CAMPBELL BIOLOGY IN FOCUS

URRY • CAIN • WASSERMAN • MINORSKY • REECE

4

A Tour of the Cell

Lecture Presentations by Kathleen Fitzpatrick and Nicole Tunbridge, Simon Fraser University

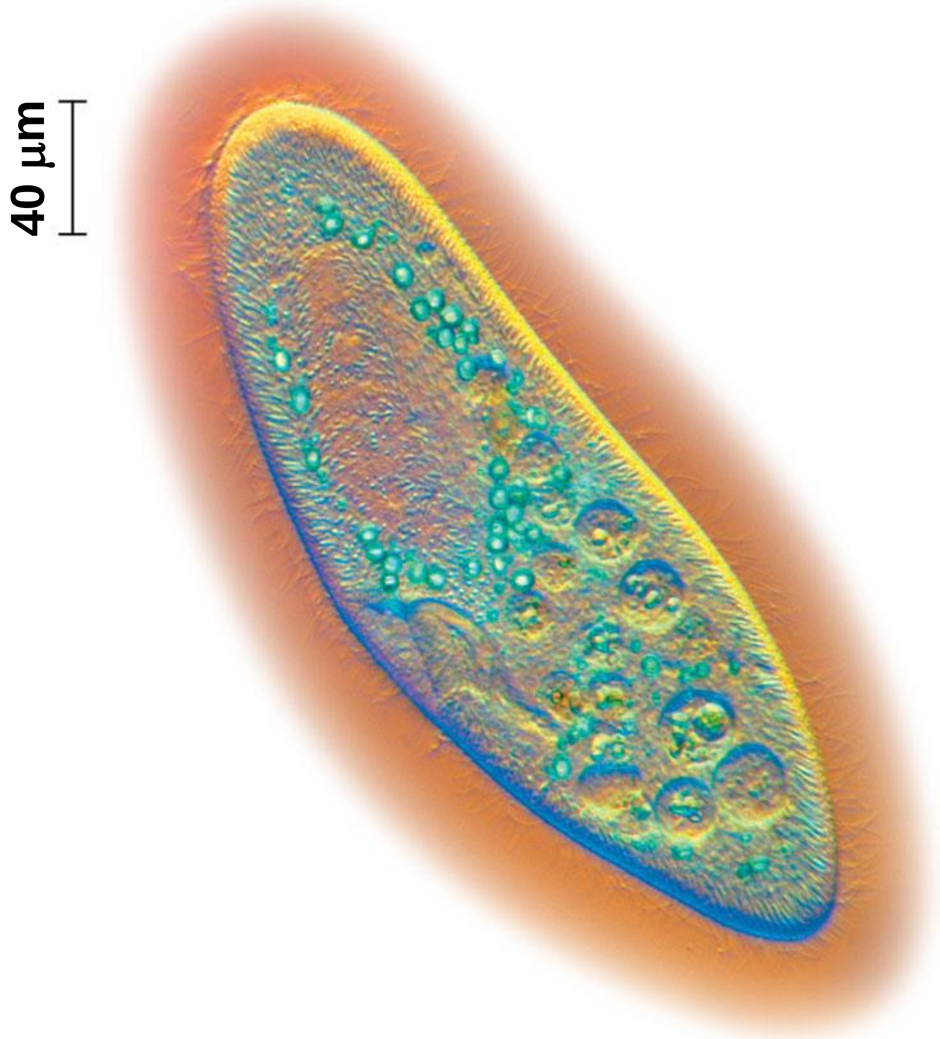
SECOND EDITION

Overview: The Fundamental Units of Life

- All organisms are made of cells
- The cell is the simplest collection of matter that can be alive
- All cells are related by their descent from earlier cells
- Though cells can differ substantially from one another, they share common features

Figure 4.1-1

Figure 4.1-2



▲ ***Paramecium caudatum***

Concept 4.1: Biologists use microscopes and the tools of biochemistry to study cells

- Most cells are too small to be seen by the unaided eye

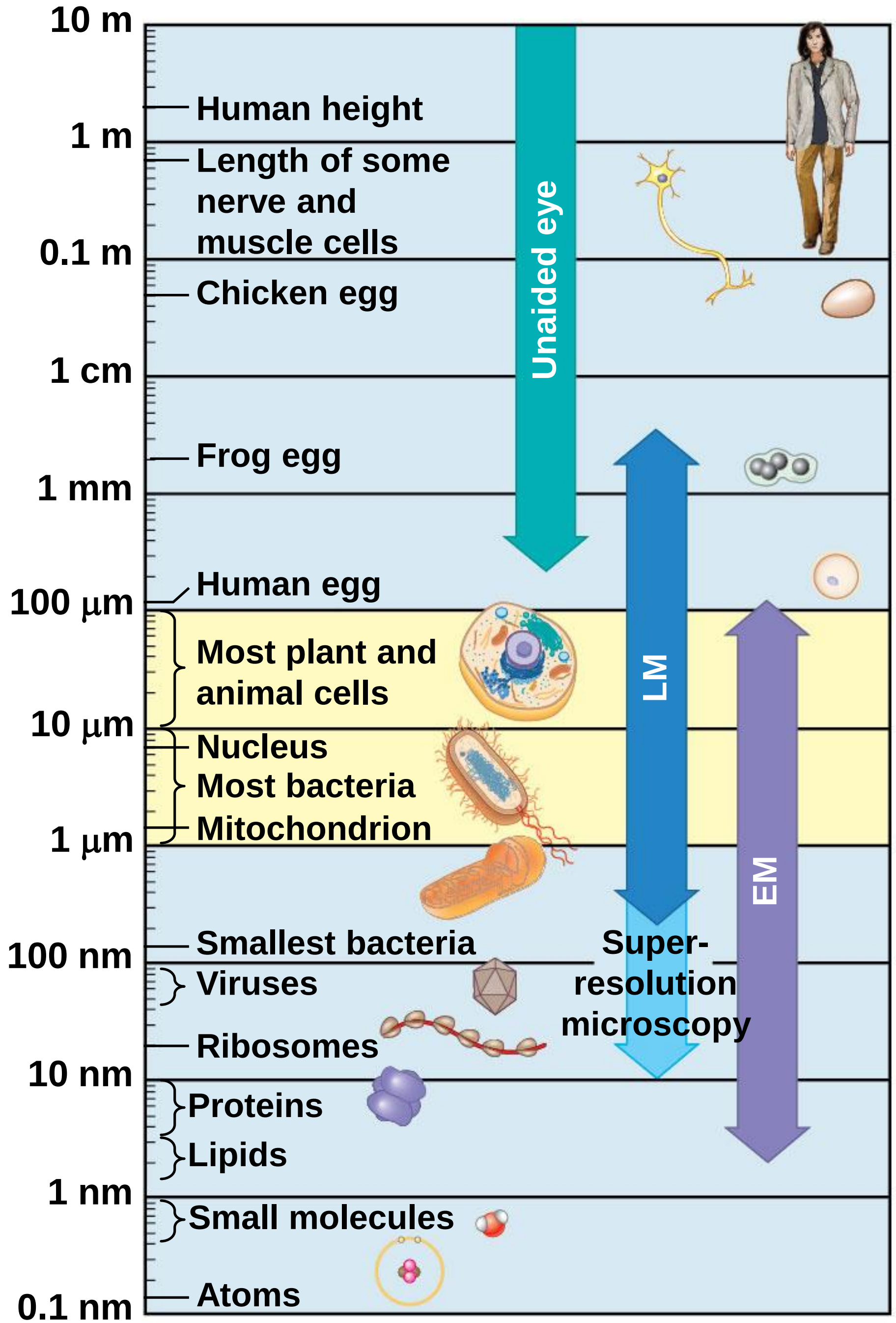
Microscopy

- Scientists use microscopes to observe cells too small to be seen with the naked eye
- In a **light microscope** (**LM**), visible light is passed through a specimen and then through glass lenses
- Lenses refract (bend) the light, so that the image is magnified

- Three important parameters of microscopy
  - 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 between two distinguishable points
  - Contrast, visible differences in parts of the sample

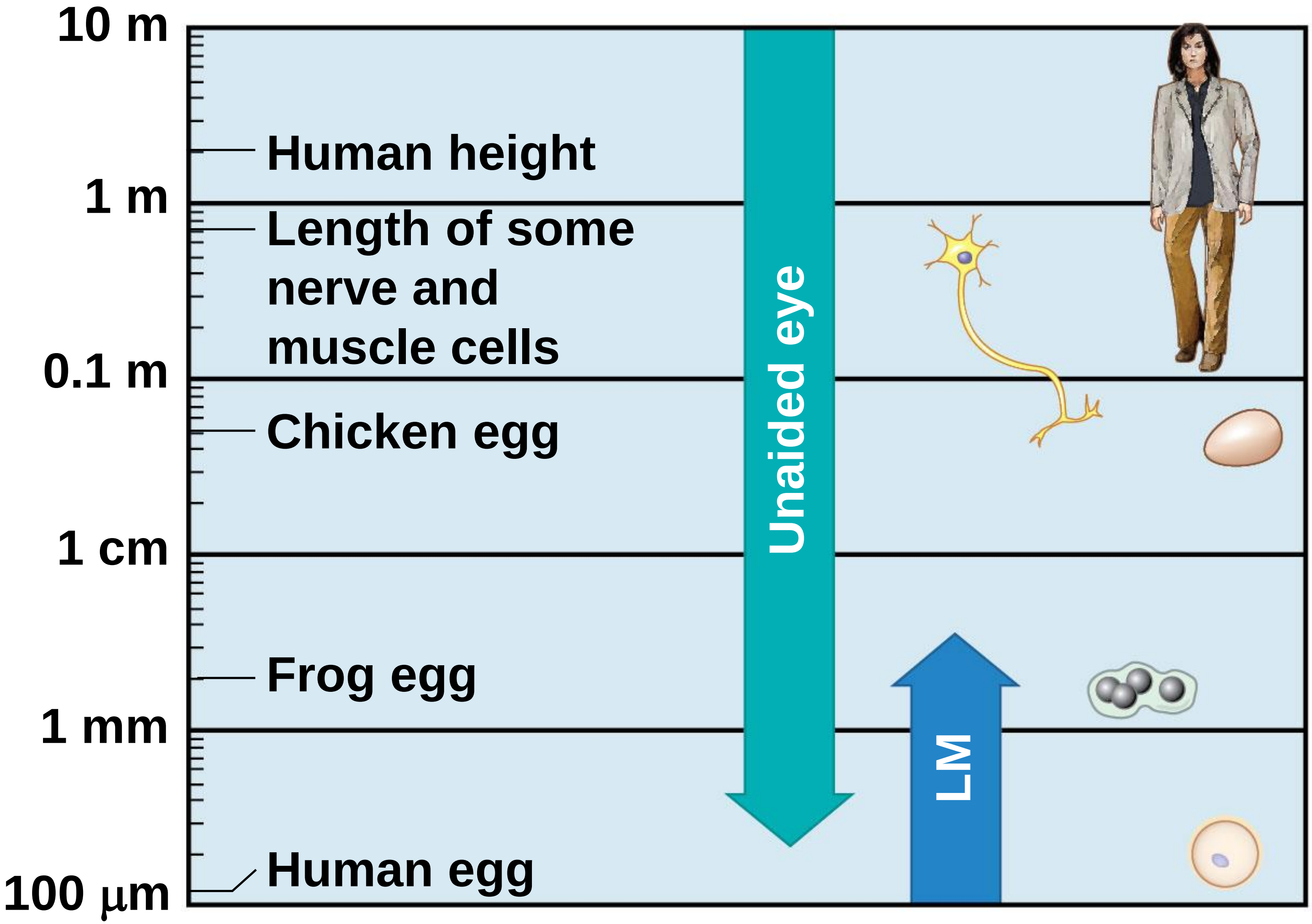
- LMs can magnify effectively to about 1,000 times the size of the actual specimen
- Various techniques enhance contrast and enable cell components to be stained or labeled
- Most subcellular structures, including **organelles** (membrane-enclosed compartments), are too small to be resolved by light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

Figure 4.2



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
Human egg
Most plant and animal cells
Nucleus
Most bacteria
Mitochondrion
Smallest bacteria
Viruses
Ribosomes
Proteins
Lipids
Small molecules
Atoms
Unaided eye
LM
EM
Super-resolution microscopy

Figure 4.2-1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1 m
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1 cm
1 mm
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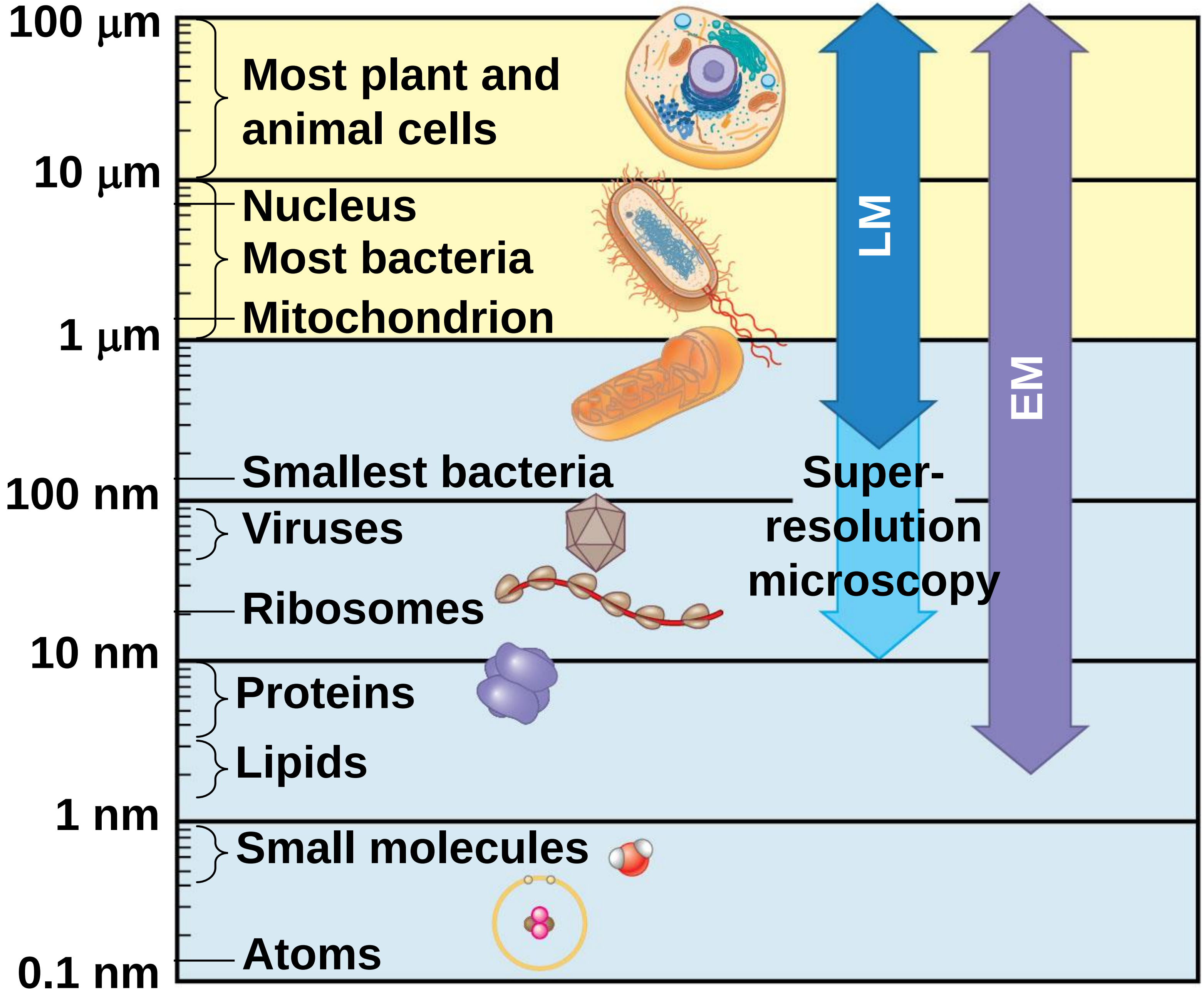
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Human egg
Unaided eye
LM

Figure 4.2-2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Most plant and animal cells
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Small molecules
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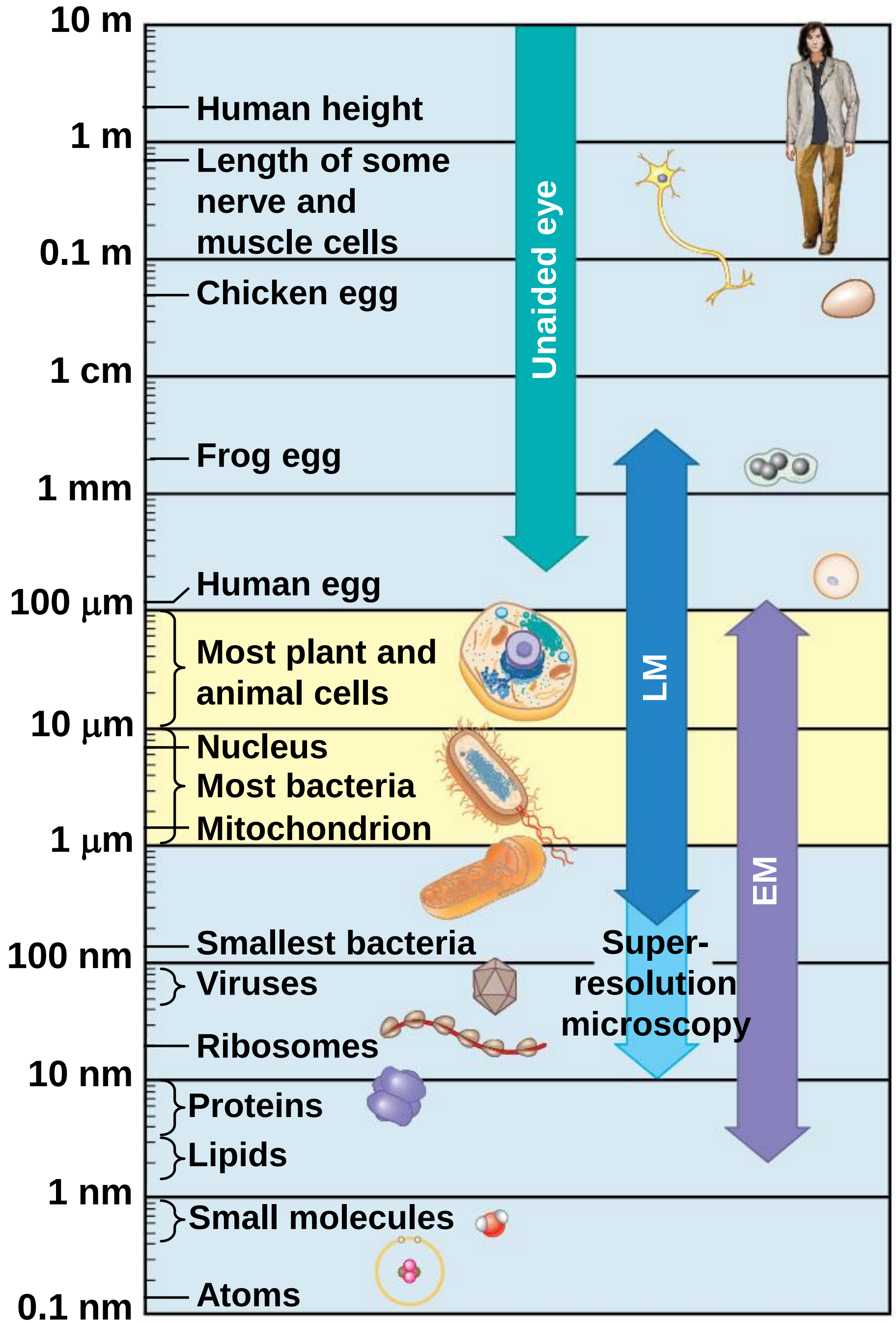
Figure 4.2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Lipids
Small molecules
Atoms
Unaided eye
LM
EM
Super-resolution microscopy

