-17



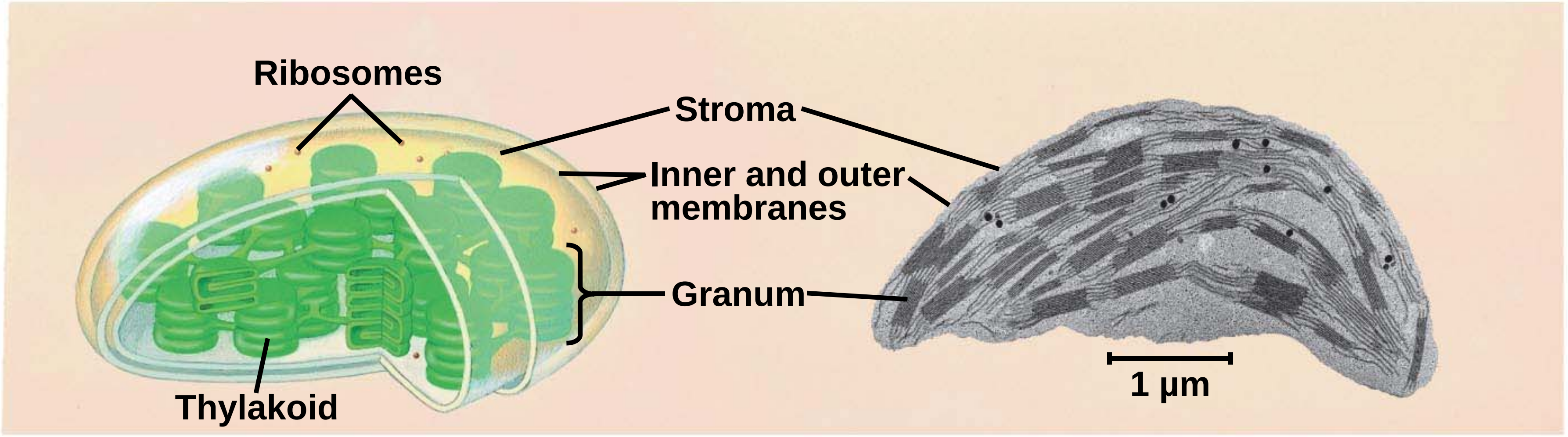
Intermembrane space
Outer membrane
Free ribosomes in the mitochondrial matrix
Inner membrane
Cristae
Matrix
0.1 µm

Chloroplasts: Capture of Light Energy

- The chloroplast is a member of a family of organelles called **plastids**
- Chloroplasts contain the green pigment chlorophyll, as well as enzymes and other molecules that function in photosynthesis
- Chloroplasts are found in leaves and other green organs of plants and in algae

- Chloroplast structure includes:
  - **Thylakoids**, membranous sacs, stacked to form a **granum**
  - **Stroma**, the internal fluid

Fig. 6-18

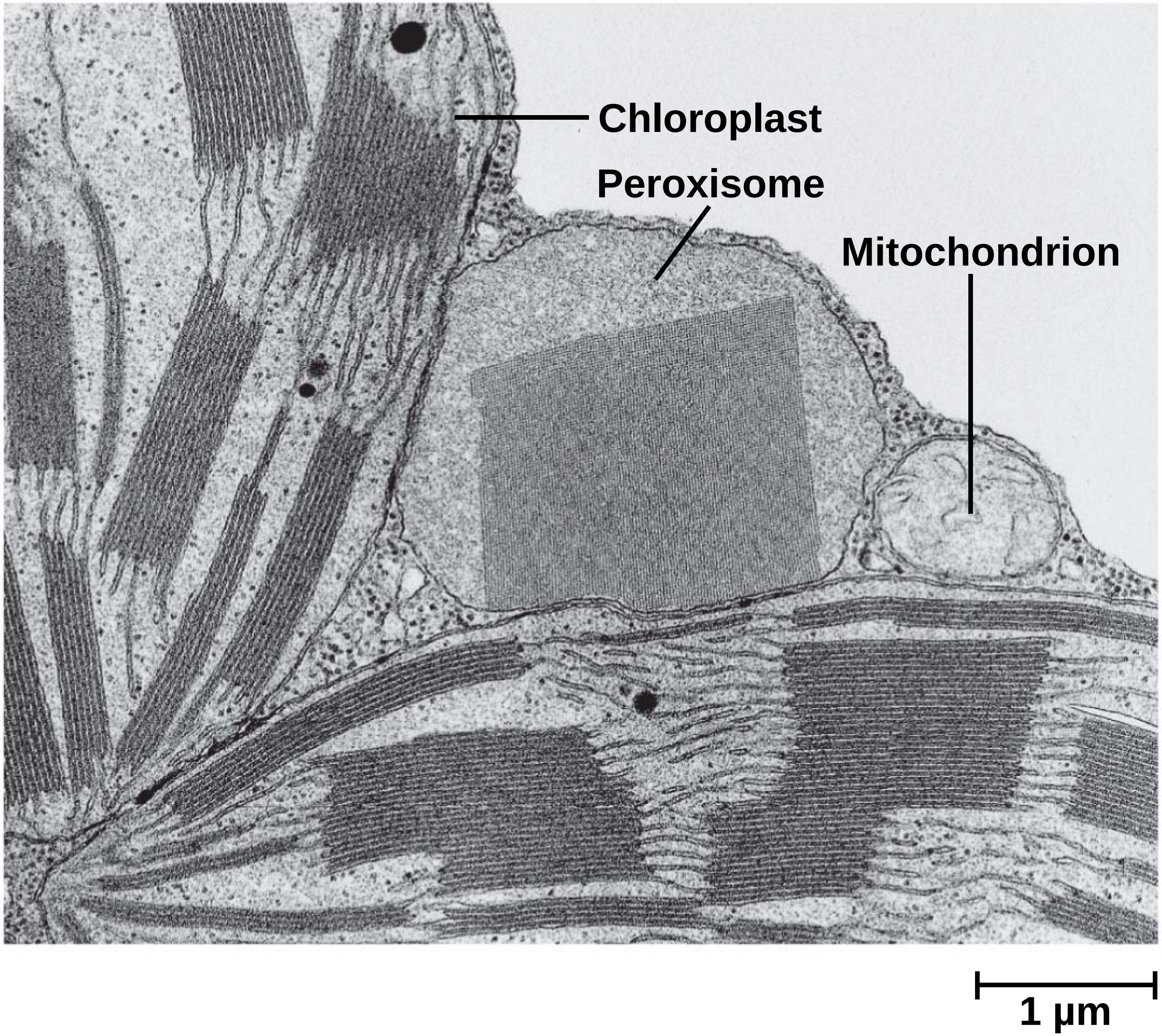


Ribosomes
Stroma
Inner and outer membranes
Granum
Thylakoid
1 µm

Peroxisomes: Oxidation

- Peroxisomes are specialized metabolic compartments bounded by a single membrane
- Peroxisomes produce hydrogen peroxide and convert it to water
- Oxygen is used to break down different types of molecules