- 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, producing images that look three-dimensional
- **Transmission electron microscopes** (**TEMs**) focus a beam of electrons through a specimen
- TEM is used mainly to study the internal structure of cells

Figure 4.3

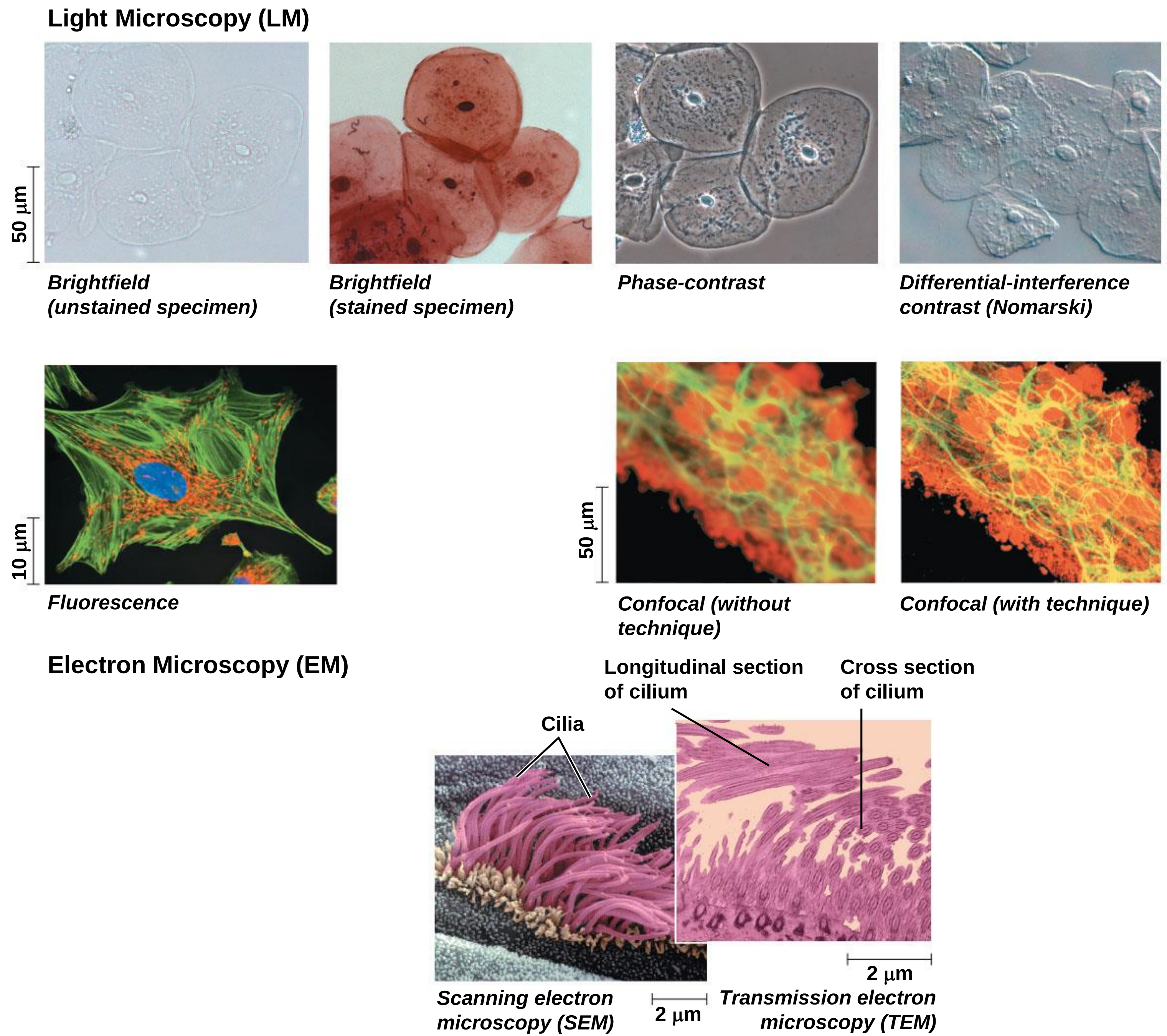
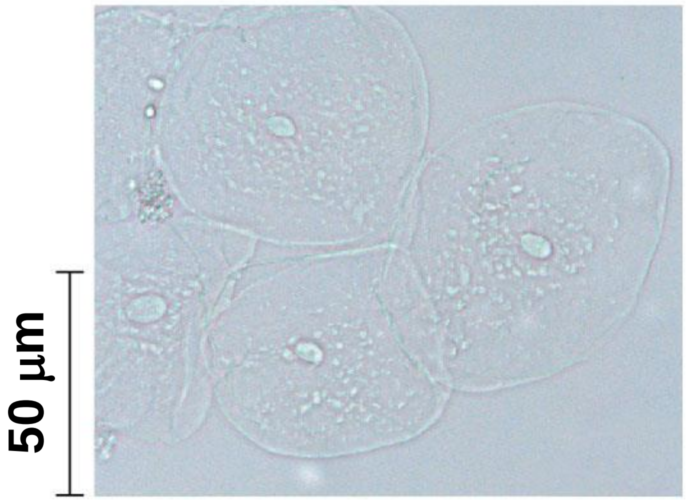
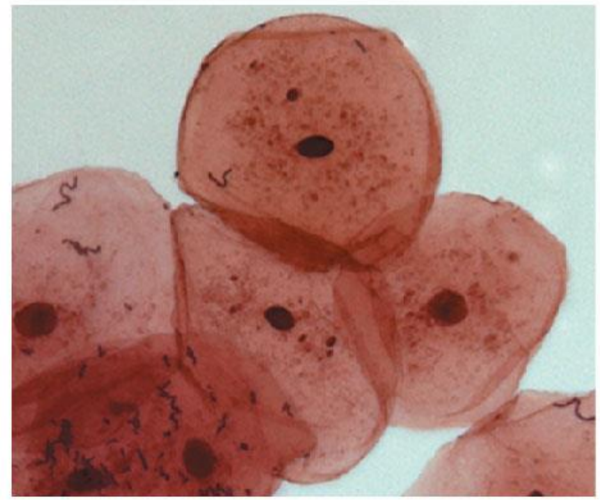

Light Microscopy (LM)
50 µm
Brightfield
(unstained specimen)
Brightfield
(stained specimen)
Phase-contrast
Differential-interference
contrast (Nomarski)
10 µm
Fluorescence
50 µm
Confocal (without
technique)
Confocal (with technique)
Electron Microscopy (EM)
Longitudinal section
of cilium
Cross section
of cilium
Cilia
2 µm
2 µm
Scanning electron
microscopy (SEM)
Transmission electron
microscopy (TEM)

Figure 4.3-1

Light Microscopy (LM)

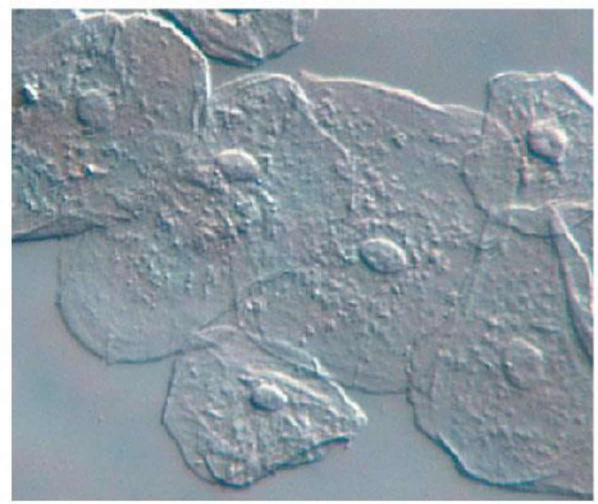


Brightfield (unstained specimen)



Brightfield (stained specimen)

Phase-contrast

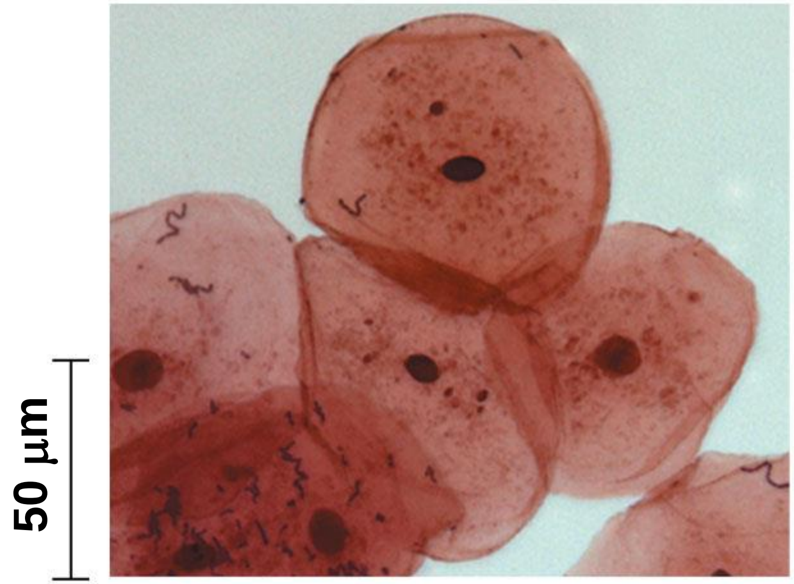


Differential-interference contrast (Nomarski)

Figure 4.3-1a

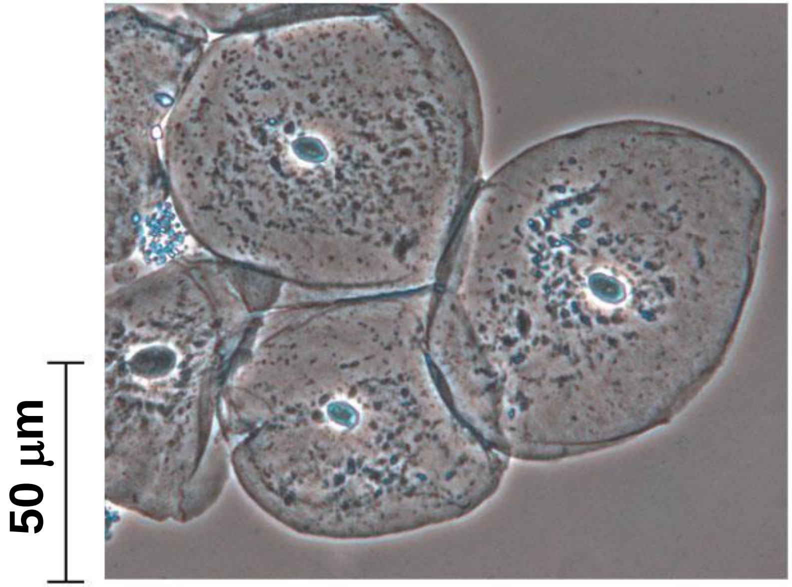
Brightfield (unstained specimen)

Figure 4.3-1b

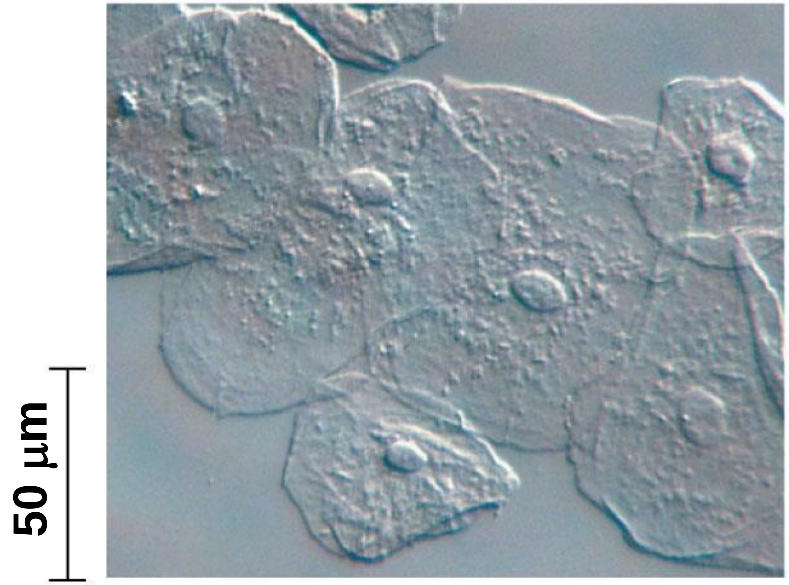


Brightfield
(stained specimen)

Figure 4.3-1c

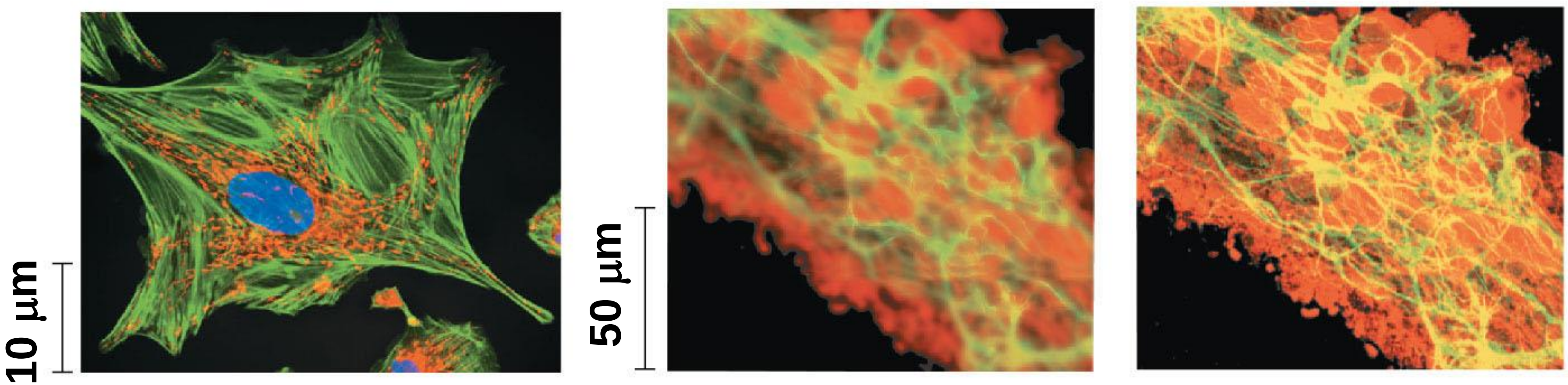


Phase-contrast



Differential-interference contrast (Nomarski)

Light Microscopy (LM)

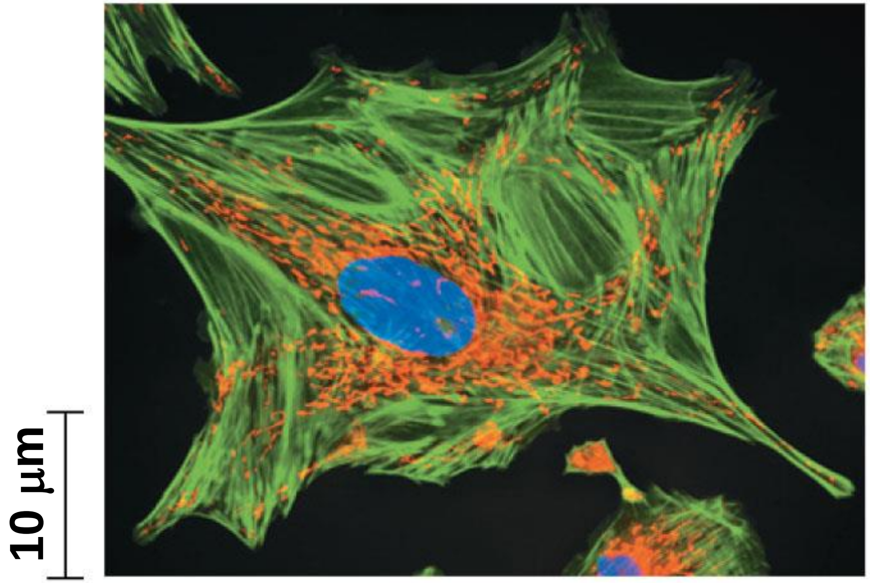


Fluorescence

Confocal (without technique)

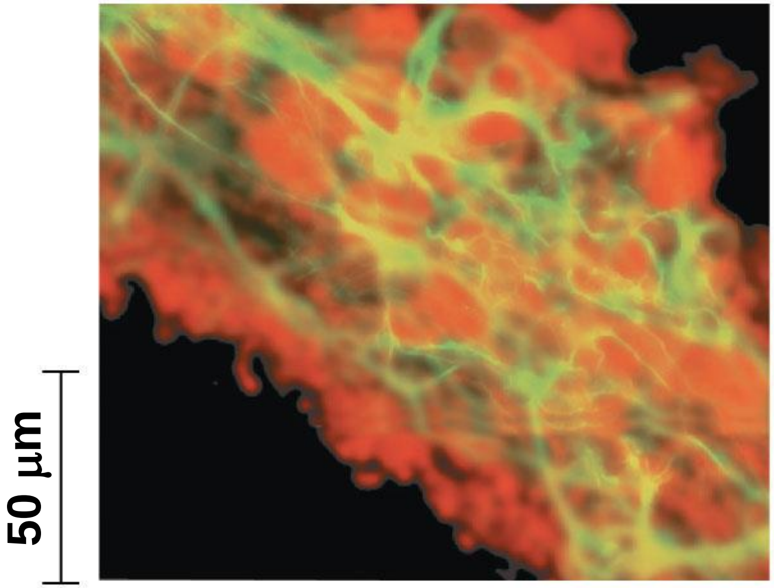
Confocal (with technique)

Figure 4.3-2a

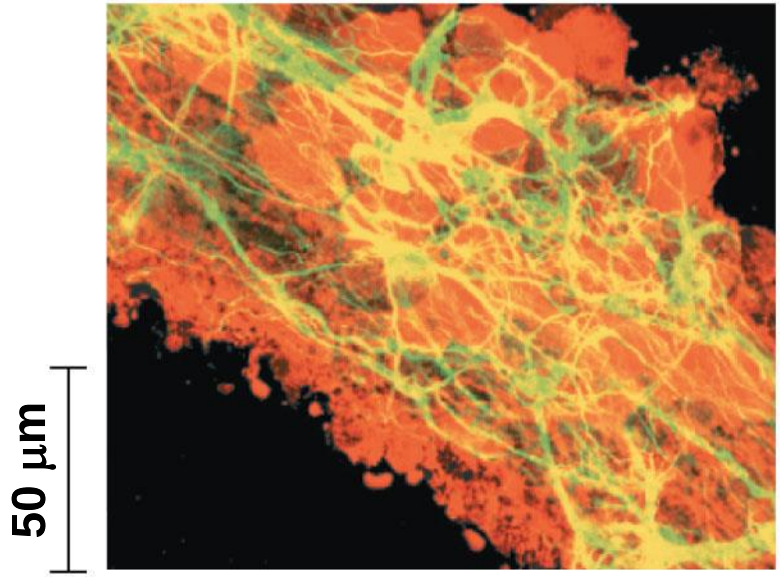


Fluorescence

Figure 4.3-2b

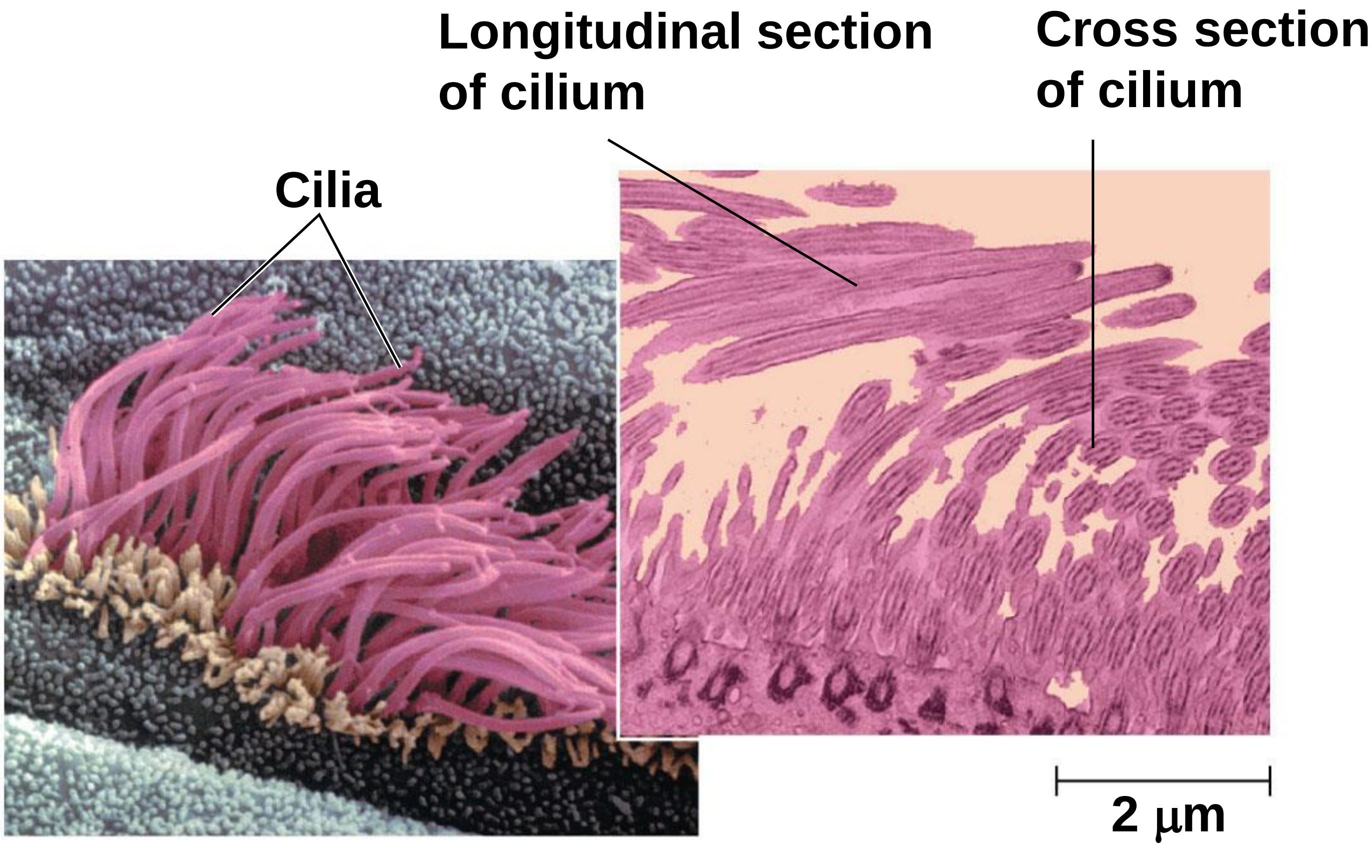


Confocal (without technique)



Confocal (with technique)

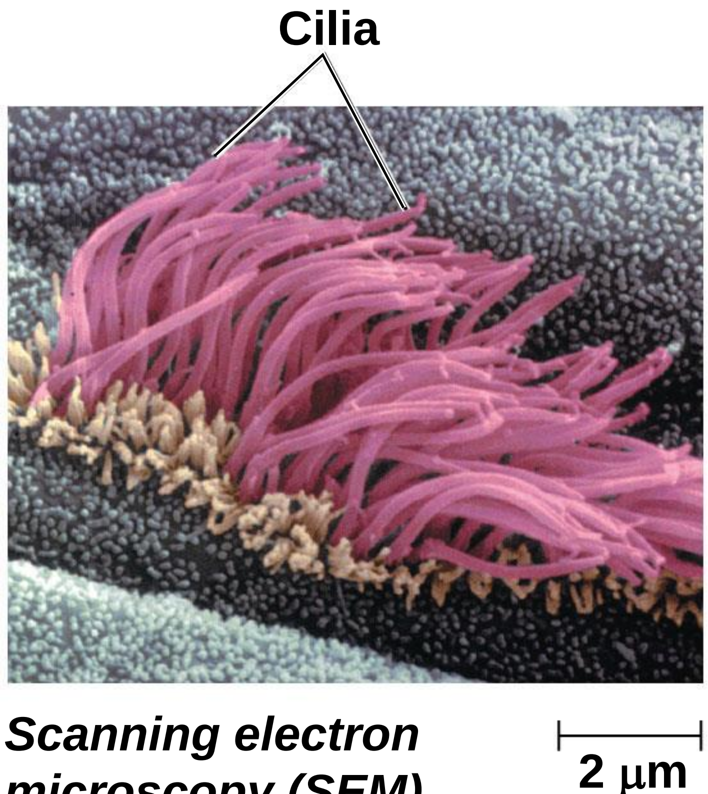
Electron Microscopy (EM)



Scanning electron microscopy (SEM)

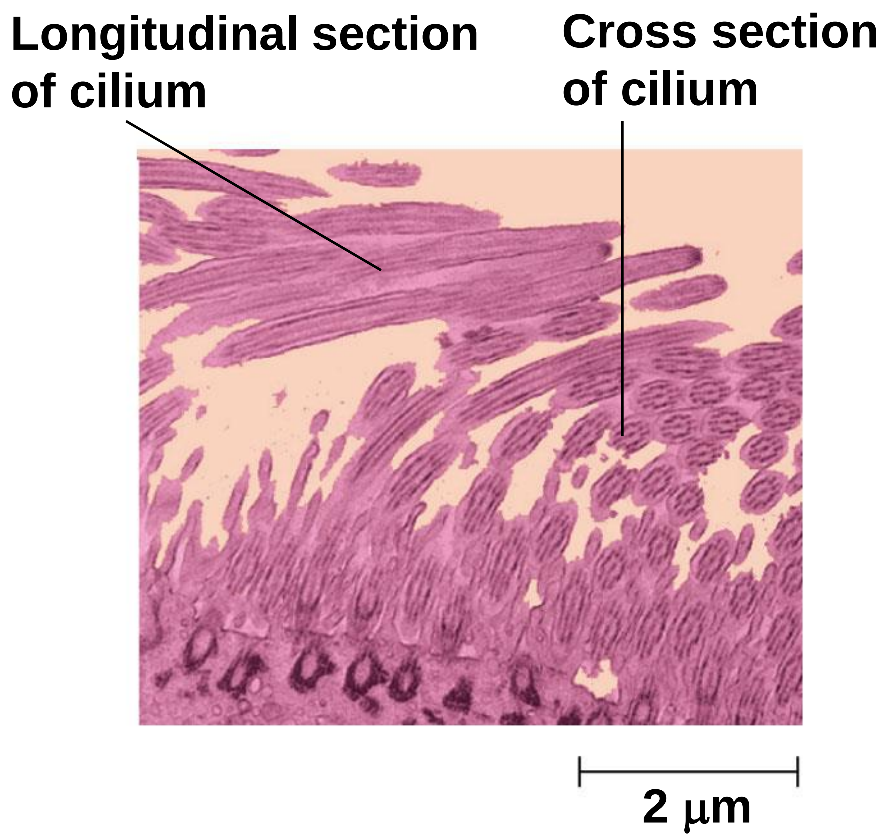
Transmission electron microscopy (TEM)

Figure 4.3-3a



Scanning electron microscopy (SEM)

Figure 4.3-3b



Transmission electron microscopy (TEM)

- Recent advances in light microscopy
  - Labeling molecules or structures with fluorescent markers improves visualization of details
  - Confocal and other types of microscopy have sharpened images of tissues and cells
  - New techniques and labeling have improved resolution so that structures as small as 10–20 μm can be distinguished

Cell Fractionation

- **Cell fractionation** breaks up cells and separates the components, using centrifugation
- Cell components separate based on their relative size
- Cell fractionation enables scientists to determine the functions of organelles
- Biochemistry and cytology help correlate cell function with structure

Concept 4.2: Eukaryotic cells have internal membranes that compartmentalize their functions

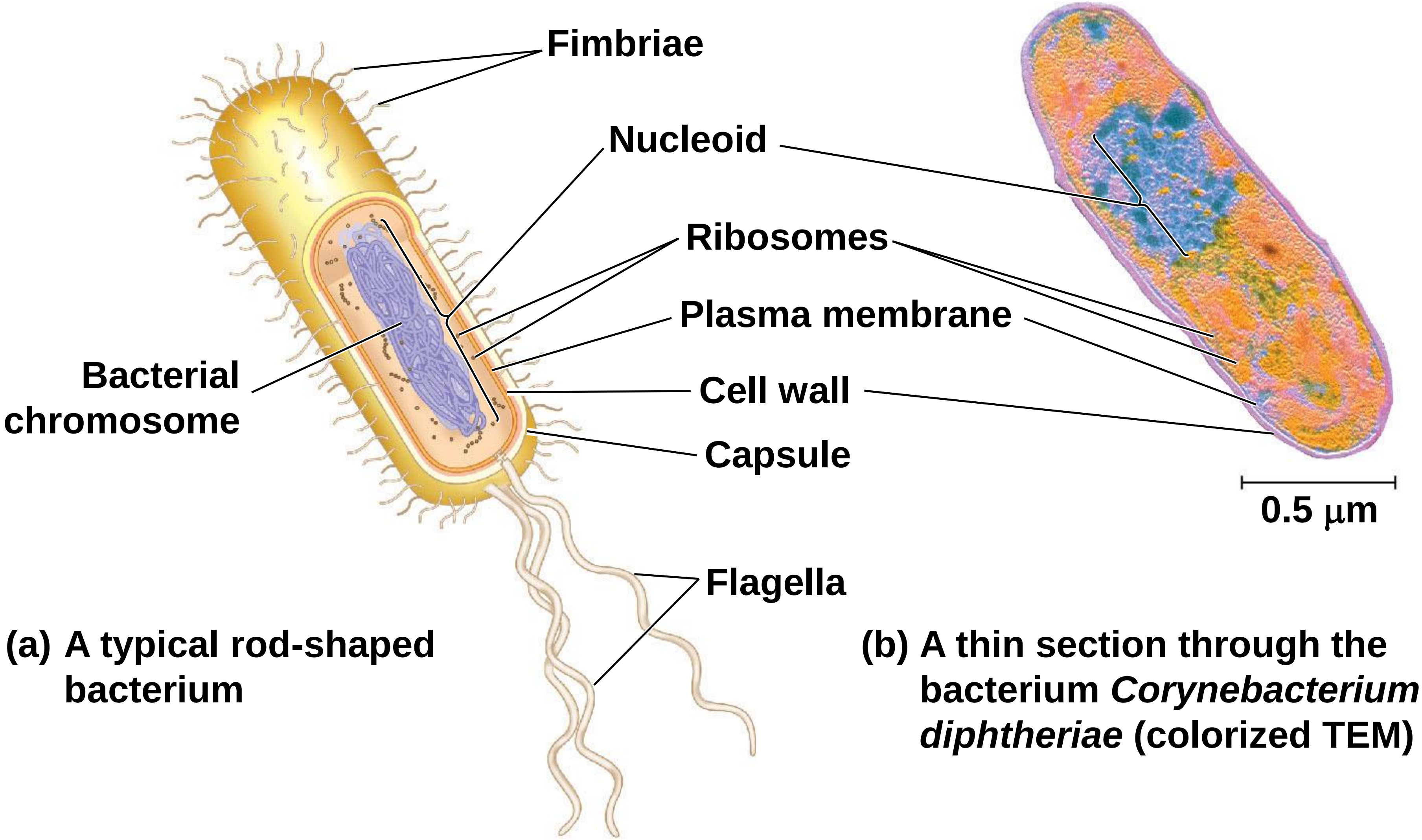
- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
- Organisms of the domains Bacteria and Archaea consist of prokaryotic cells
- Protists, fungi, animals, and plants all consist of eukaryotic cells

Comparing Prokaryotic and Eukaryotic Cells

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

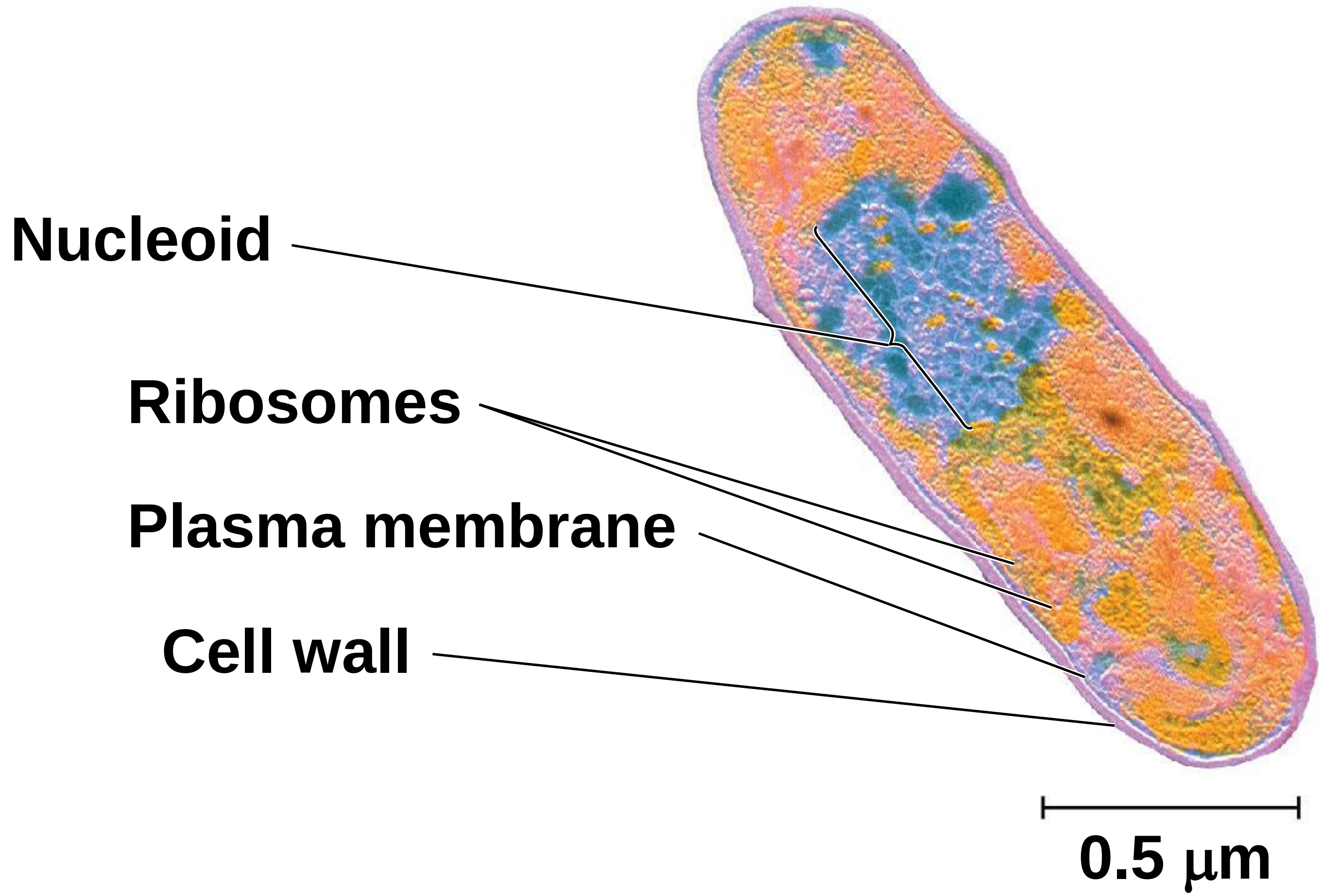
- In a **eukaryotic cell** most of the DNA is in the nucleus, an organelle that is bounded by a double membrane
- **Prokaryotic cells** are characterized by having
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
- Both types of cells contain **cytoplasm** bound by the plasma membrane

Figure 4.4



(a) A typical rod-shaped bacterium

(b) A thin section through the bacterium *Corynebacterium diphtheriae* (colorized TEM)



(b) A thin section through the bacterium *Corynebacterium diphtheria* (colorized TEM)

- Eukaryotic cells are generally much larger than prokaryotic cells
- Typical bacteria are 1–5 μm in diameter
- Eukaryotic cells are typically 10–100 μm in diameter