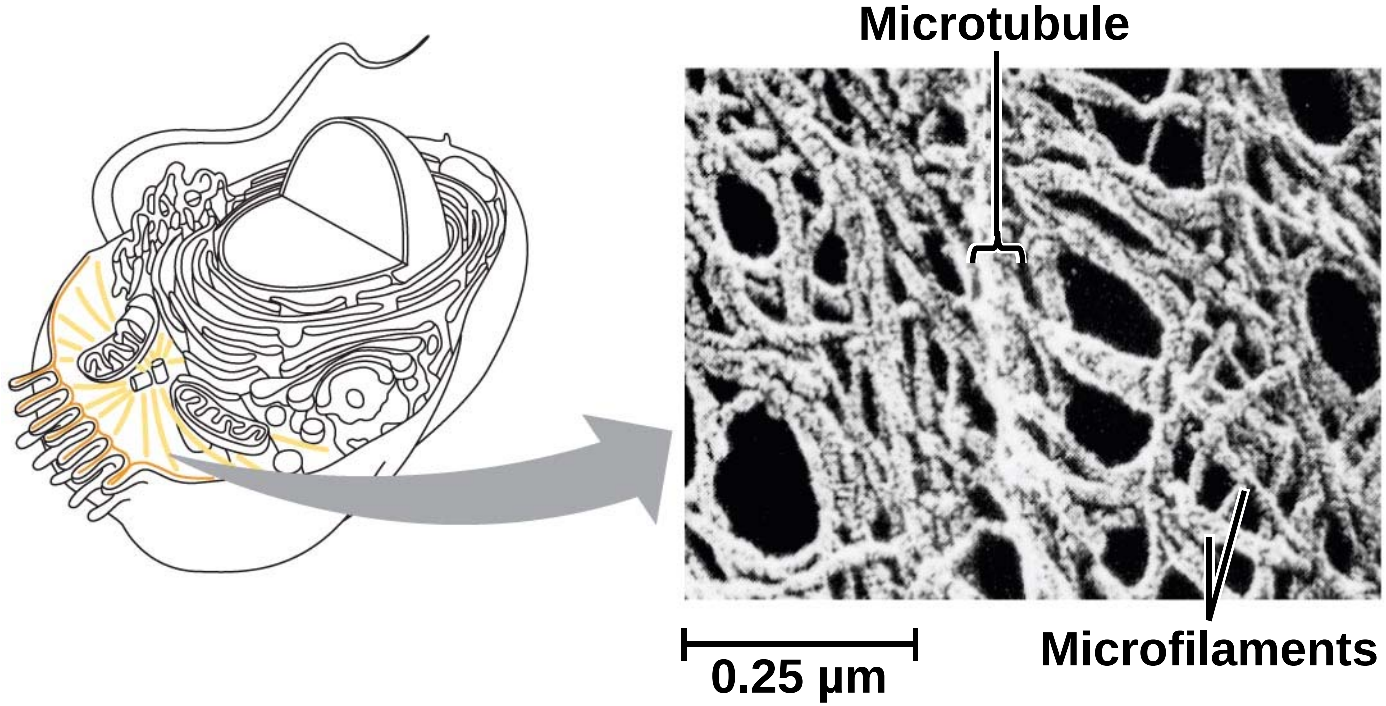
Fig. 6-19



Concept 6.6: The cytoskeleton is a network of fibers that organizes structures and activities in the cell

- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm
- It organizes the cell's structures and activities, anchoring many organelles
- It is composed of three types of molecular structures:
  - Microtubules
  - Microfilaments
  - Intermediate filaments

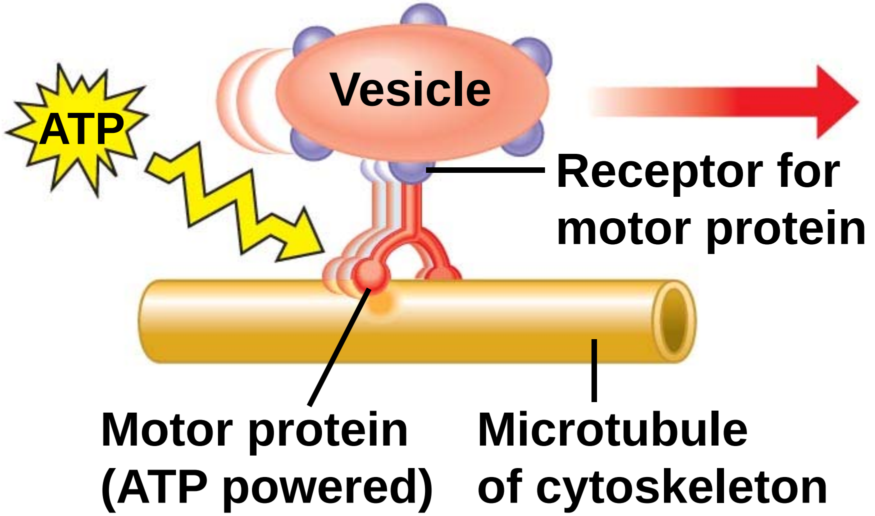
Fig. 6-20



Roles of the Cytoskeleton: Support, Motility, and Regulation

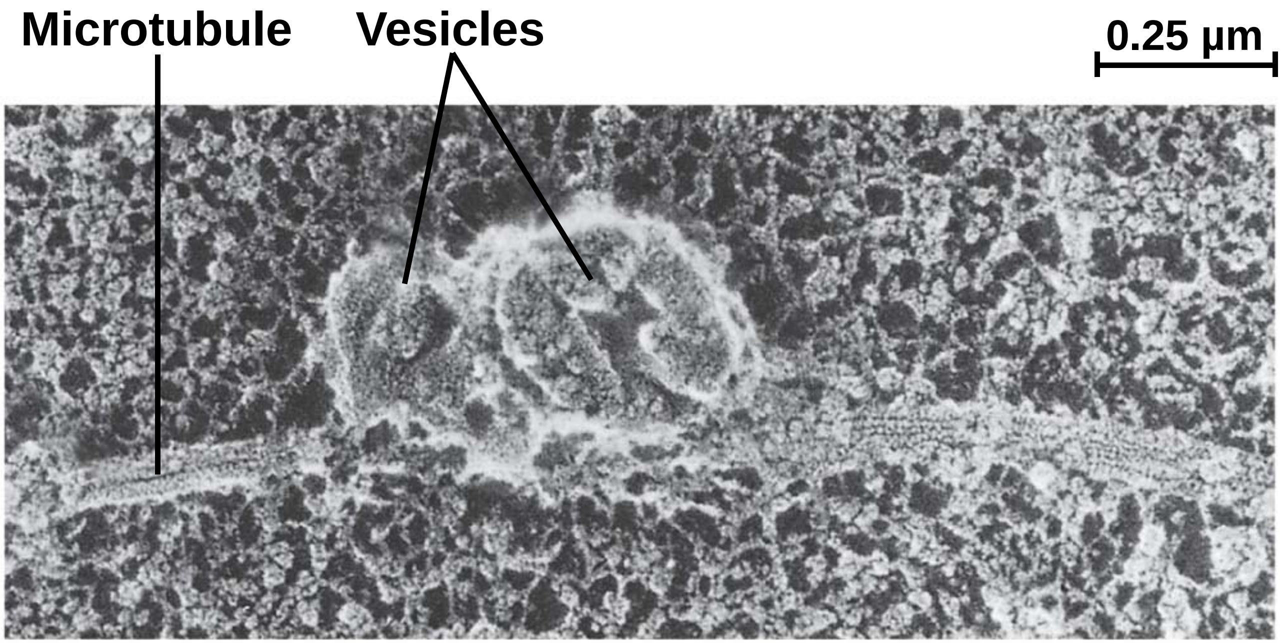
- The cytoskeleton helps to support the cell and maintain its shape
- It interacts with **motor proteins** to produce motility
- Inside the cell, vesicles can travel along “monorails” provided by the cytoskeleton
- Recent evidence suggests that the cytoskeleton may help regulate biochemical activities

Fig. 6-21



ATP
Vesicle
Receptor for motor protein
Motor protein (ATP powered)
Microtubule of cytoskeleton

(a)



Microtubule
Vesicles
0.25 µm

(b)

Components of the Cytoskeleton

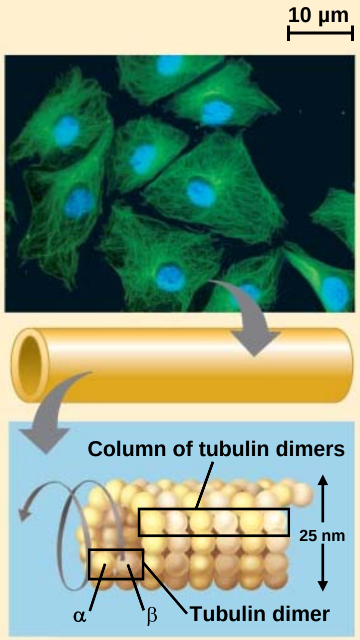
- Three main types of fibers make up the cytoskeleton:
  - *Microtubules* are the thickest of the three components of the cytoskeleton
  - *Microfilaments*, also called actin filaments, are the thinnest components
  - *Intermediate filaments* are fibers with diameters in a middle range

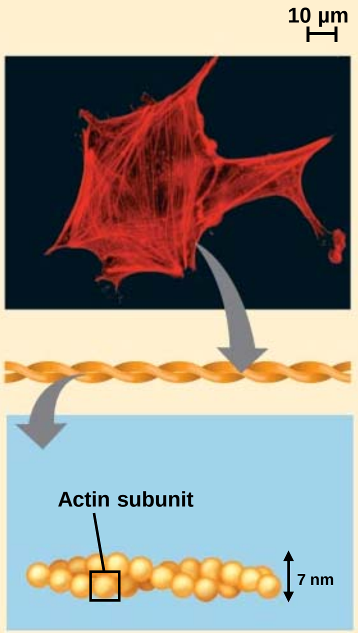
Table 6-1

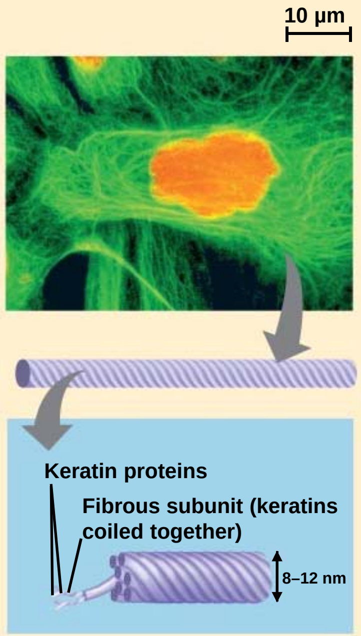
Table 6.1 The Structure and Function of the Cytoskeleton

Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two intertwined strands of actin, each a polymer of actin subunits	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, a dimer consisting of α-tubulin and β-tubulin	Actin	One of several different proteins of the keratin family, depending on cell type
Main functions	Maintenance of cell shape (compression-resisting "girders") Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape (tension-bearing elements) Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape (tension-bearing elements) Anchorage of nucleus and certain other organelles Formation of nuclear lamina

Micrographs of fibroblasts, a favorite cell type for cell biology studies. Each has been experimentally treated to fluorescently tag the structure of interest.