- 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

Figure 4.5

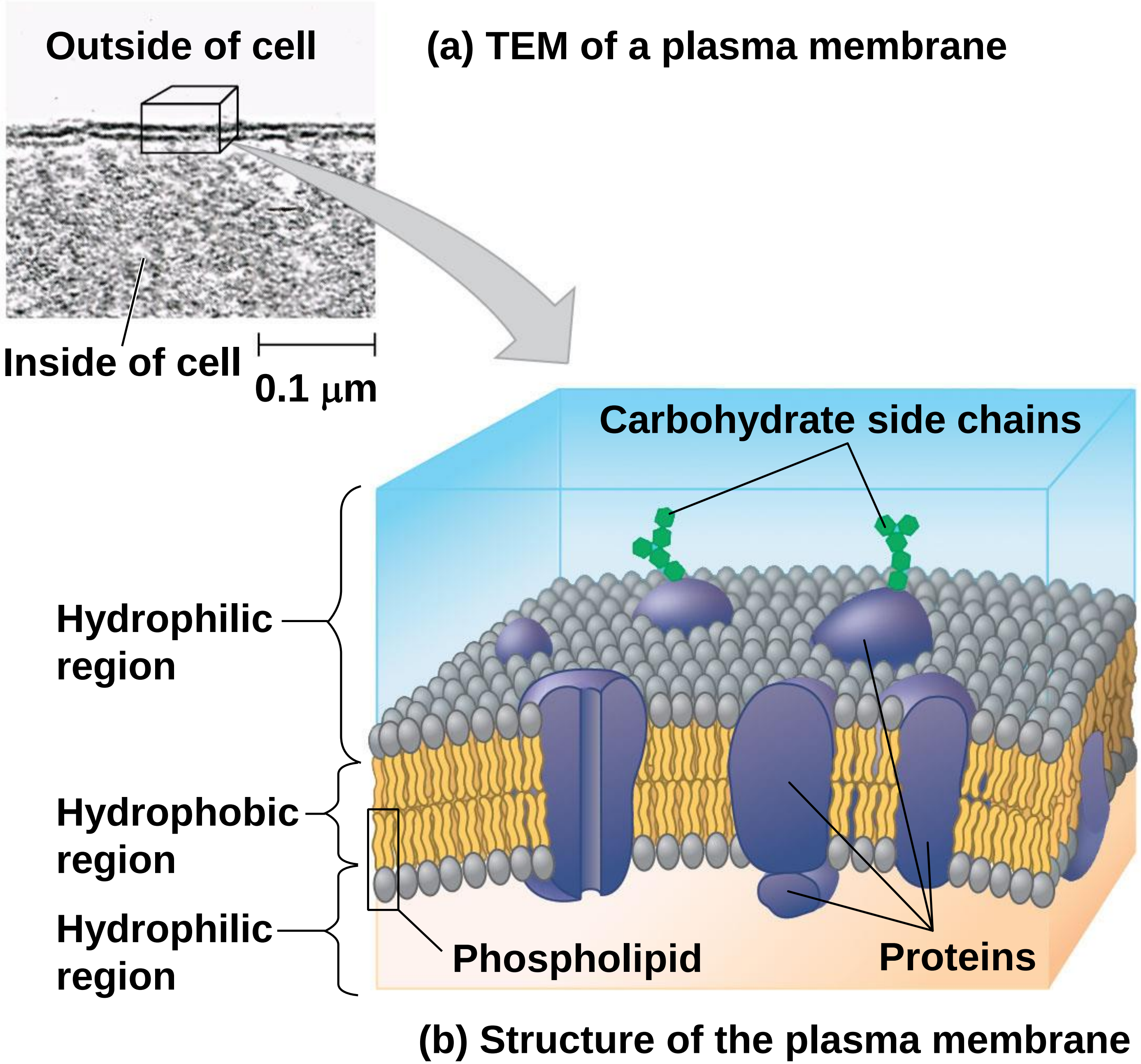
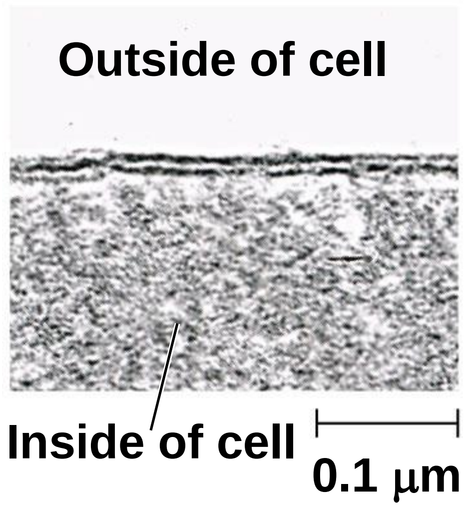

Outside of cell
(a) TEM of a plasma membrane
Inside of cell
0.1 μm
Carbohydrate side chains
Hydrophilic region
Hydrophobic region
Hydrophilic region
Phospholipid
Proteins
(b) Structure of the plasma membrane

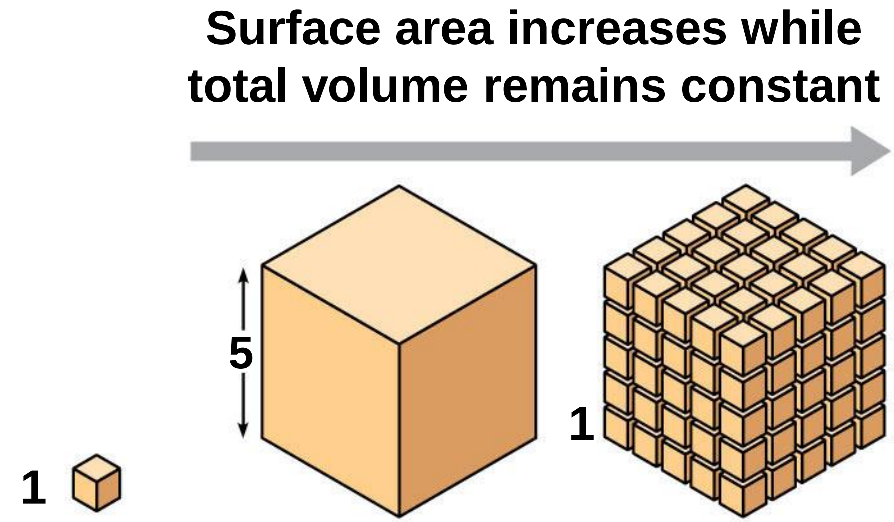
Figure 4.5-1



(a) TEM of a plasma membrane

- Metabolic requirements set upper limits on the size of cells
- The ratio of surface area to volume 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

Figure 4.6



Total surface area [sum of the surface areas (height × width) of all box 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 divide the cell into compartments—organelles
- The plasma membrane and organelle membranes participate directly in the cell’s metabolism

Animation: Tour of an Animal Cell

Animation: Tour of a Plant Cell

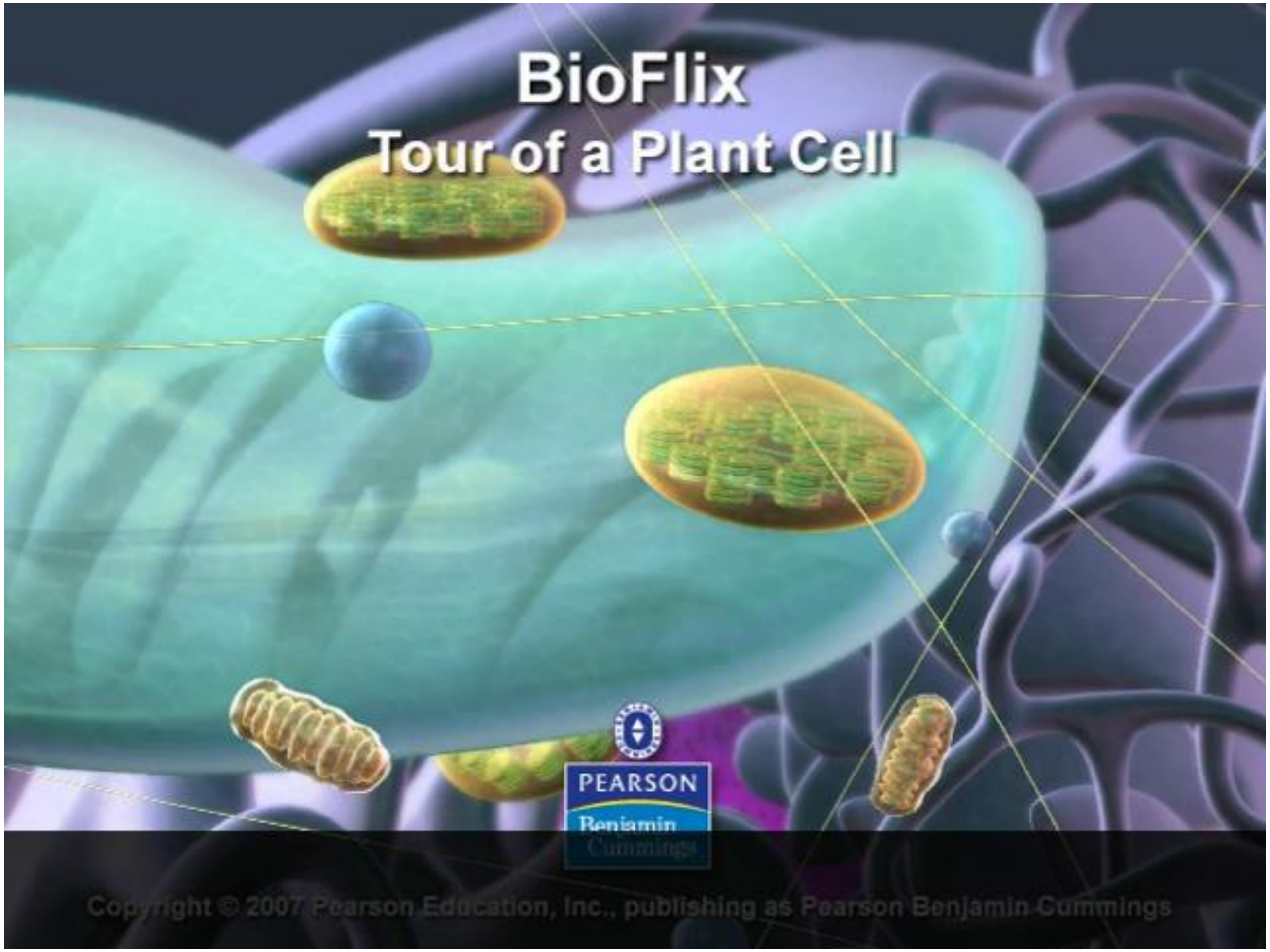


Figure 4.7-1

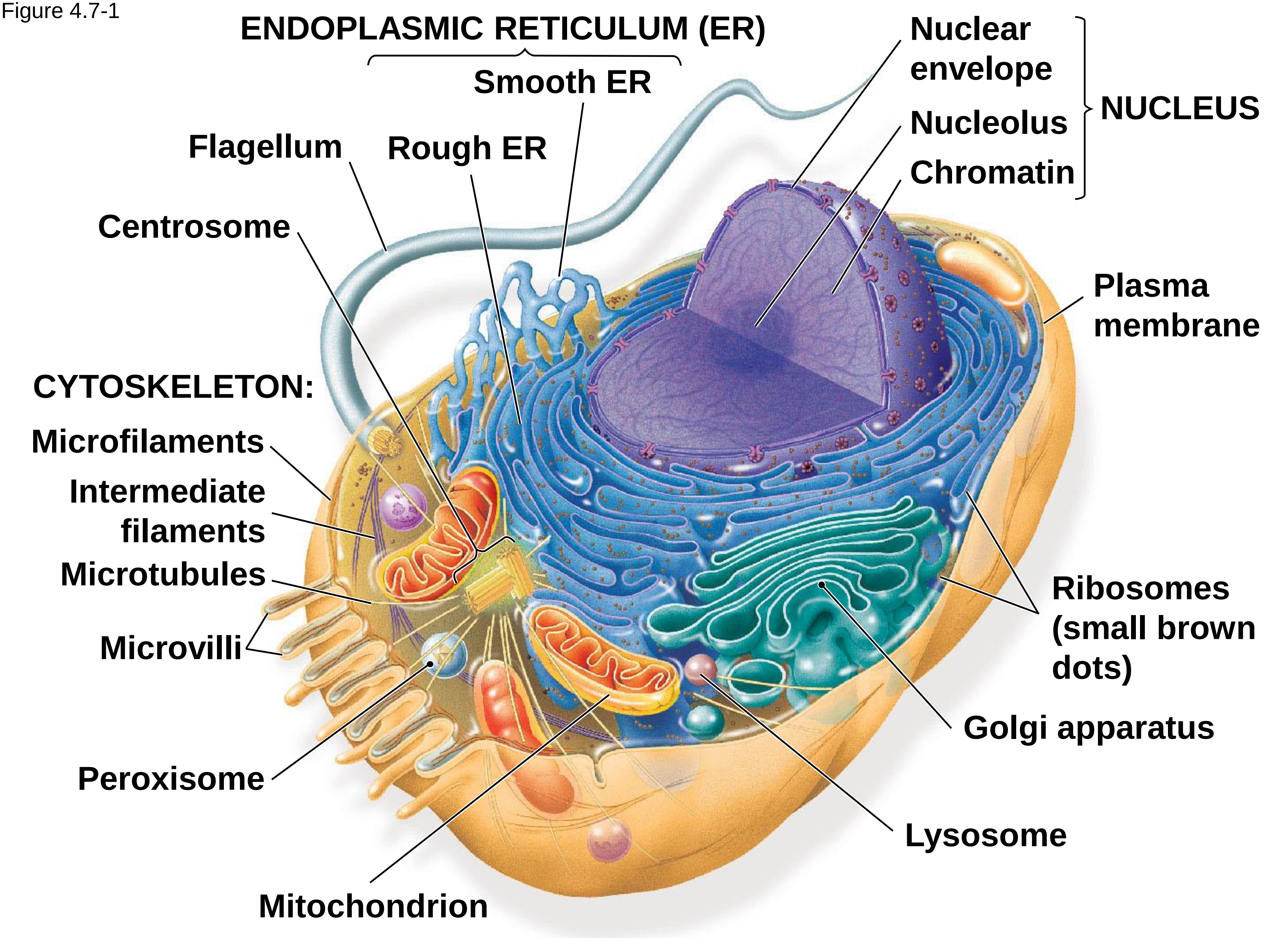
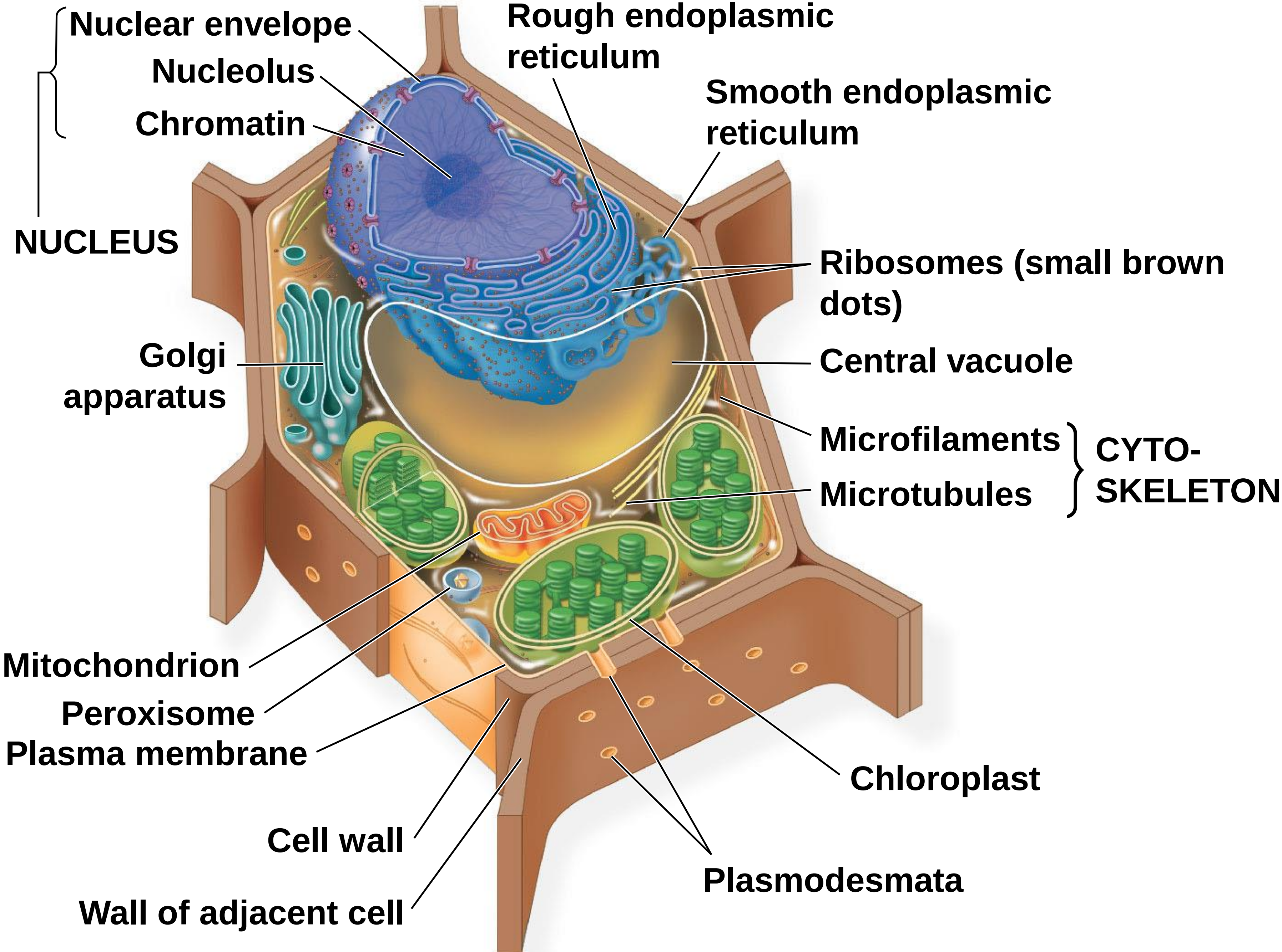
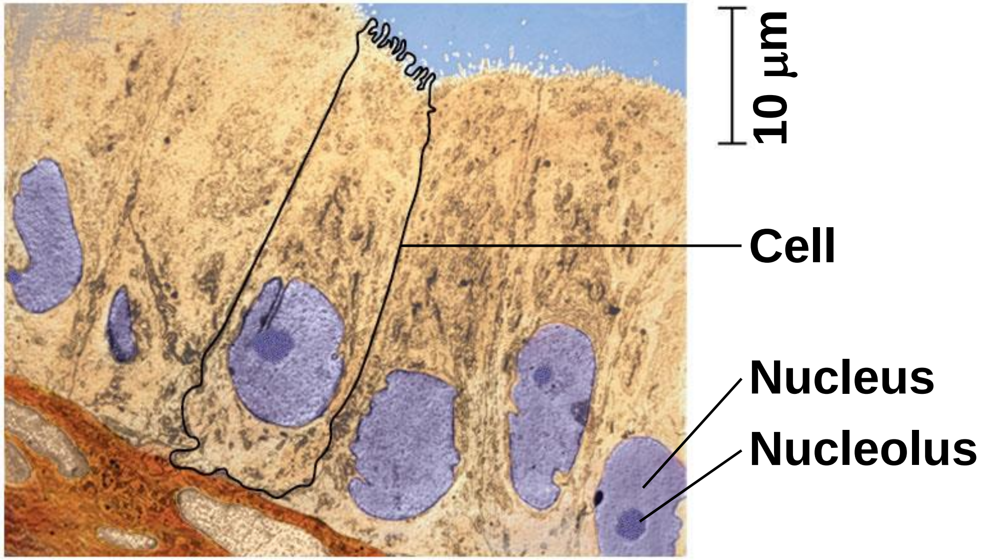

ENDOPLASMIC RETICULUM (ER)
Smooth ER
Rough ER
Flagellum
Centrosome
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Microvilli
Peroxisome
Mitochondrion
Nuclear envelope
Nucleolus
Chromatin
NUCLEUS
Plasma membrane
Ribosomes (small brown dots)
Golgi apparatus
Lysosome