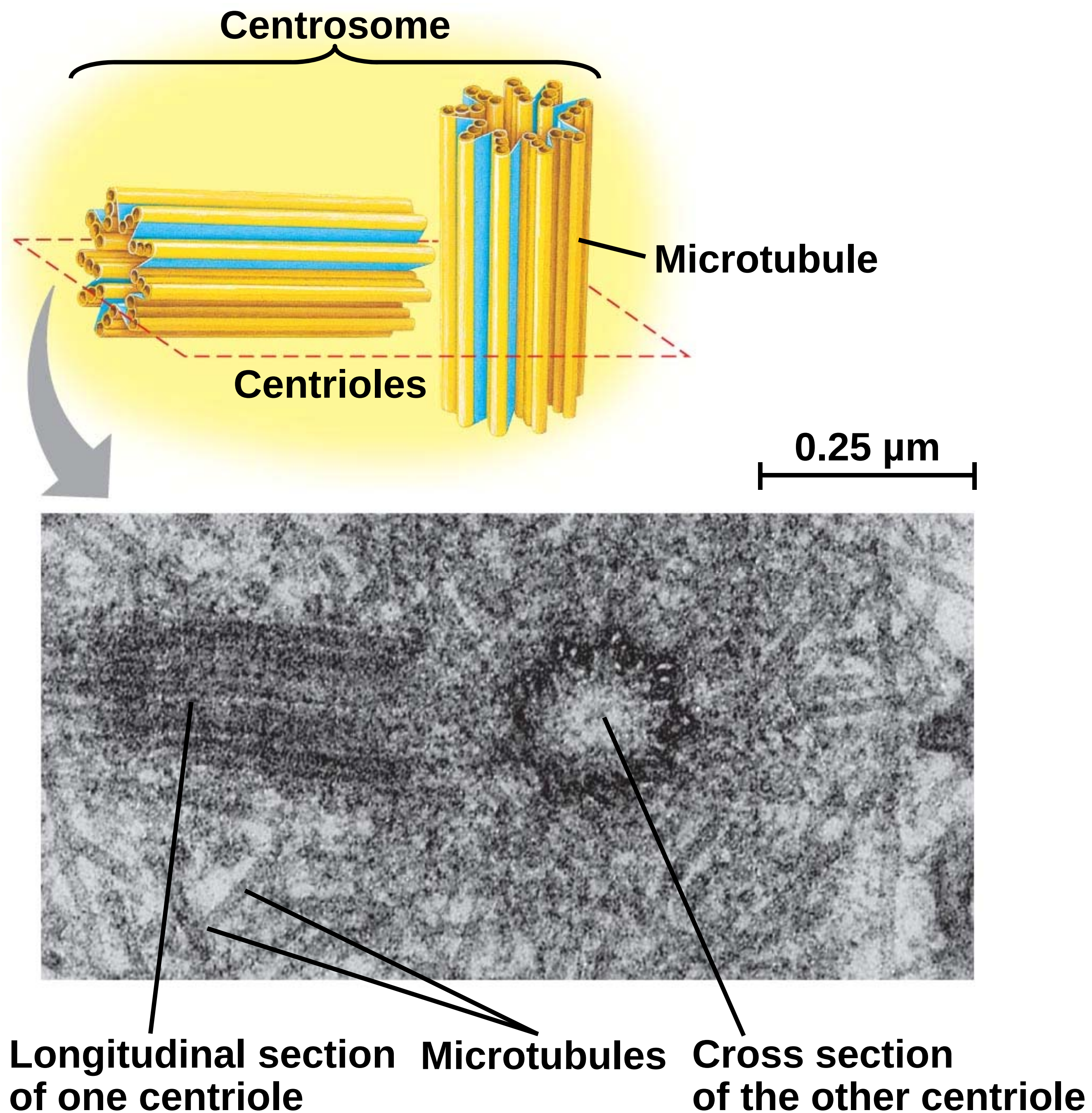
Microtubules

- **Microtubules** are hollow rods about 25 nm in diameter and about 200 nm to 25 microns long
- Functions of microtubules:
  - Shaping the cell
  - Guiding movement of organelles
  - Separating chromosomes during cell division

Centrosomes and Centrioles

- In many cells, microtubules grow out from a **centrosome** near the nucleus
- The centrosome is a “microtubule-organizing center”
- In animal cells, the centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring

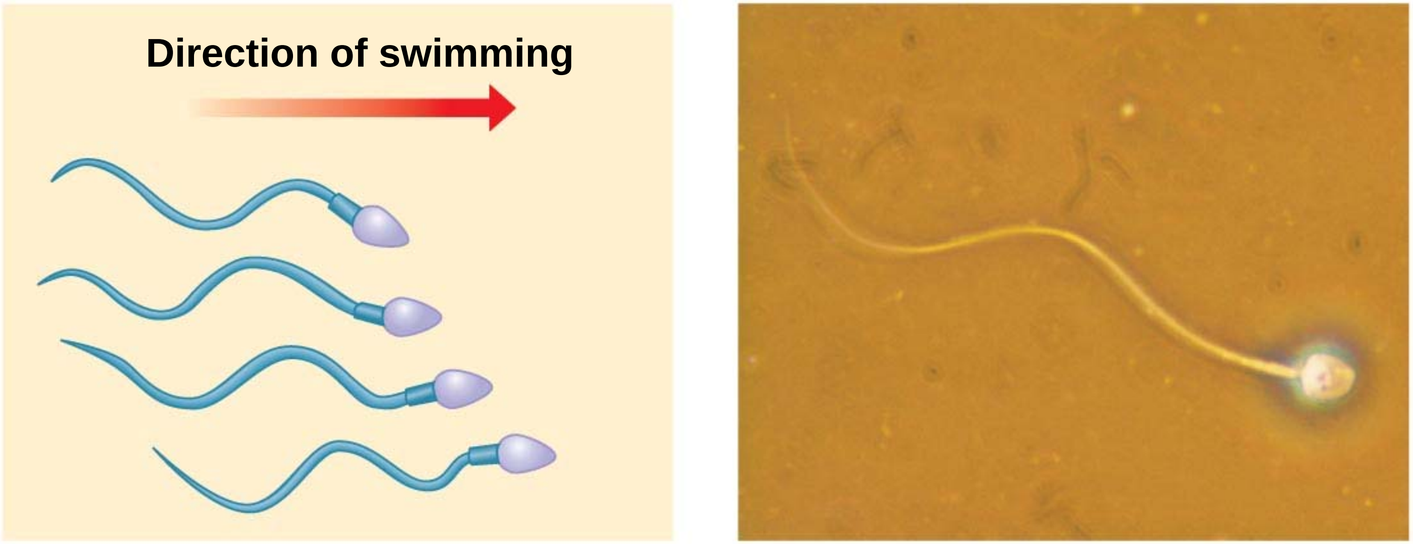
Fig. 6-22


Centrosome
Microtubule
Centrioles
0.25 µm
Longitudinal section of one centriole
Microtubules
Cross section of the other centriole