Figure 4.7-2

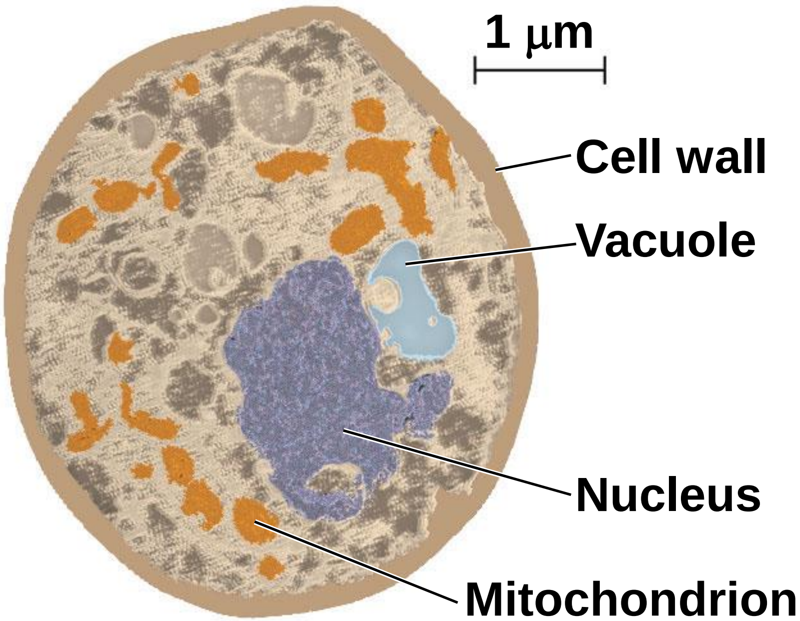

Nuclear envelope
Nucleolus
Chromatin
NUCLEUS
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Ribosomes (small brown dots)
Golgi apparatus
Central vacuole
Microfilaments
Microtubules
CYTO-SKELETON
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Chloroplast
Plasmodesmata



Human cells from lining of uterus
(colorized TEM)

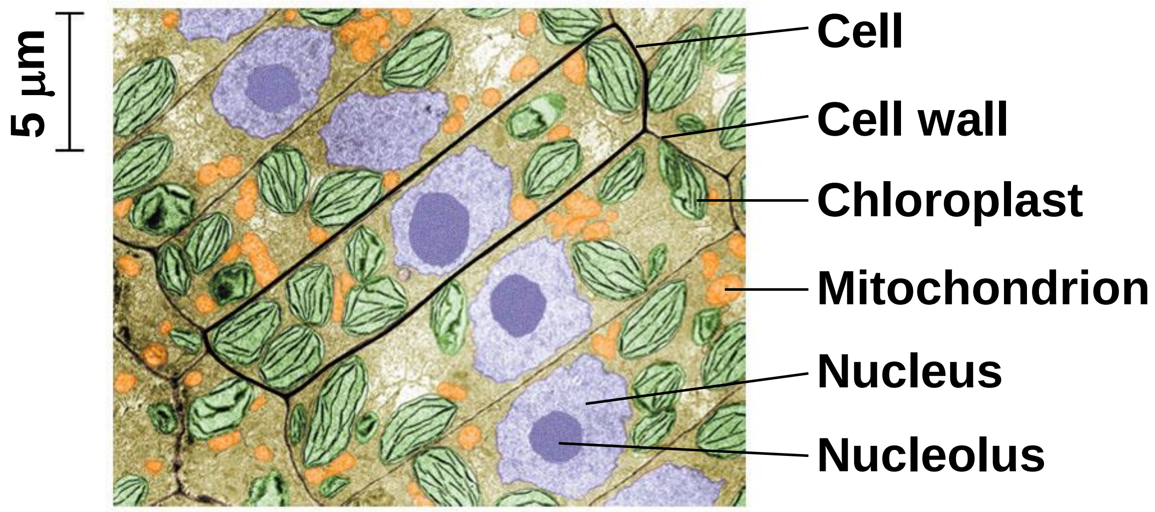
Figure 4.7-4

Yeast cells budding (colorized SEM)



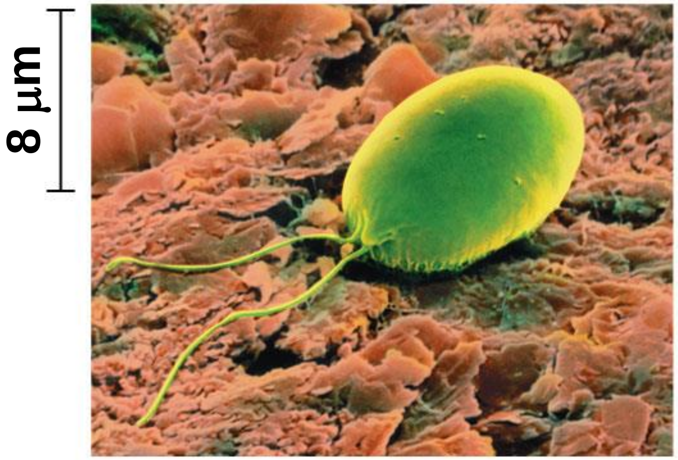
A single yeast cell
(colorized TEM)

Figure 4.7-6



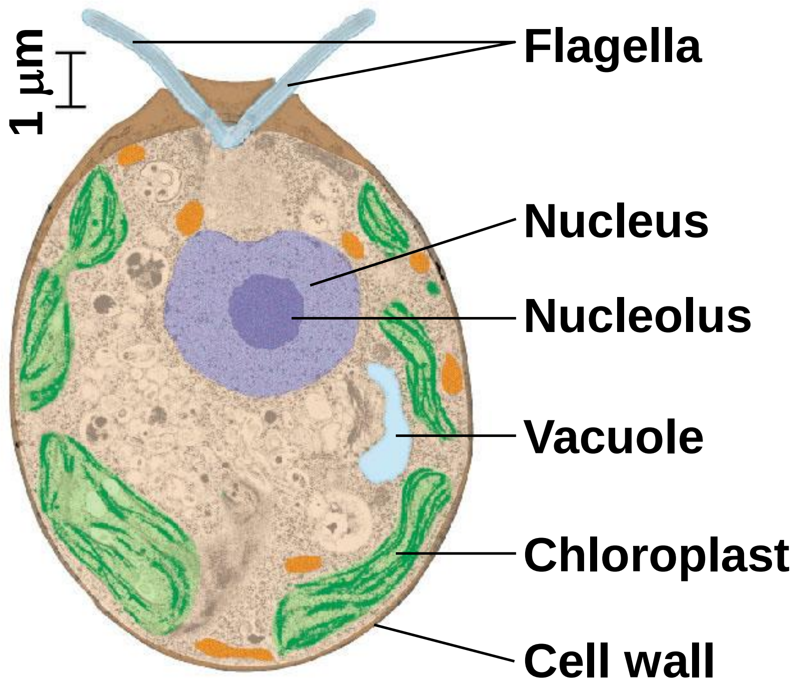
Cells from duckweed
(colorized TEM)

Figure 4.7-7



Chlamydomonas
(colorized SEM)

Figure 4.7-8



Chlamydomonas
(colorized TEM)

Concept 4.3: 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

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

Figure 4.8

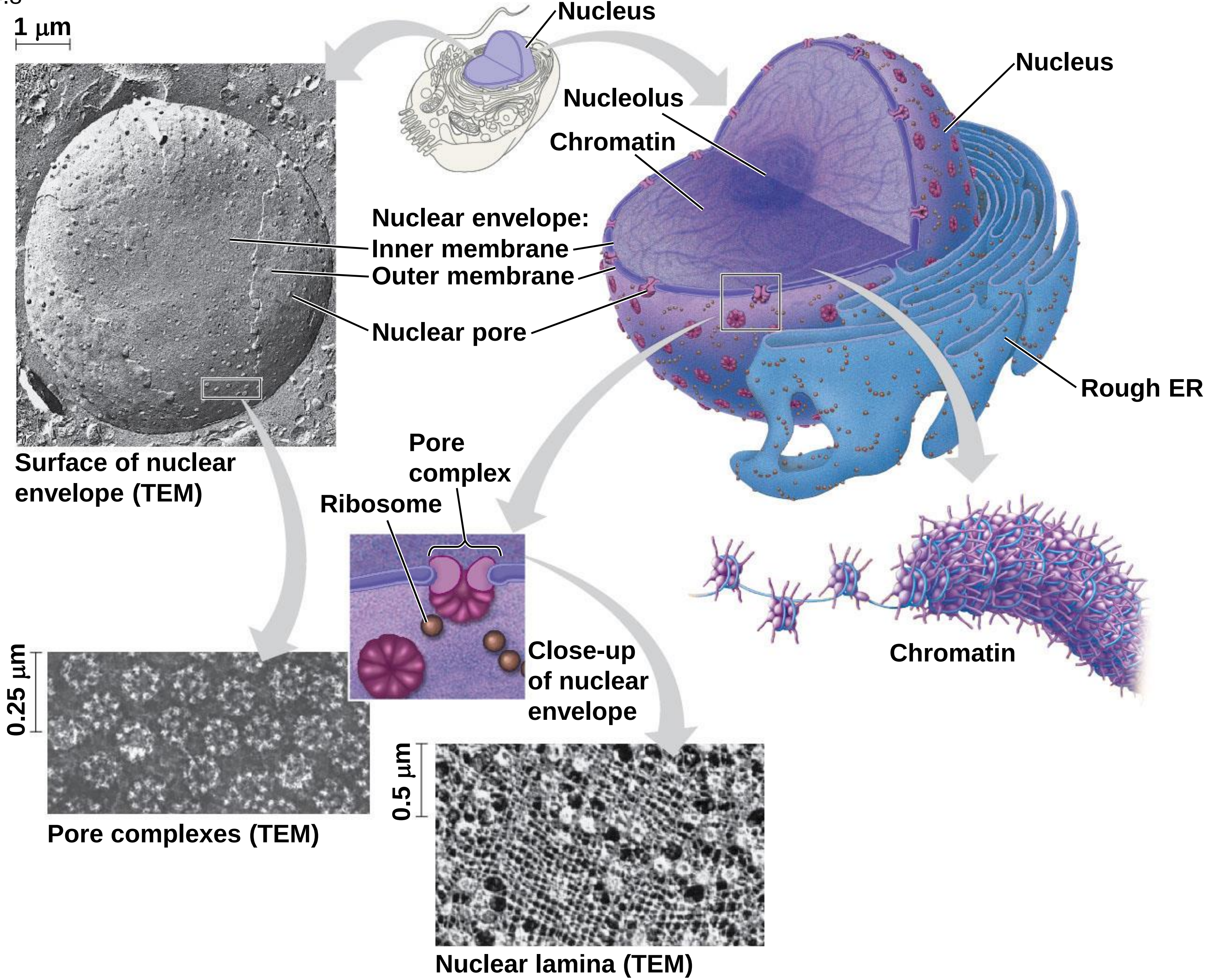
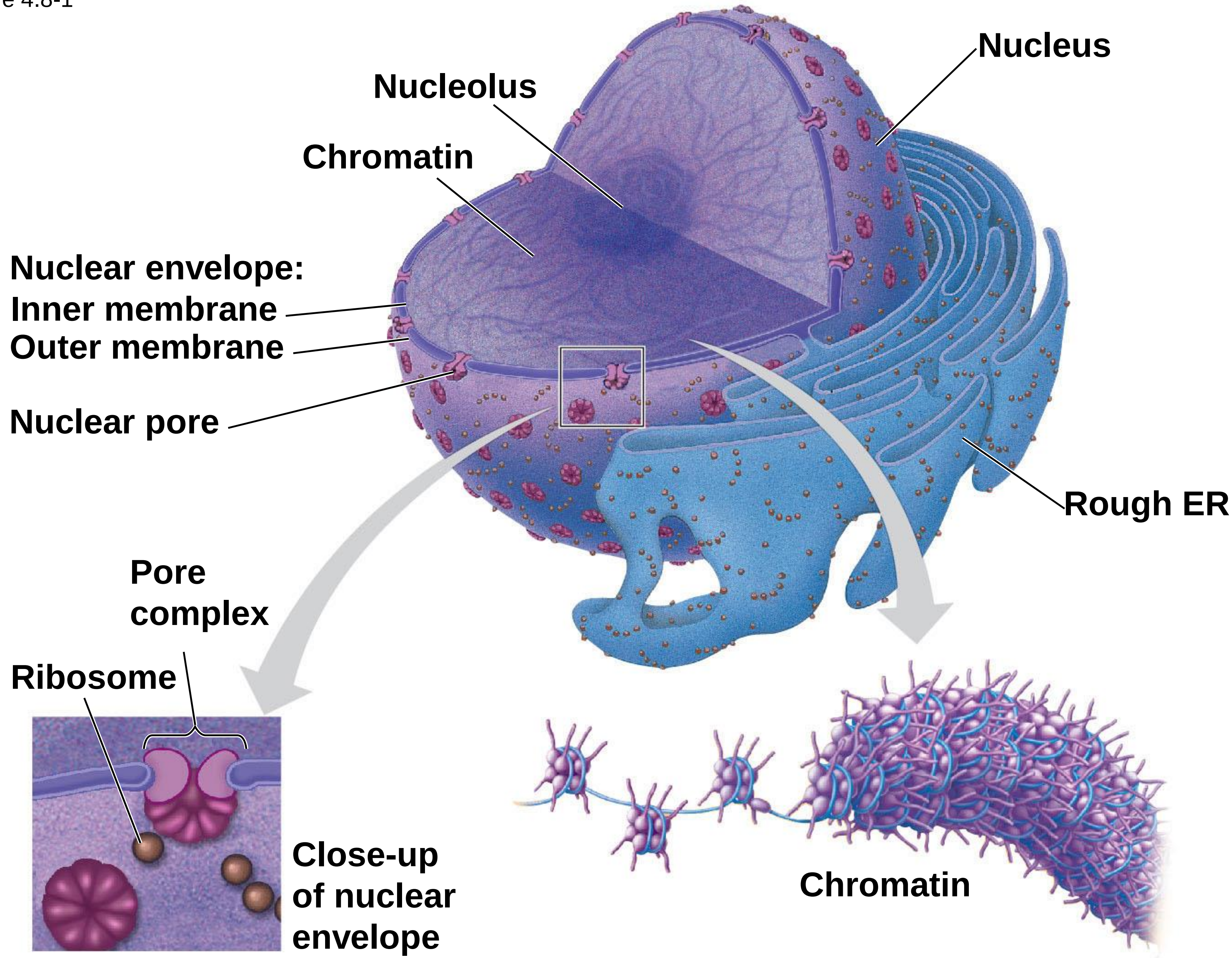

1 μm
Nucleus
Nucleus
Nucleolus
Chromatin
Nuclear envelope:
Inner membrane
Outer membrane
Nuclear pore
Rough ER
Surface of nuclear envelope (TEM)
Pore complex
Ribosome
Chromatin
0.25 μm
Close-up of nuclear envelope
0.5 μm
Pore complexes (TEM)
Nuclear lamina (TEM)

Figure 4.8-1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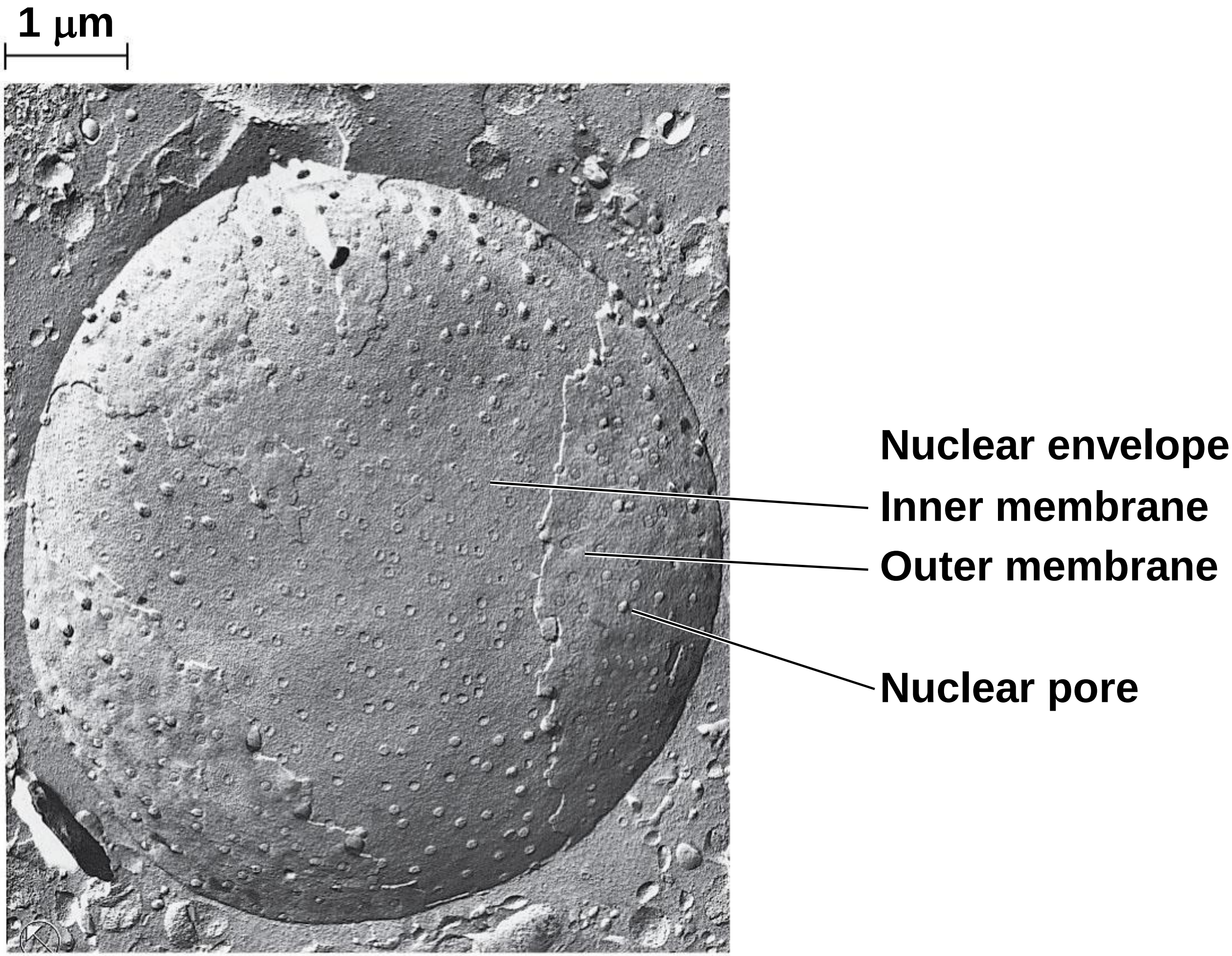
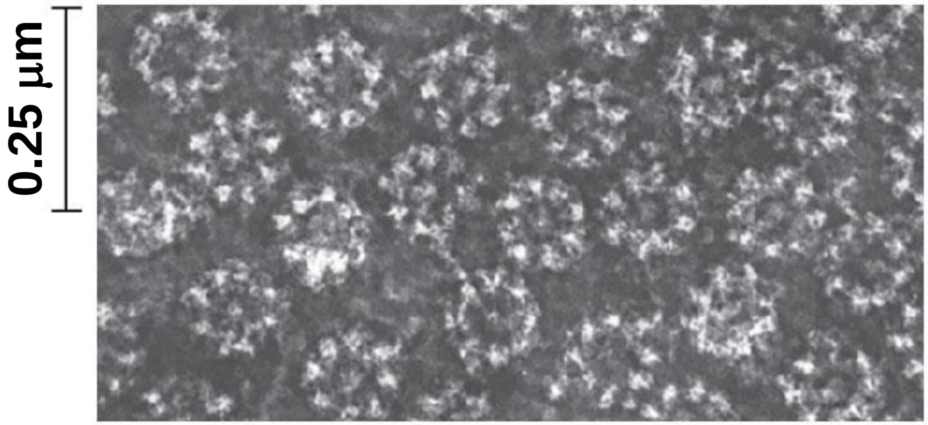
Nucleolus
Chromatin
Nuclear envelope:
Inner membrane
Outer membrane
Nuclear pore
Rough ER
Pore complex
Ribosome
Close-up of nuclear envelope
Chromatin

Figure 4.8-2



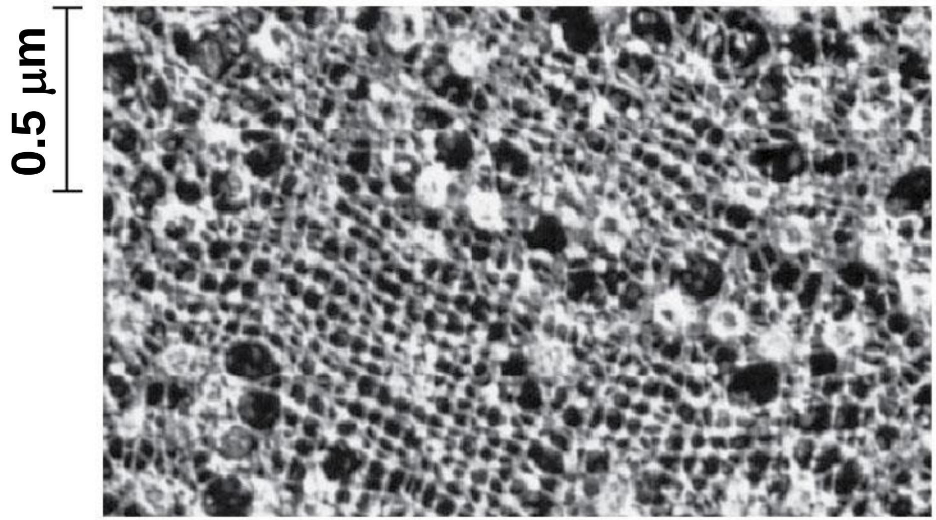
Surface of nuclear envelope (TEM)

Figure 4.8-3



Pore complexes (TEM)

Figure 4.8-4



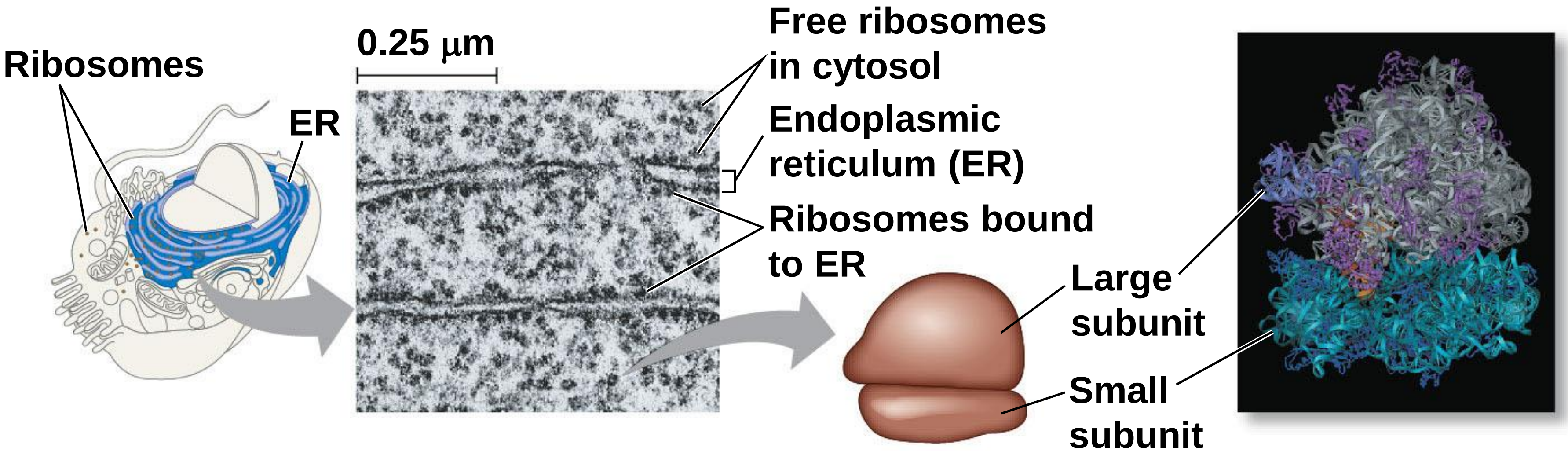
Nuclear lamina (TEM)

- In the nucleus, DNA is organized into discrete units called **chromosomes**
- Each chromosome is one long DNA molecule associated with proteins
- The DNA and proteins of chromosomes together are called **chromatin**
- Chromatin condenses to form discrete chromosomes as a cell prepares to divide
- The **nucleolus** is located within the nucleus and is the site of ribosomal RNA (rRNA) synthesis

Ribosomes: Protein Factories

- **Ribosomes** are complexes 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)

Figure 4.9

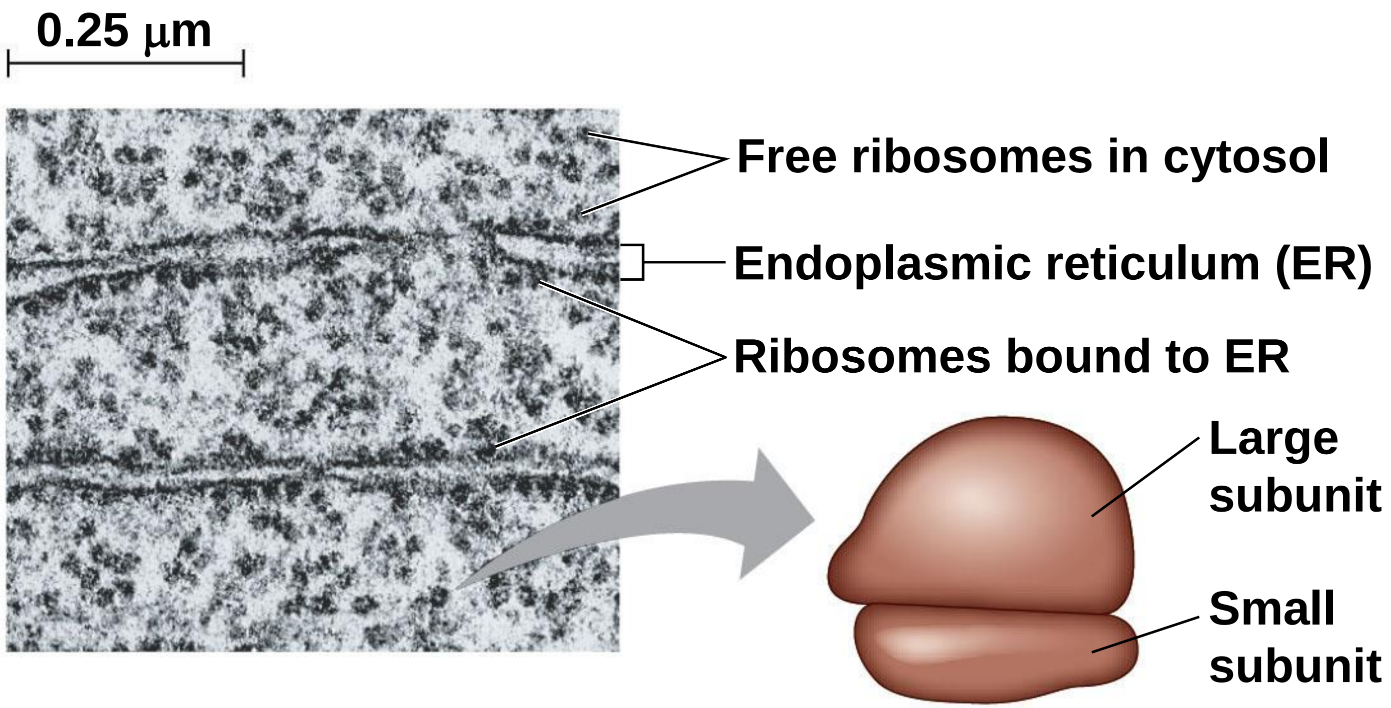


TEM showing ER and ribosomes

Diagram of a ribosome

Computer model of a ribosome

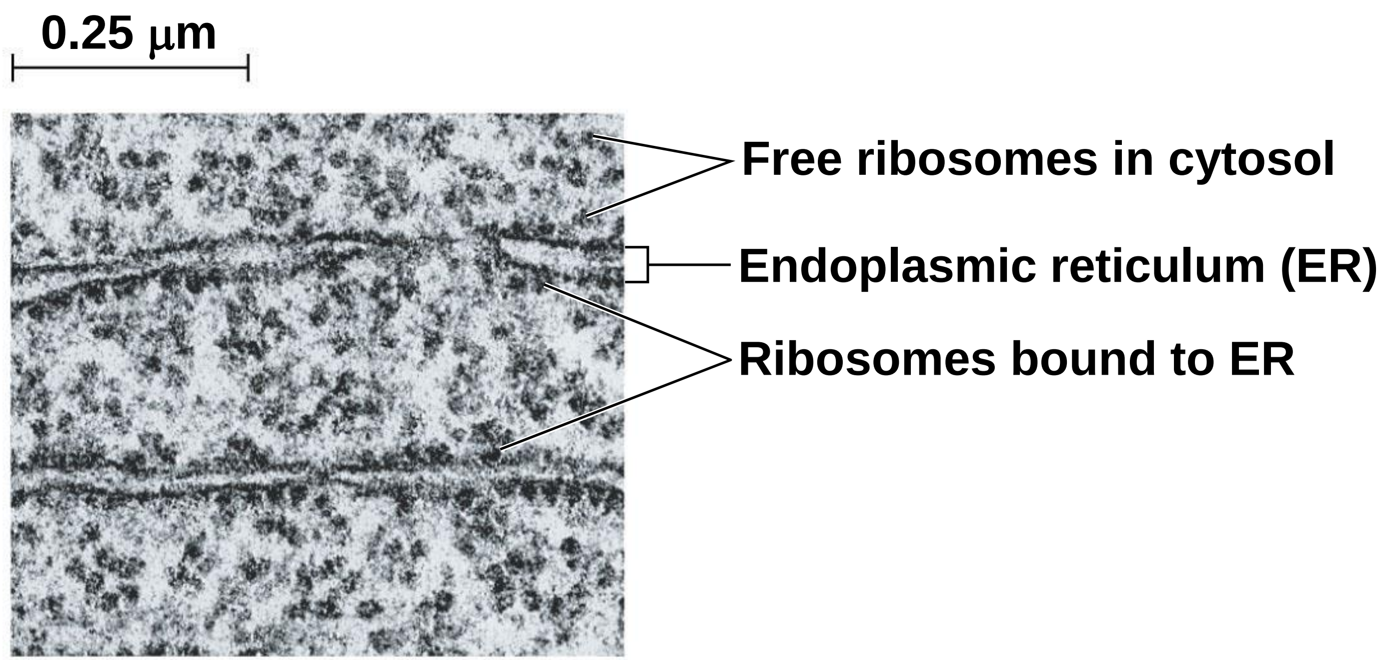
Figure 4.9-1



TEM showing ER and ribosomes

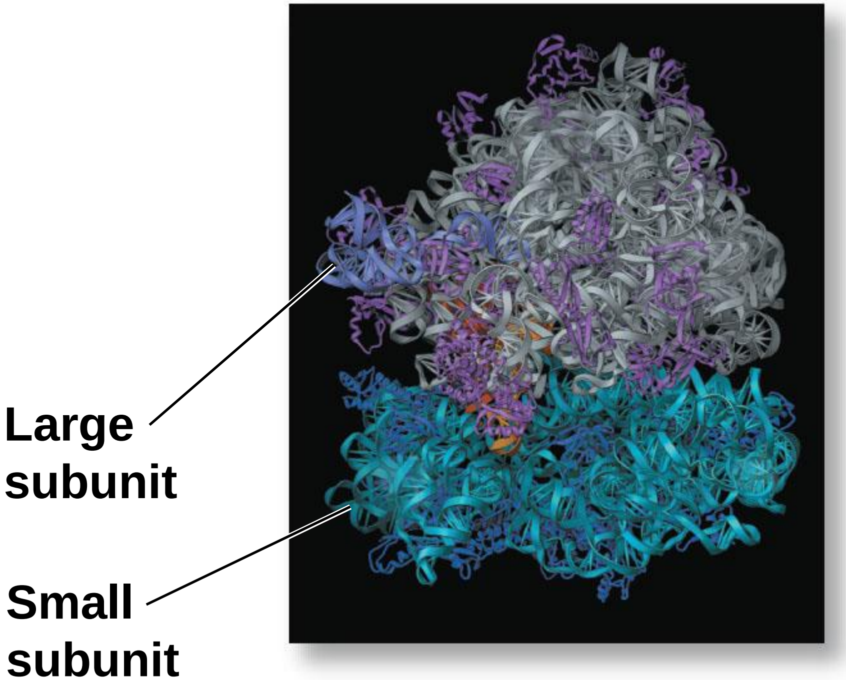
Diagram of a ribosome

Figure 4.9-1a



TEM showing ER and ribosomes

Figure 4.9-2



Computer model of a ribosome

Concept 4.4: 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 through 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**: lacks ribosomes
  - **Rough ER**: surface is studded with ribosomes