Cilia and Flagella

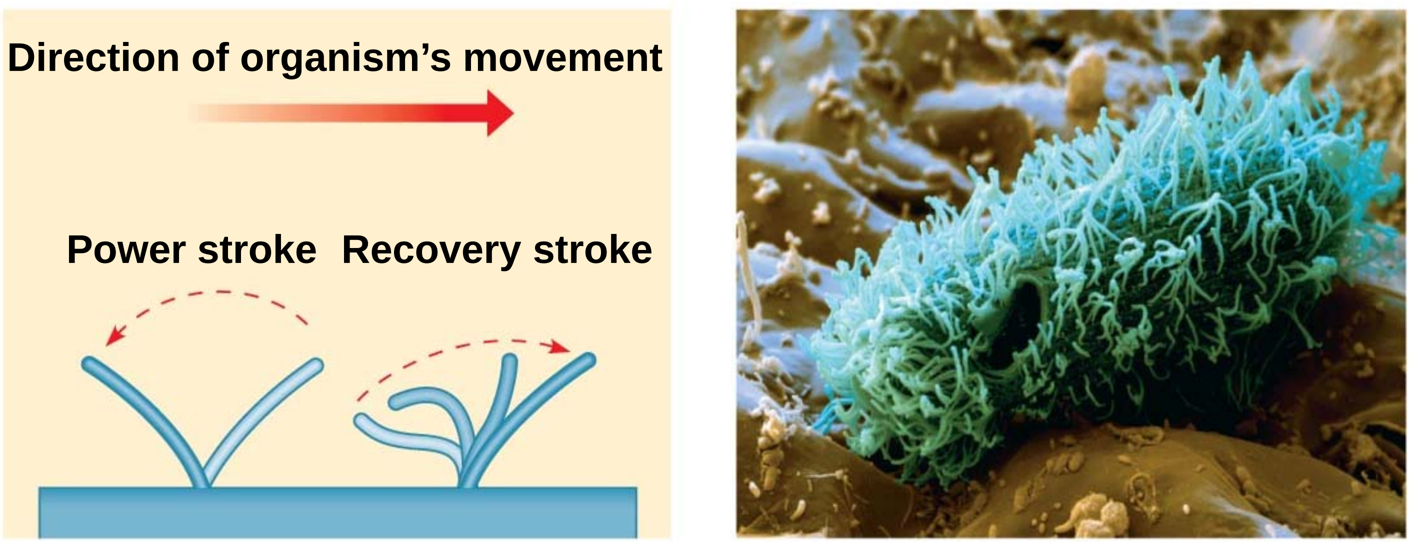
- Microtubules control the beating of **cilia** and **flagella**, locomotor appendages of some cells
- Cilia and flagella differ in their beating patterns

Fig. 6-23



(a) Motion of flagella

5 µm

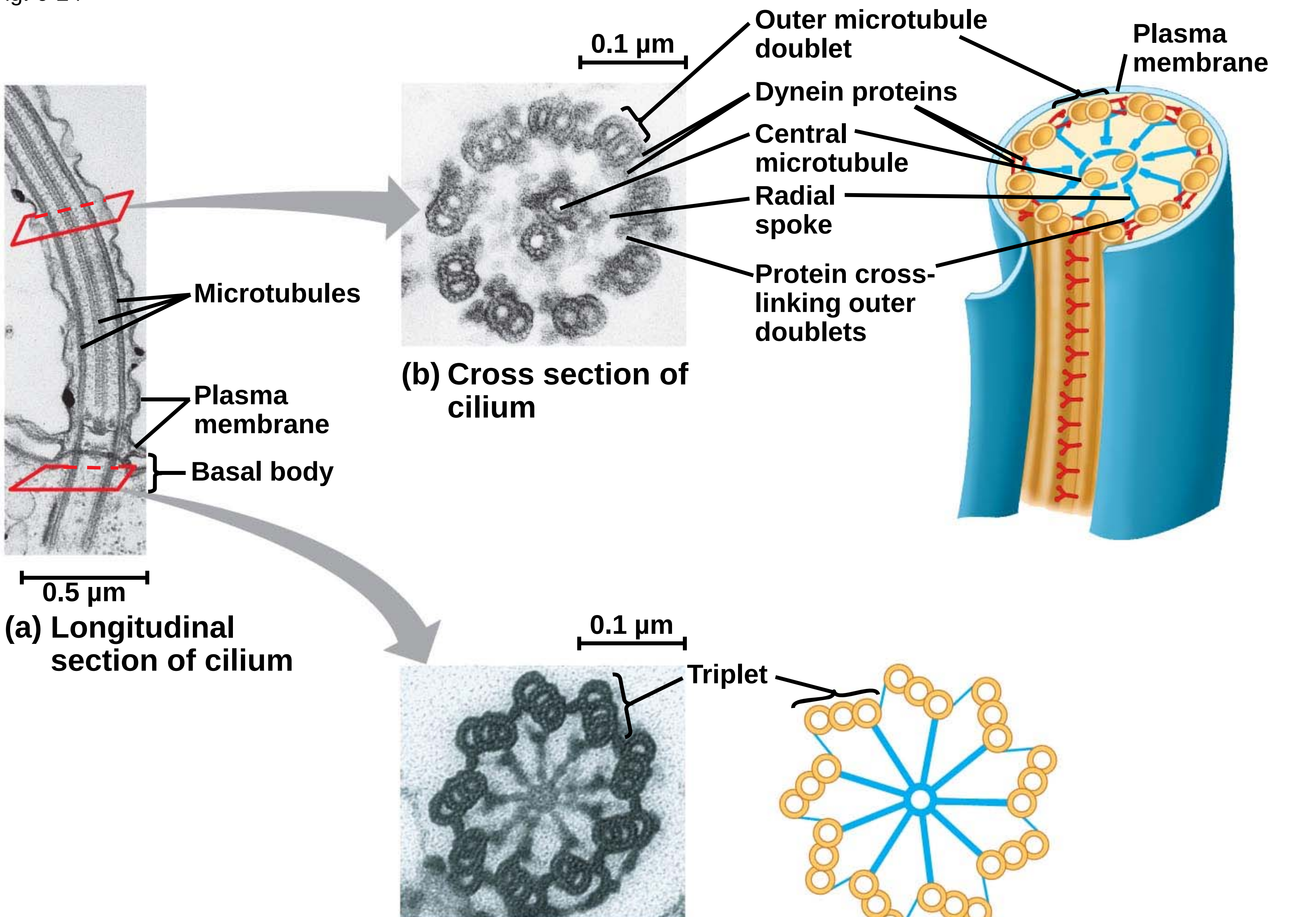


(b) Motion of cilia

15 µm

- Cilia and flagella share a common ultrastructure:
  - A core of microtubules sheathed by the plasma membrane
  - A **basal body** that anchors the cilium or flagellum
  - A motor protein called **dynein**, which drives the bending movements of a cilium or flagellum

Fig. 6-24



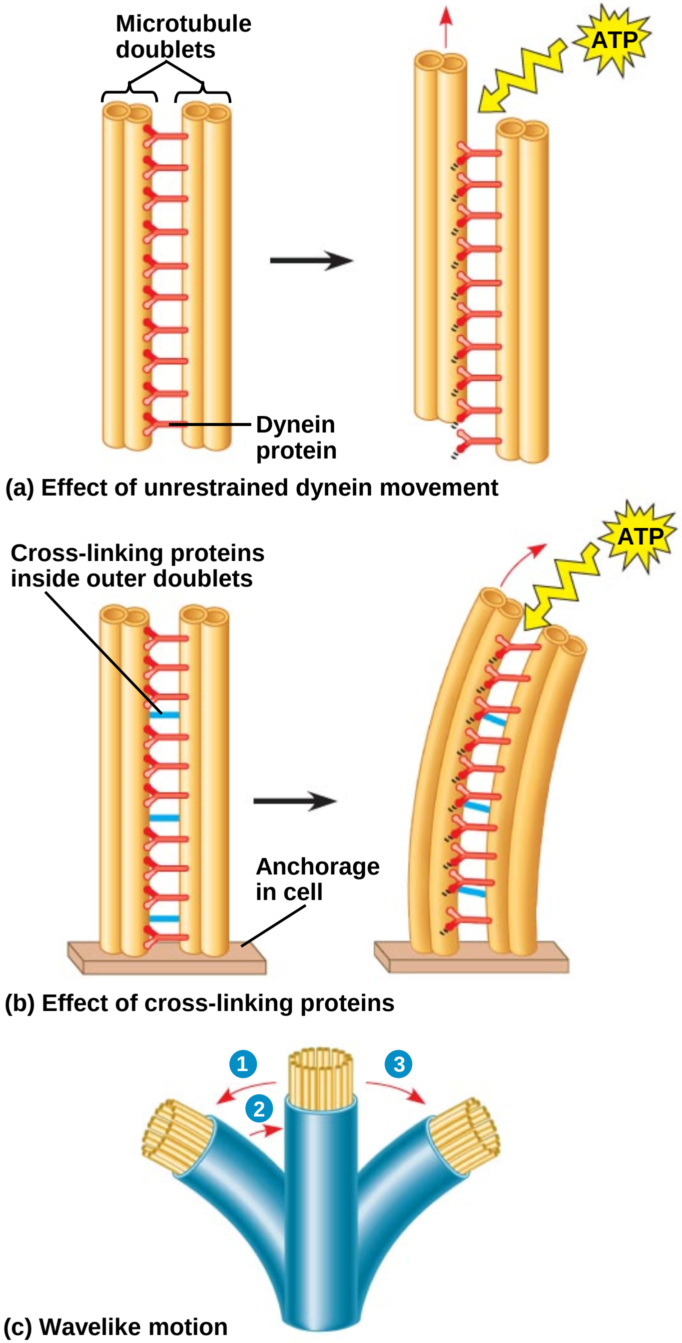
(a) Longitudinal section of cilium

(b) Cross section of cilium

(c) Cross section of basal body

- How dynein “walking” moves flagella and cilia:
  - Dynein arms alternately grab, move, and release the outer microtubules
  - Protein cross-links limit sliding
  - Forces exerted by dynein arms cause doublets to curve, bending the cilium or flagellum

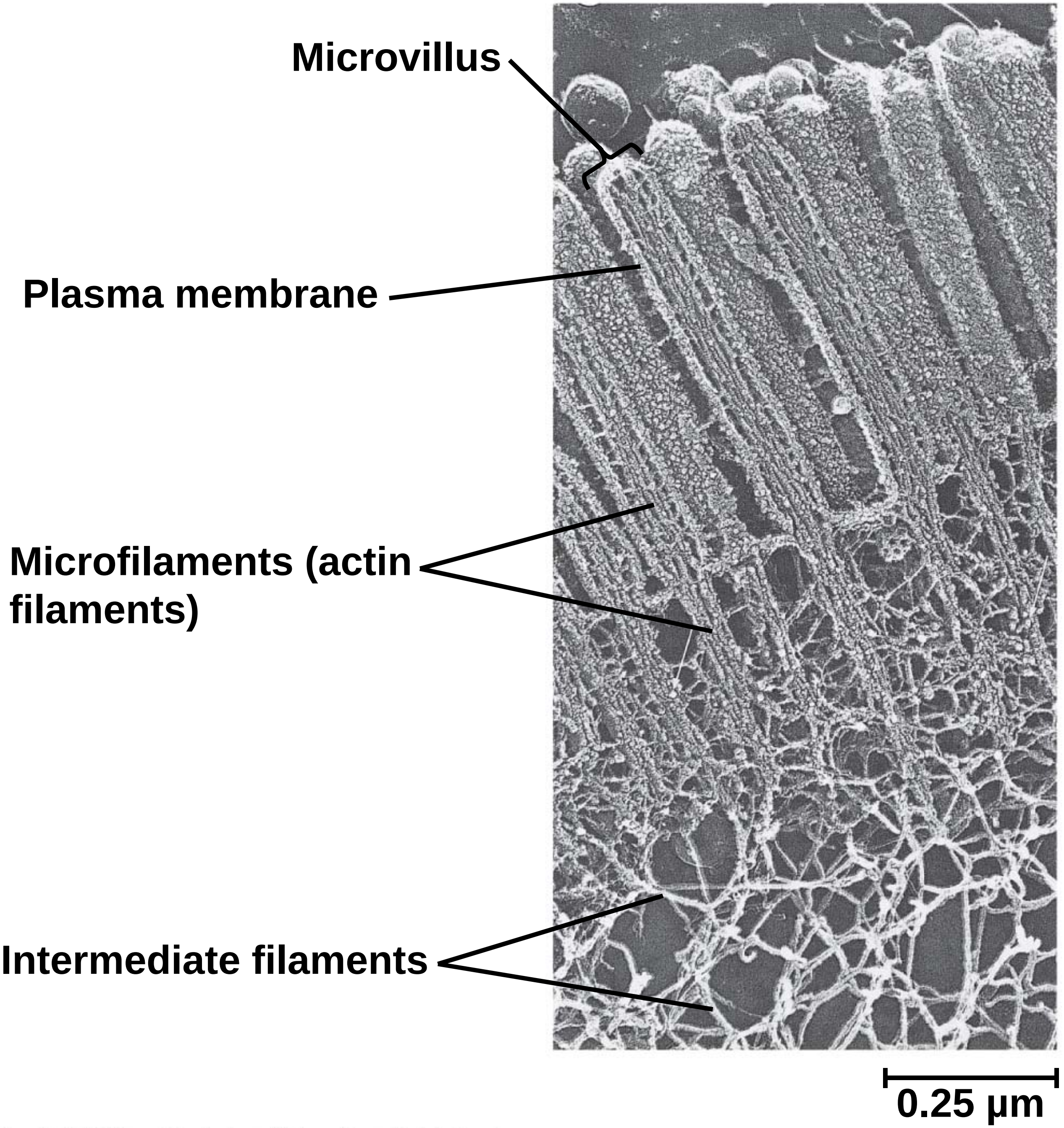
Fig. 6-25


Microtubule doublets
ATP
Dynein protein
(a) Effect of unrestrained dynein movement
Cross-linking proteins inside outer doublets
ATP
Anchorage in cell
(b) Effect of cross-linking proteins
1
3
2
(c) Wavelike motion

Microfilaments (Actin Filaments)

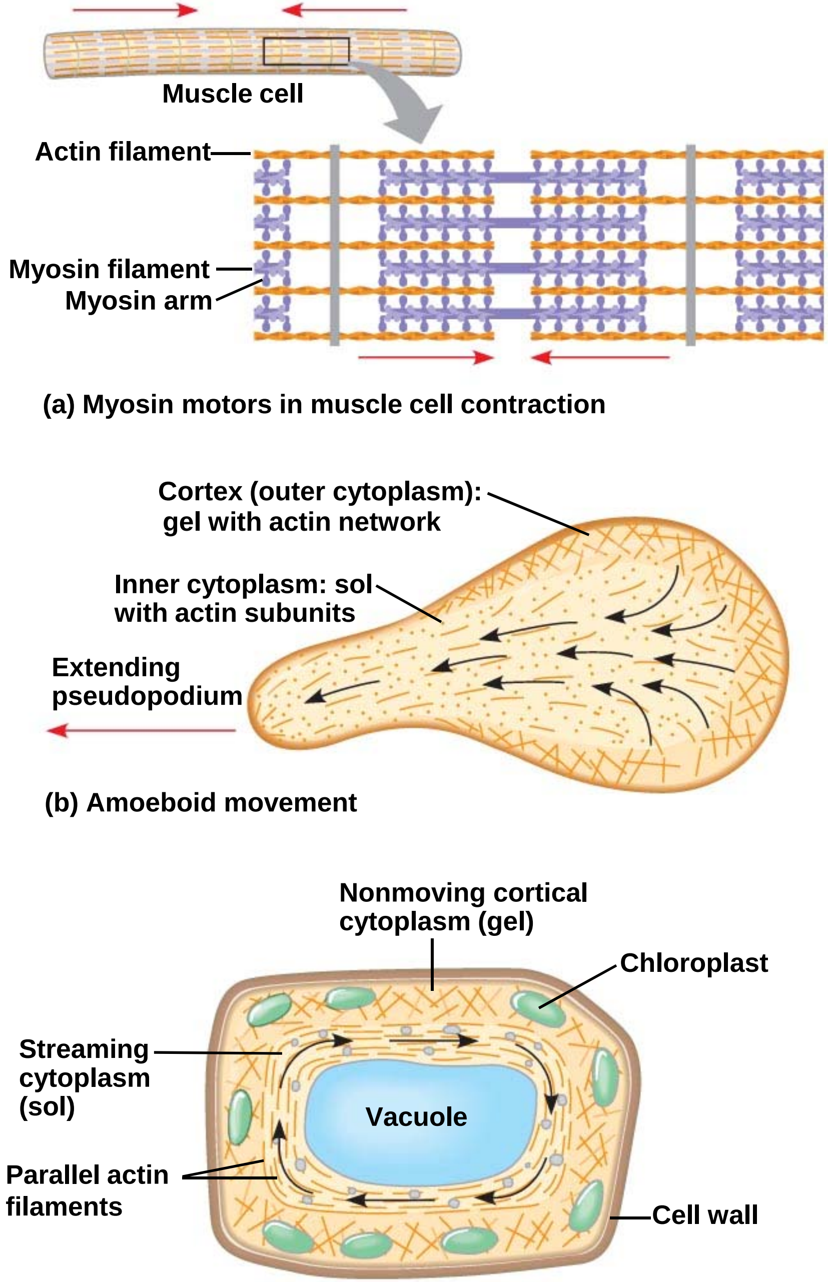
- **Microfilaments** are solid rods about 7 nm in diameter, built as a twisted double chain of **actin** subunits
- The structural role of microfilaments is to bear tension, resisting pulling forces within the cell
- They form a 3-D network called the **cortex** just inside the plasma membrane to help support the cell’s shape
- Bundles of microfilaments make up the core of microvilli of intestinal cells