Video: Endoplasmic Reticulum

Video: ER and Mitochondria

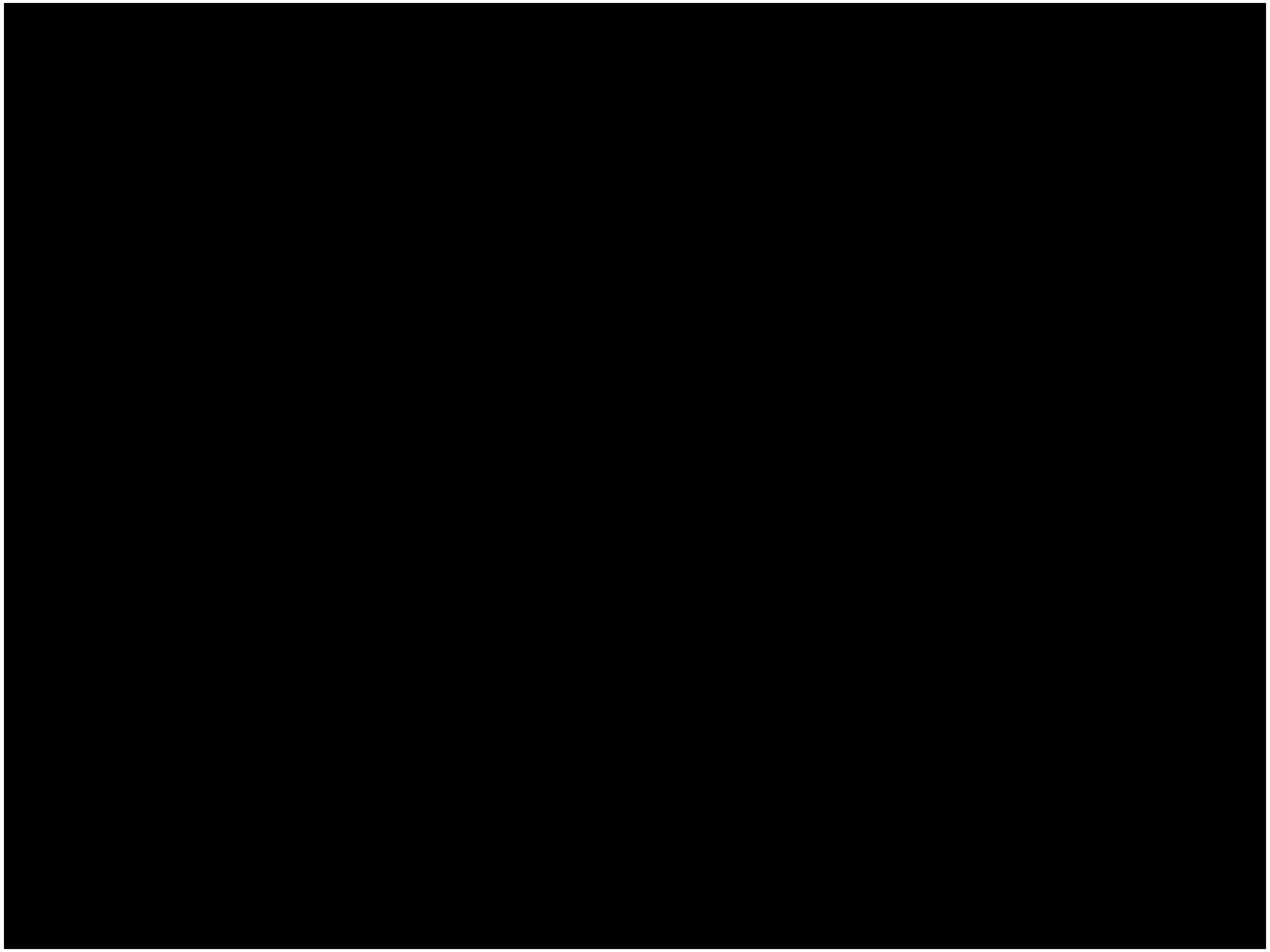
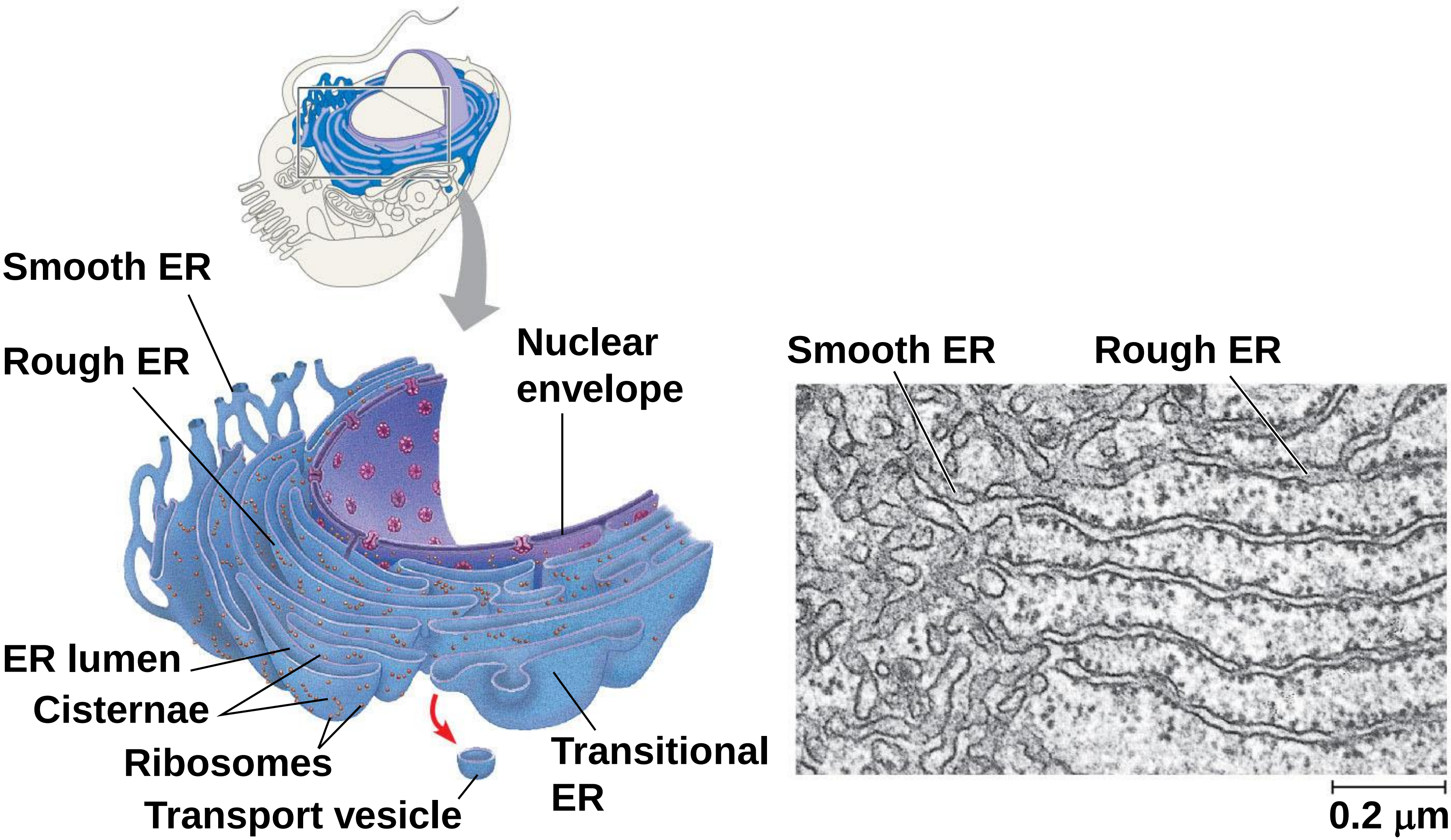
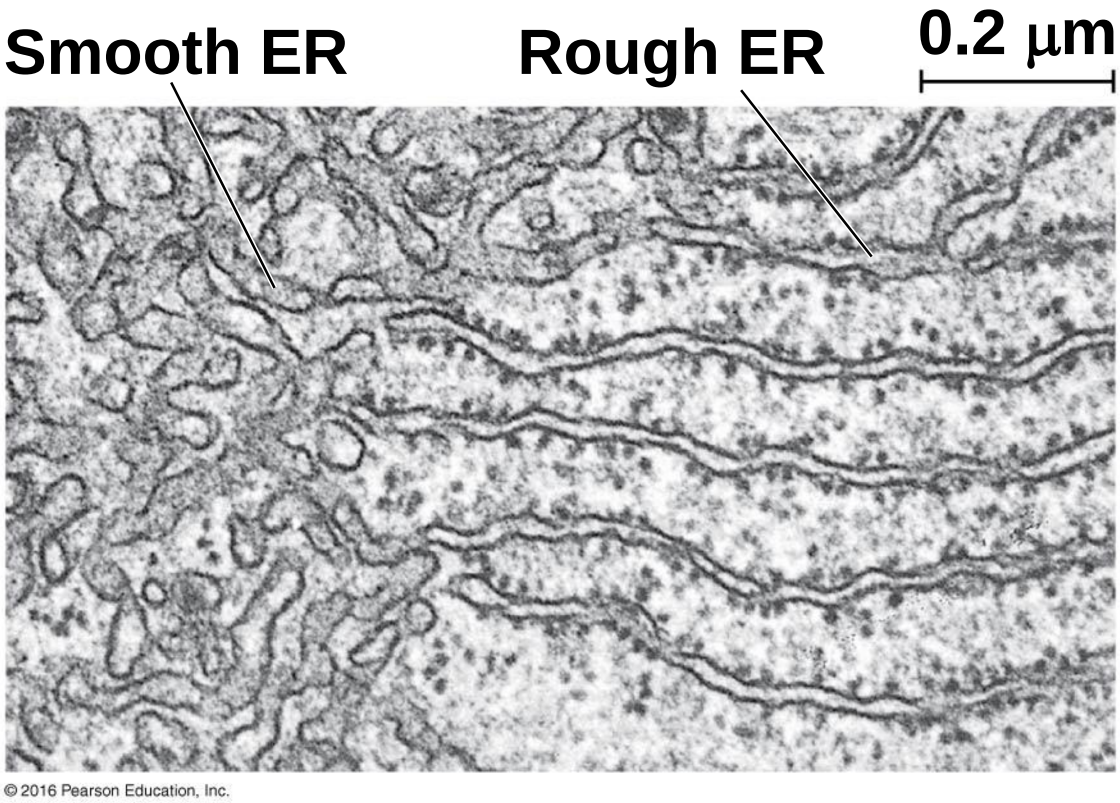


Figure 4.10



Smooth ER
Rough ER
Nuclear envelope
ER lumen
Cisternae
Ribosomes
Transport vesicle
Transitional ER
Smooth ER
Rough ER
0.2 μm

Figure 4.10-1



Functions of Smooth ER

- The smooth ER
  - Synthesizes lipids
  - Metabolizes carbohydrates
  - Detoxifies drugs and poisons
  - Stores calcium ions

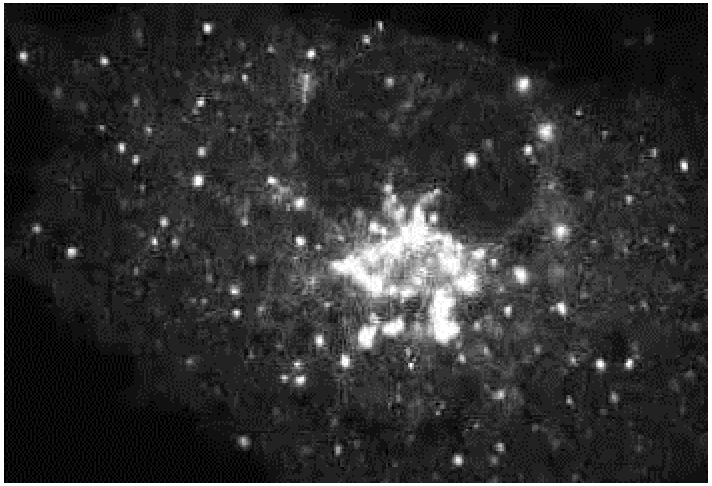
Functions of Rough ER

- 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

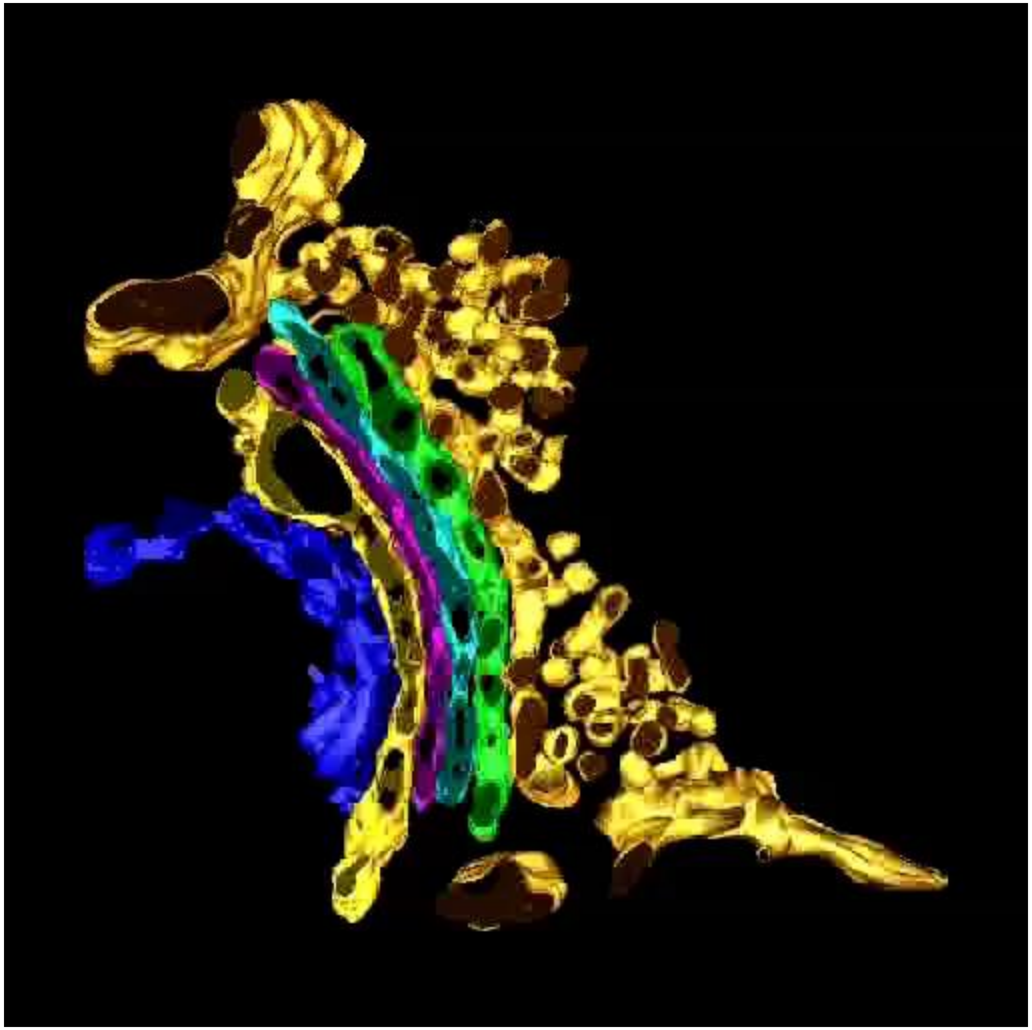
The Golgi Apparatus: Shipping and Receiving Center

- 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

Video: ER to Golgi Traffic



Video: Golgi 3-D



Video: Golgi Secretion

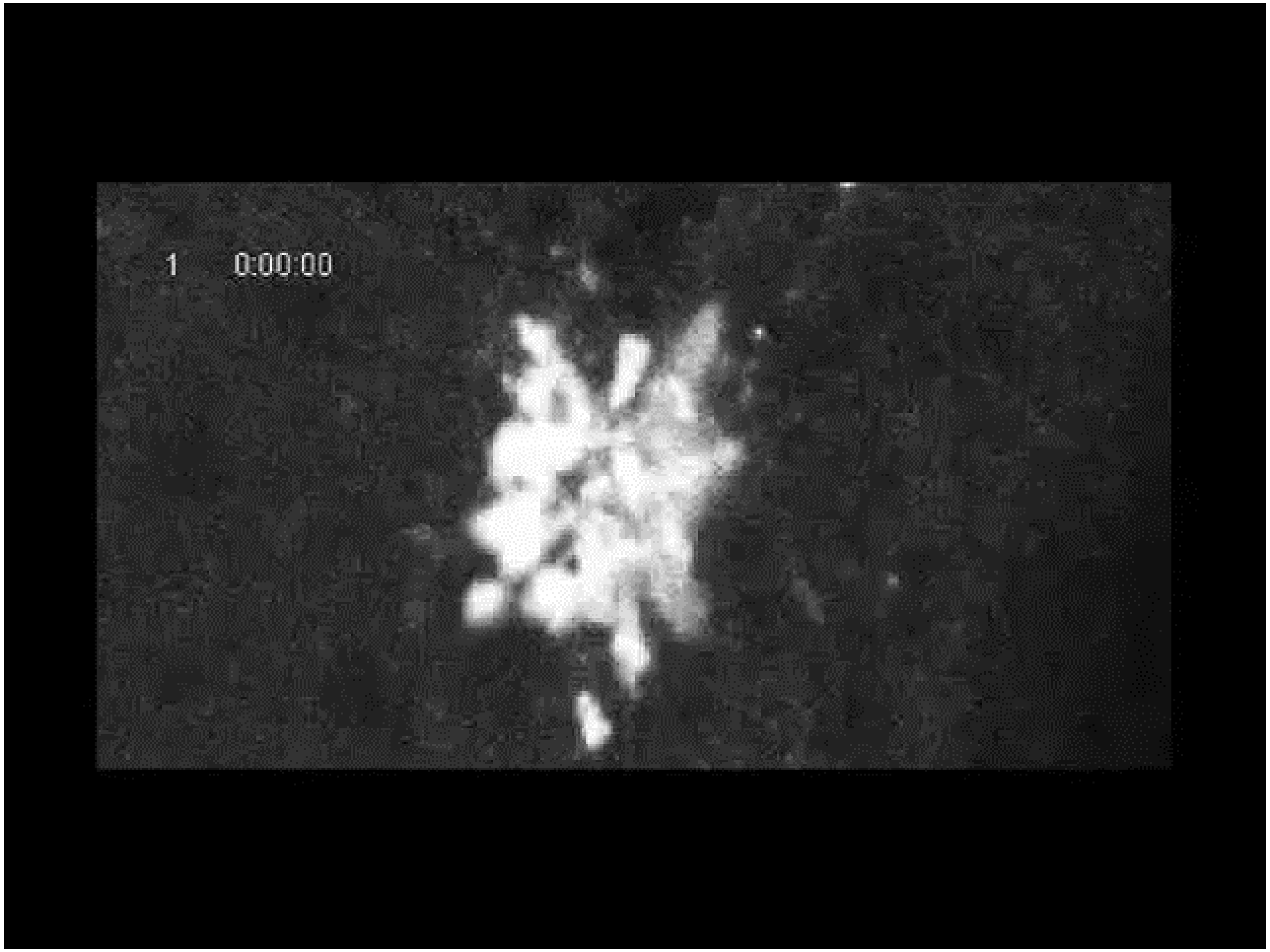


Figure 4.11

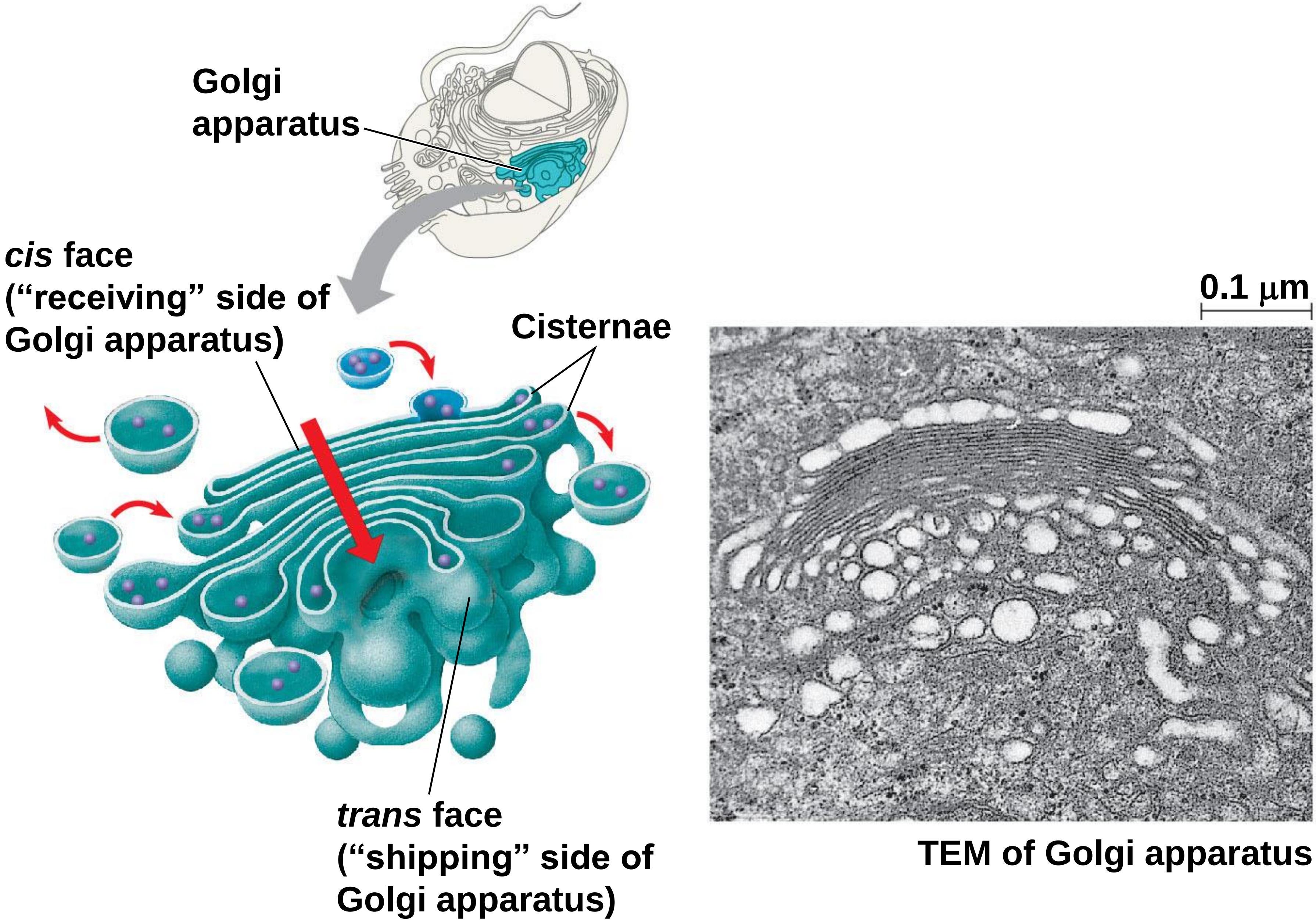
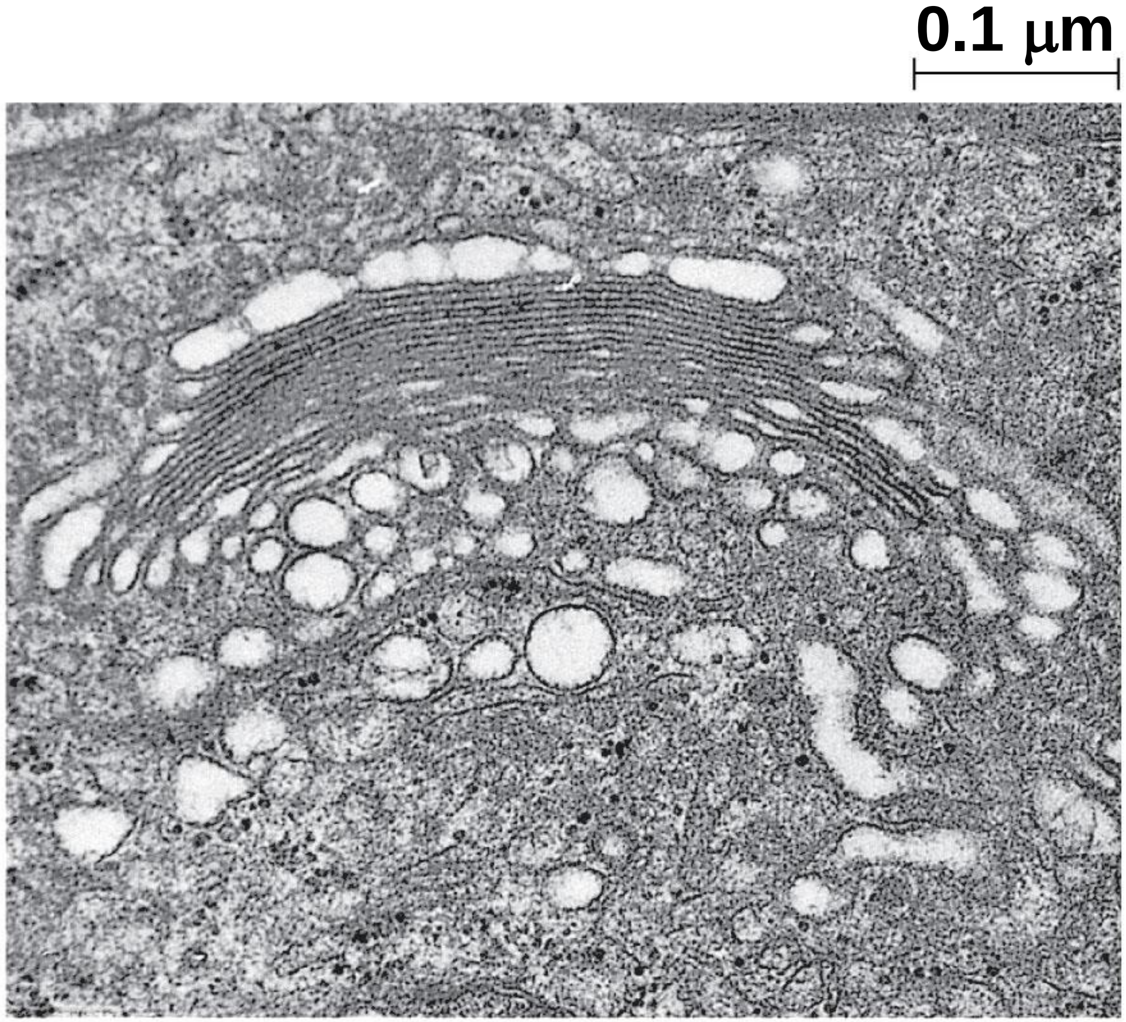