Fig. 6-26


Microvillus
Plasma membrane
Microfilaments (actin filaments)
Intermediate filaments
0.25 µm

- Microfilaments that function in cellular motility contain the protein **myosin** in addition to actin
- In muscle cells, thousands of actin filaments are arranged parallel to one another
- Thicker filaments composed of myosin interdigitate with the thinner actin fibers

Fig. 6-27



(a) Myosin motors in muscle cell contraction

(b) Amoeboid movement

(c) Cytoplasmic streaming in plant cells

- Localized contraction brought about by actin and myosin also drives amoeboid movement
- **Pseudopodia** (cellular extensions) extend and contract through the reversible assembly and contraction of actin subunits into microfilaments

- **Cytoplasmic streaming** is a circular flow of cytoplasm within cells
- This streaming speeds distribution of materials within the cell
- In plant cells, actin-myosin interactions and sol-gel transformations drive cytoplasmic streaming

Intermediate Filaments

- **Intermediate filaments** range in diameter from 8–12 nanometers, larger than microfilaments but smaller than microtubules
- They support cell shape and fix organelles in place
- Intermediate filaments are more permanent cytoskeleton fixtures than the other two classes

Concept 6.7: Extracellular components and connections between cells help coordinate cellular activities

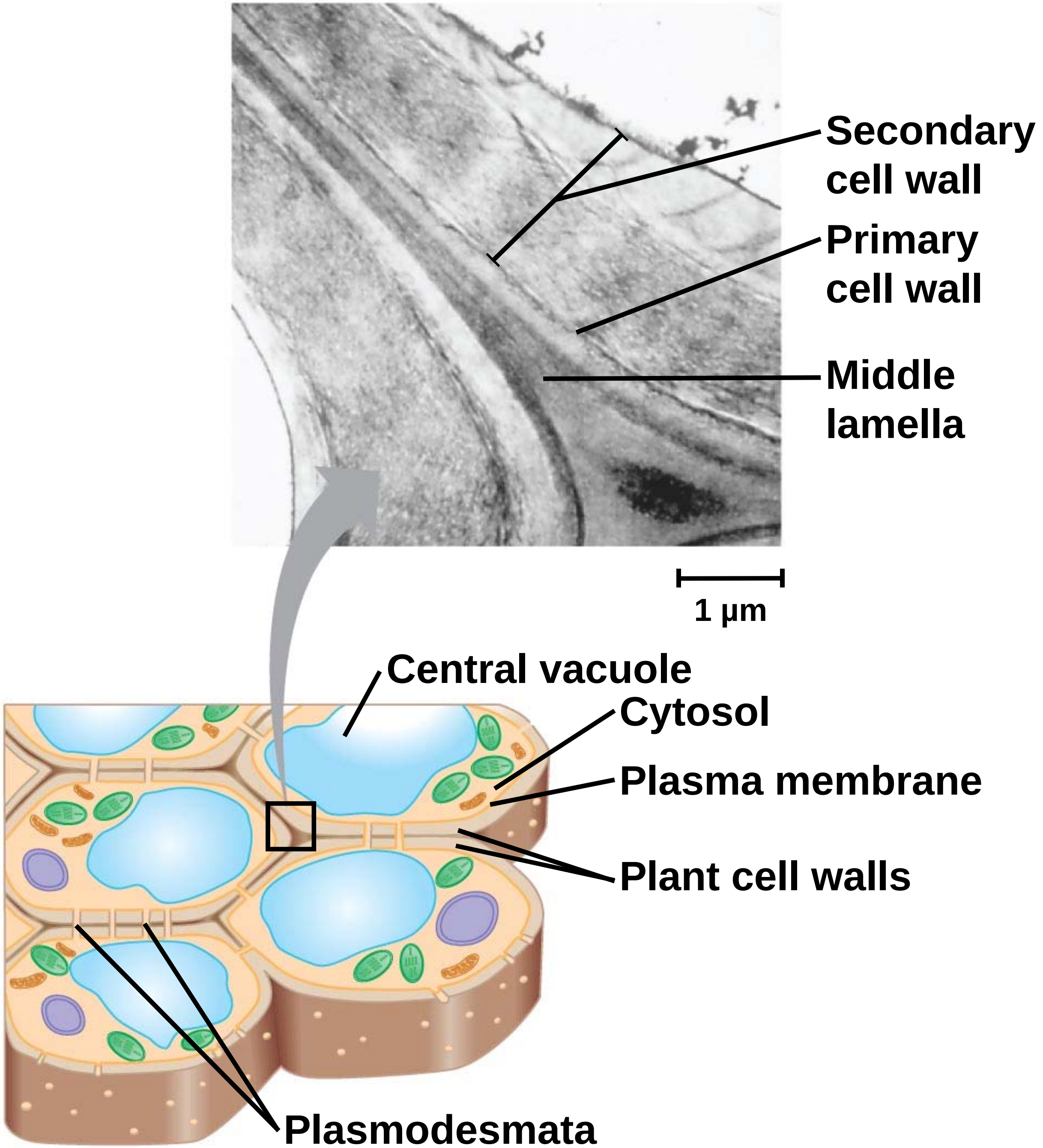
- Most cells synthesize and secrete materials that are external to the plasma membrane
- These extracellular structures include:
  - Cell walls of plants
  - The extracellular matrix (ECM) of animal cells
  - Intercellular junctions

Cell Walls of Plants

- The **cell wall** is an extracellular structure that distinguishes plant cells from animal cells
- Prokaryotes, fungi, and some protists also have cell walls
- The cell wall protects the plant cell, maintains its shape, and prevents excessive uptake of water
- Plant cell walls are made of cellulose fibers embedded in other polysaccharides and protein

- Plant cell walls may have multiple layers:
  - **Primary cell wall**: relatively thin and flexible
  - **Middle lamella**: thin layer between primary walls of adjacent cells
  - **Secondary cell wall** (in some cells): added between the plasma membrane and the primary cell wall
- Plasmodesmata are channels between adjacent plant cells

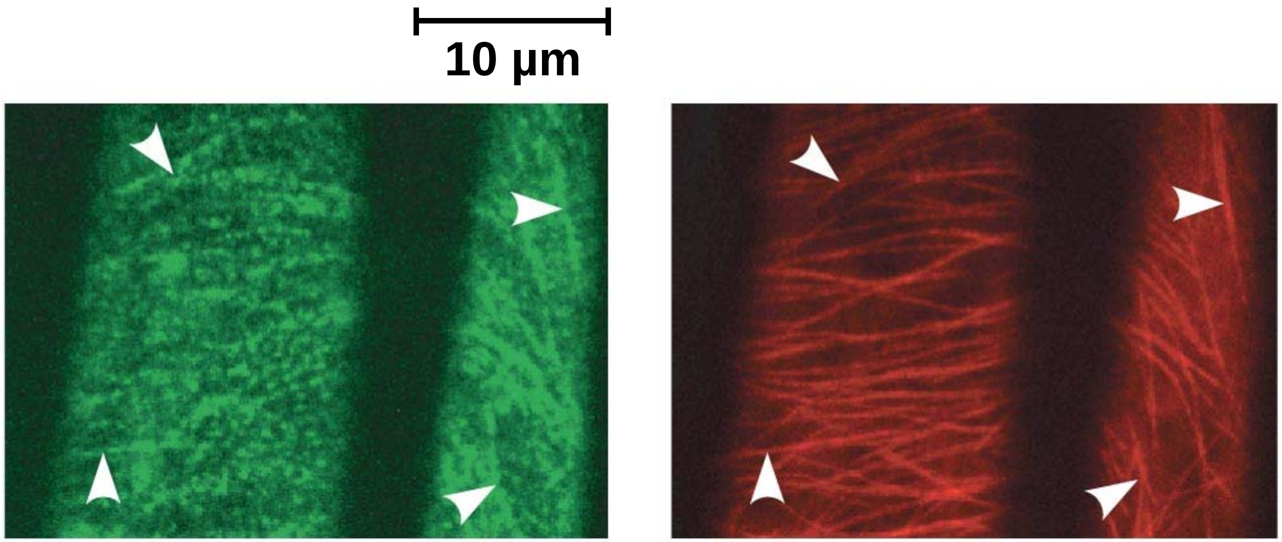
Fig. 6-28



Secondary cell wall
Primary cell wall
Middle lamella
1 µm
Central vacuole
Cytosol
Plasma membrane
Plant cell walls
Plasmodesmata

Fig. 6-29

RESULTS



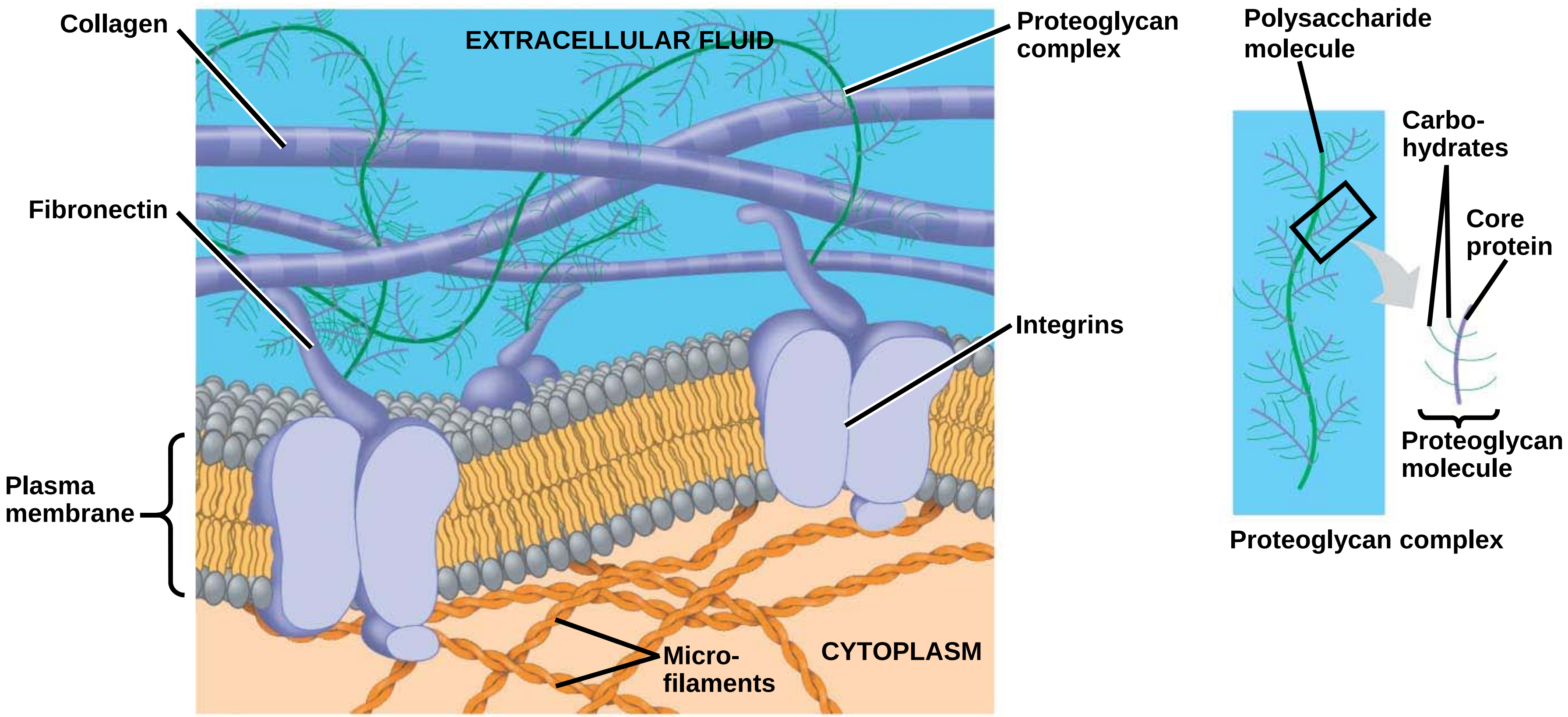
Distribution of cellulose synthase over time

Distribution of microtubules over time

The Extracellular Matrix (ECM) of Animal Cells

- Animal cells lack cell walls but are covered by an elaborate **extracellular matrix (ECM)**
- The ECM is made up of glycoproteins such as **collagen**, **proteoglycans**, and **fibronectin**
- ECM proteins bind to receptor proteins in the plasma membrane called **integrins**

Fig. 6-30


Collagen
EXTRACELLULAR FLUID
Proteoglycan complex
Polysaccharide molecule
Carbo-hydrates
Core protein
Fibronectin
Integrins
Proteoglycan molecule
Plasma membrane
Proteoglycan complex
Micro-filaments
CYTOPLASM

- Functions of the ECM:
  - Support
  - Adhesion
  - Movement
  - Regulation

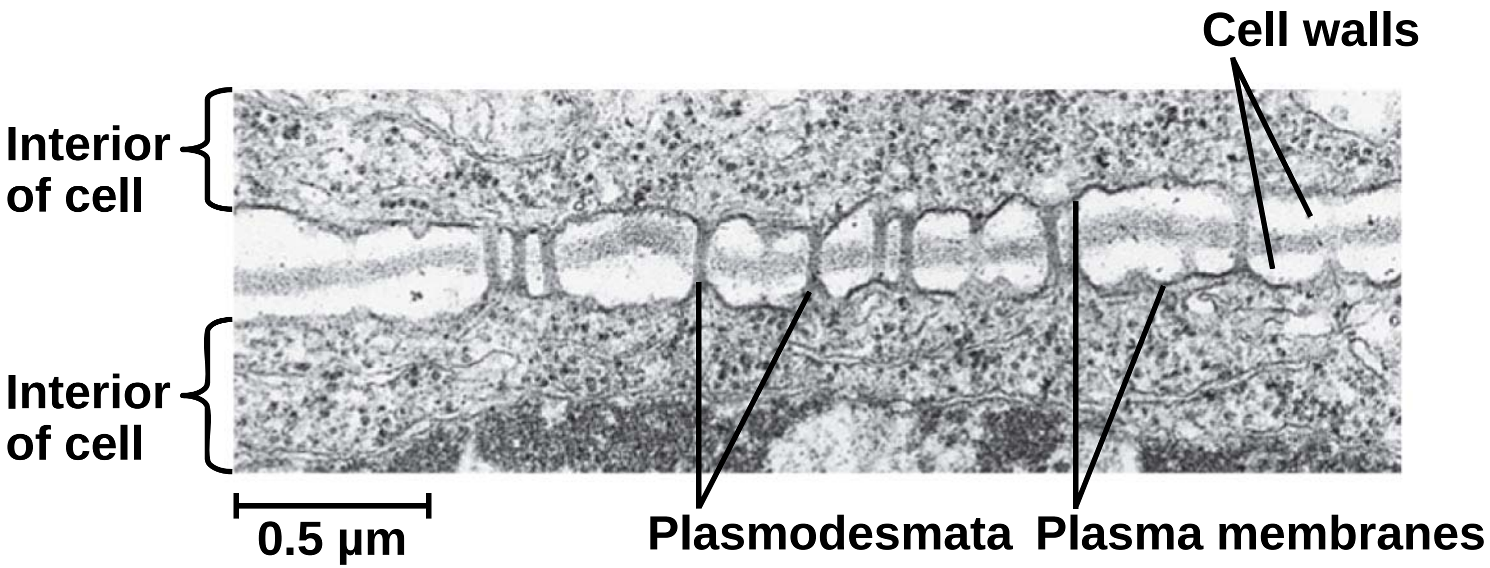
Intercellular Junctions

- Neighboring cells in tissues, organs, or organ systems often adhere, interact, and communicate through direct physical contact
- Intercellular junctions facilitate this contact
- There are several types of intercellular junctions
  - Plasmodesmata
  - Tight junctions
  - Desmosomes
  - Gap junctions

Plasmodesmata in Plant Cells

- **Plasmodesmata** are channels that perforate plant cell walls
- Through plasmodesmata, water and small solutes (and sometimes proteins and RNA) can pass from cell to cell

Fig. 6-31

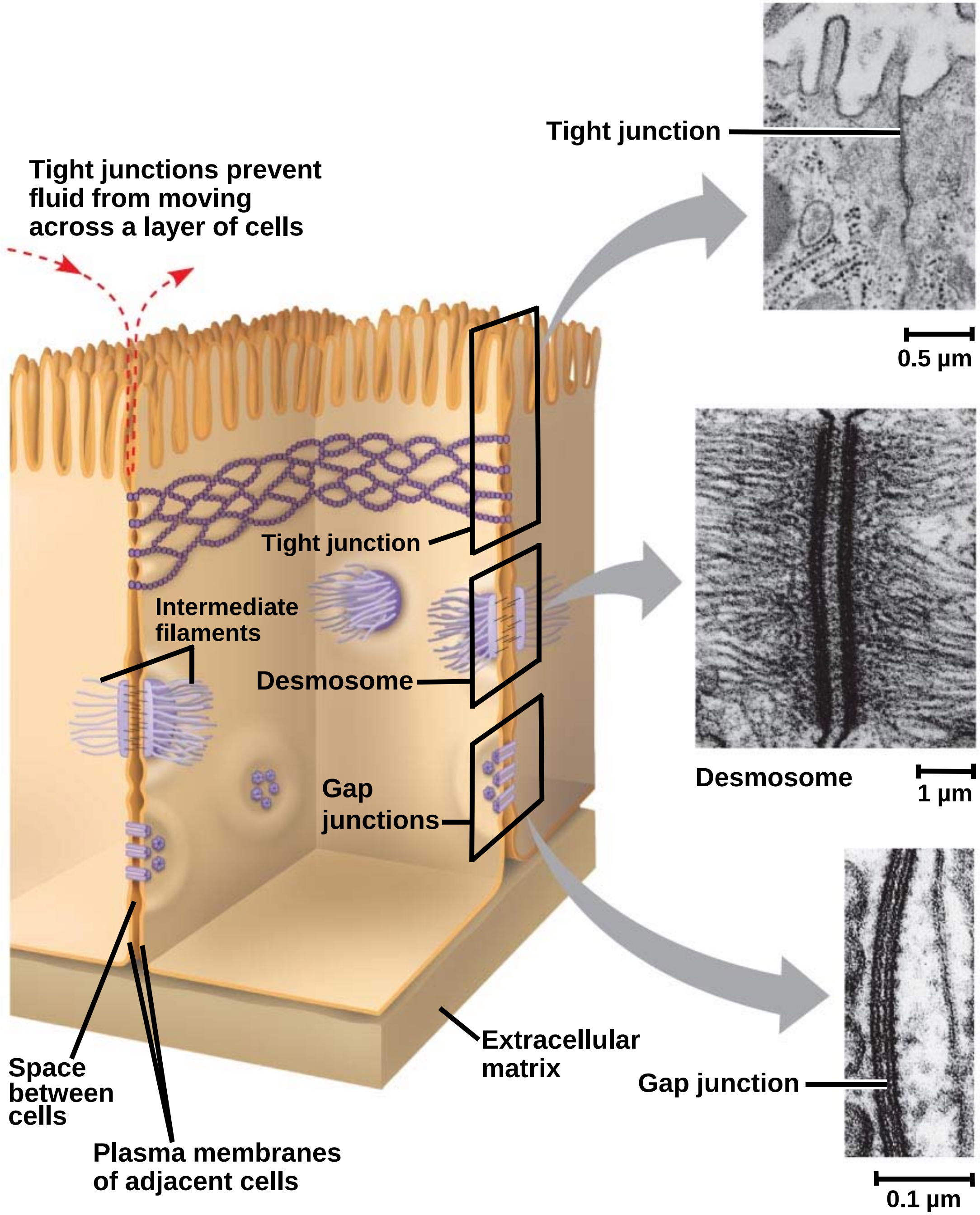


Cell walls
Interior of cell
Interior of cell
0.5 µm
Plasmodesmata
Plasma membranes

Tight Junctions, Desmosomes, and Gap Junctions in Animal Cells

- At **tight junctions**, membranes of neighboring cells are pressed together, preventing leakage of extracellular fluid
- **Desmosomes** (anchoring junctions) fasten cells together into strong sheets
- **Gap junctions** (communicating junctions) provide cytoplasmic channels between adjacent cells

Fig. 6-32

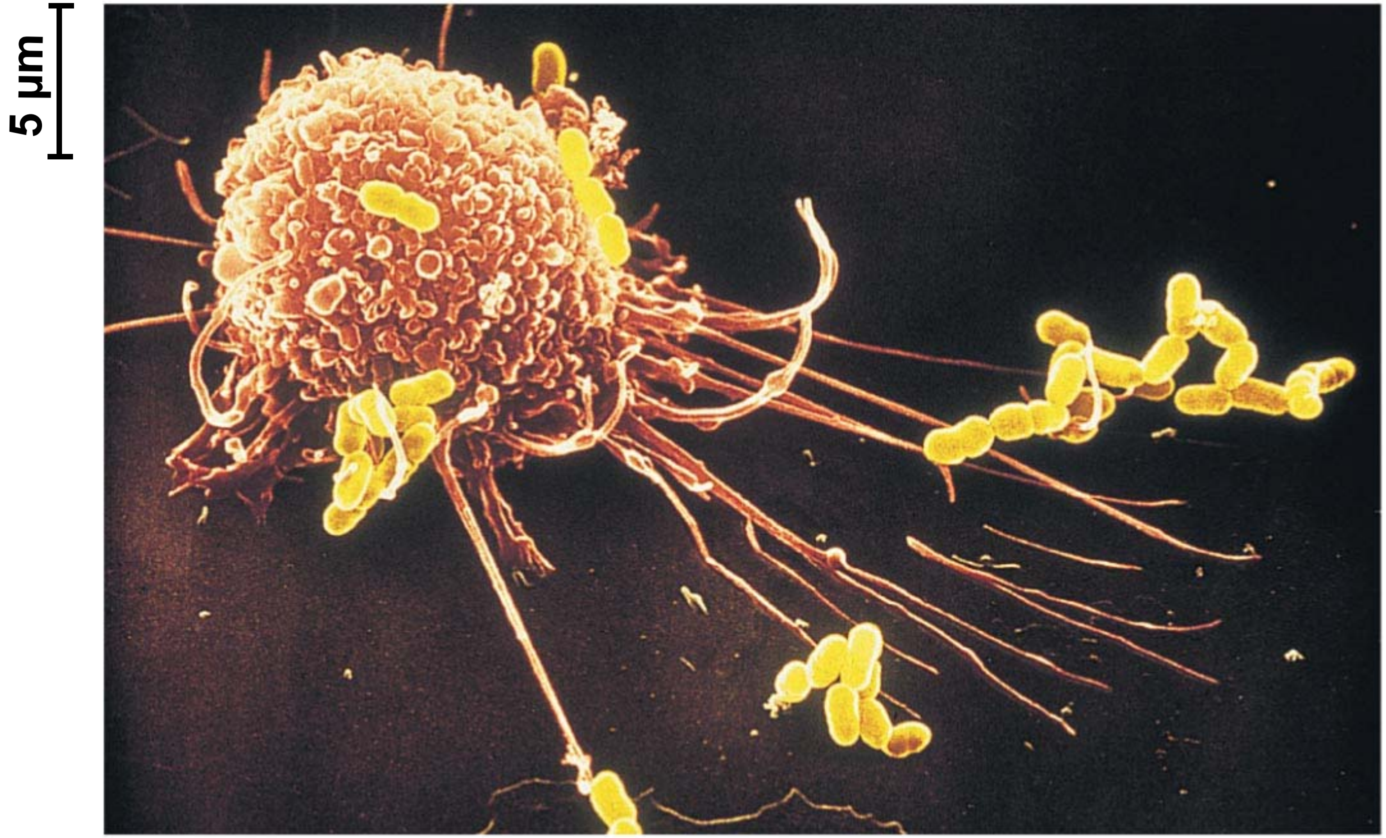


Tight junctions prevent fluid from moving across a layer of cells
Tight junction
Intermediate filaments
Desmosome
Gap junctions
Space between cells
Plasma membranes of adjacent cells
Extracellular matrix
Tight junction
0.5 µm
Desmosome
1 µm
Gap junction
0.1 µm

The Cell: A Living Unit Greater Than the Sum of Its Parts

- Cells rely on the integration of structures and organelles in order to function
- For example, a macrophage's ability to destroy bacteria involves the whole cell, coordinating components such as the cytoskeleton, lysosomes, and plasma membrane

A macrophage destroys bacteria



You should now be able to:

1. Distinguish between the following pairs of terms: magnification and resolution; prokaryotic and eukaryotic cell; free and bound ribosomes; smooth and rough ER
2. Describe the structure and function of the components of the endomembrane system
3. Briefly explain the role of mitochondria, chloroplasts, and peroxisomes
4. Describe the functions of the cytoskeleton

5. Compare the structure and functions of microtubules, microfilaments, and intermediate filaments
6. Explain how the ultrastructure of cilia and flagella relate to their functions
7. Describe the structure of a plant cell wall
8. Describe the structure and roles of the extracellular matrix in animal cells
9. Describe four different intercellular junctions