Golgi apparatus
cis face
(“receiving” side of Golgi apparatus)
Cisternae
trans face
(“shipping” side of Golgi apparatus)
0.1 μm
TEM of Golgi apparatus

Figure 4.11-1



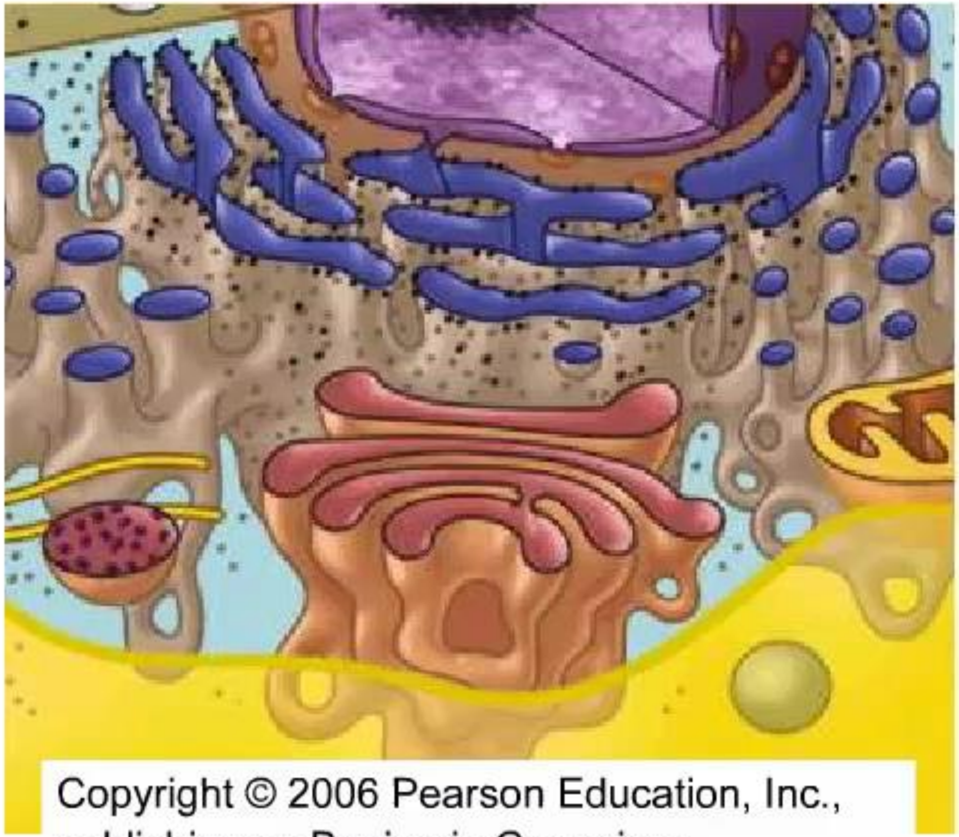
TEM of Golgi apparatus

Lysosomes: Digestive Compartments

- A **lysosome** is a membranous sac of hydrolytic enzymes that can digest macromolecules
- Lysosomal enzymes work best in the acidic environment inside the lysosome
- The three-dimensional shape of lysosomal proteins protects them from digestion by lysosomal enzymes

- 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

Animation: Lysosome Formation



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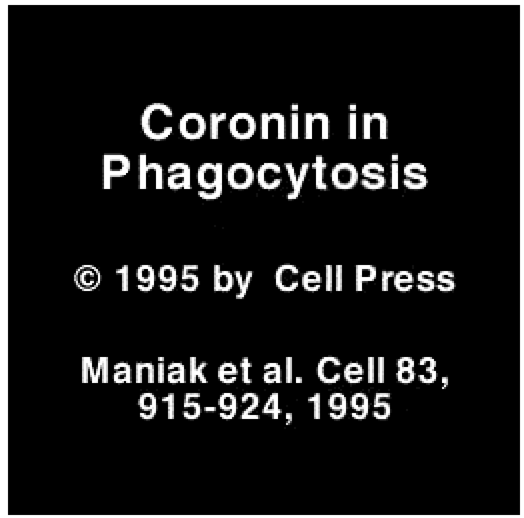
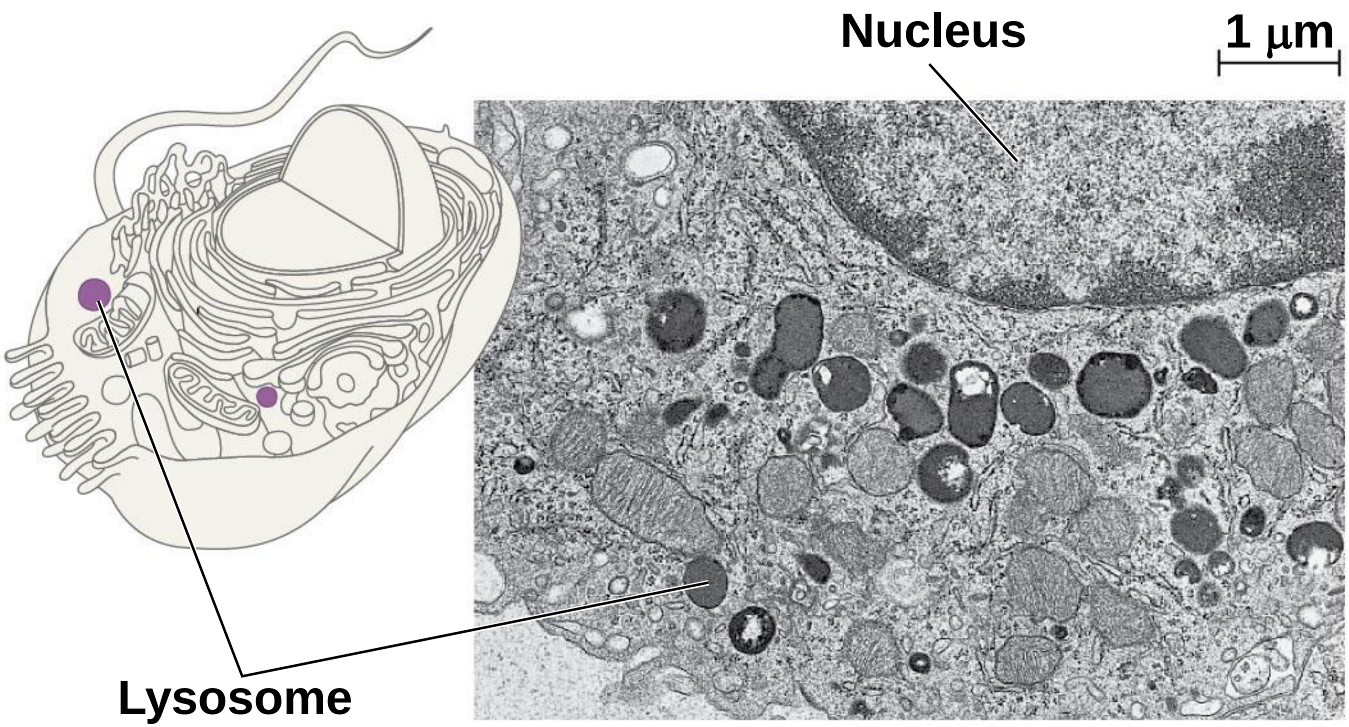
Video: Phagocytosis



Video: *Paramecium* Vacuole

Figure 4.12


Nucleus
1 µm
Lysosome

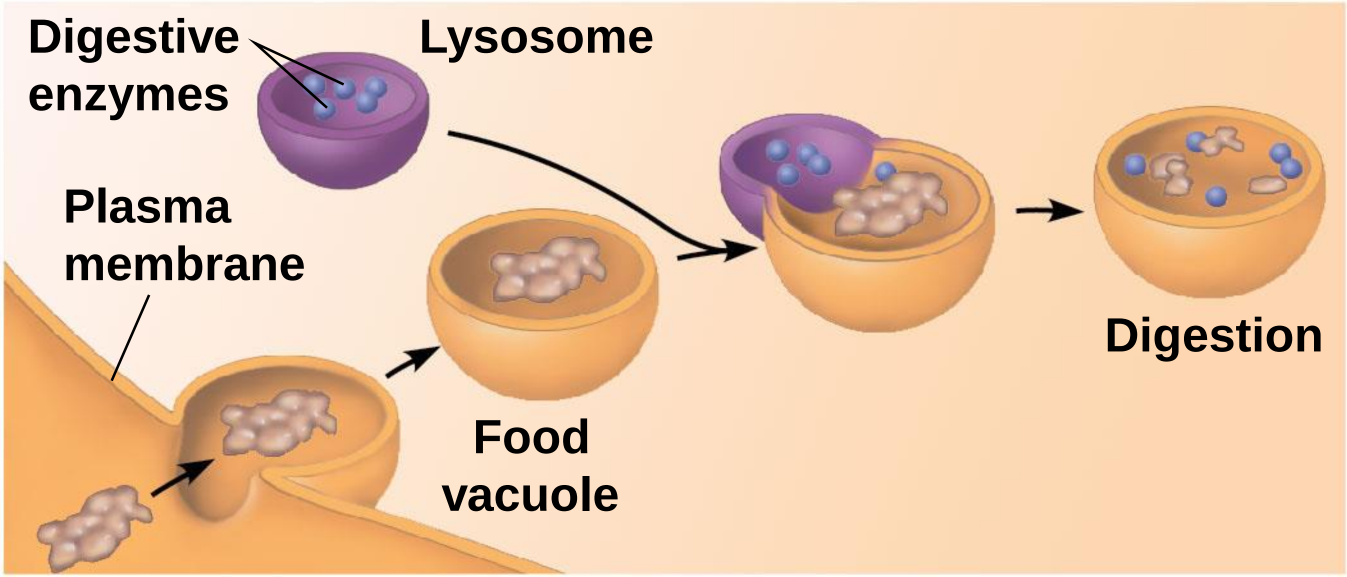

Digestive enzymes
Lysosome
Plasma membrane
Food vacuole
Digestion

Figure 4.12-1

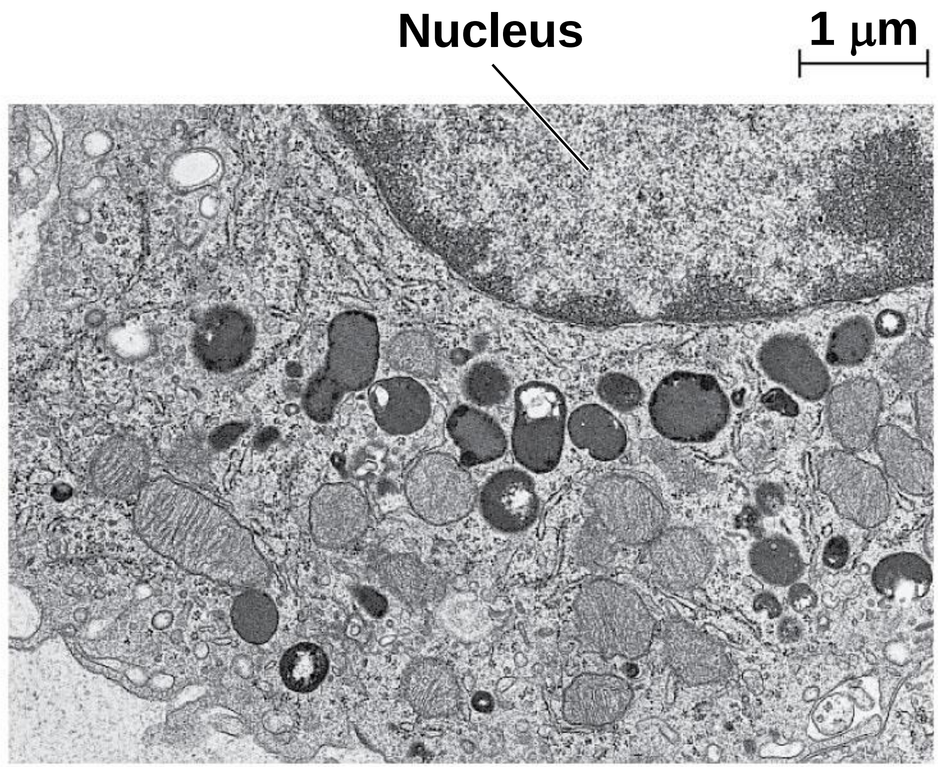


Figure 4.13

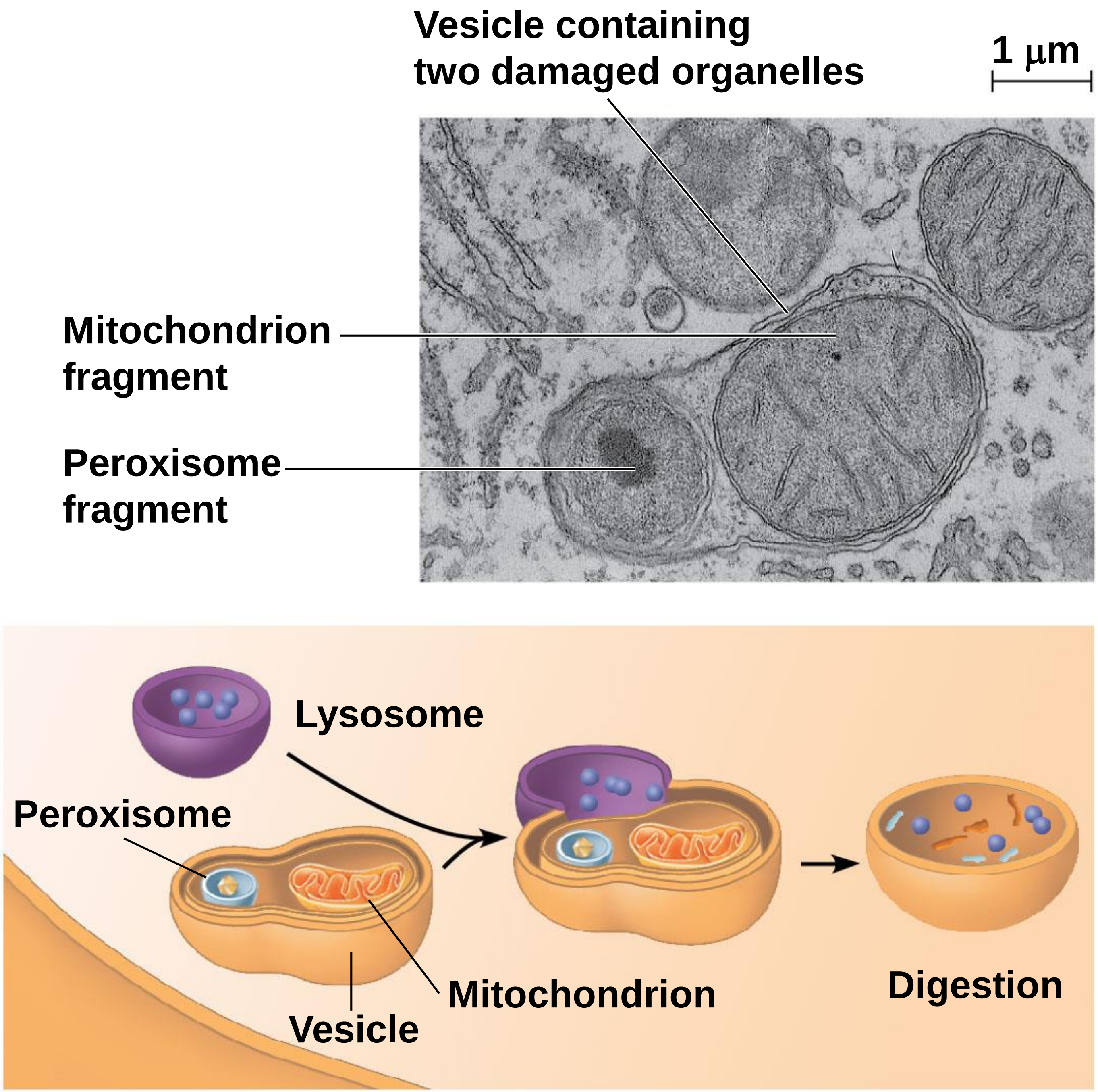
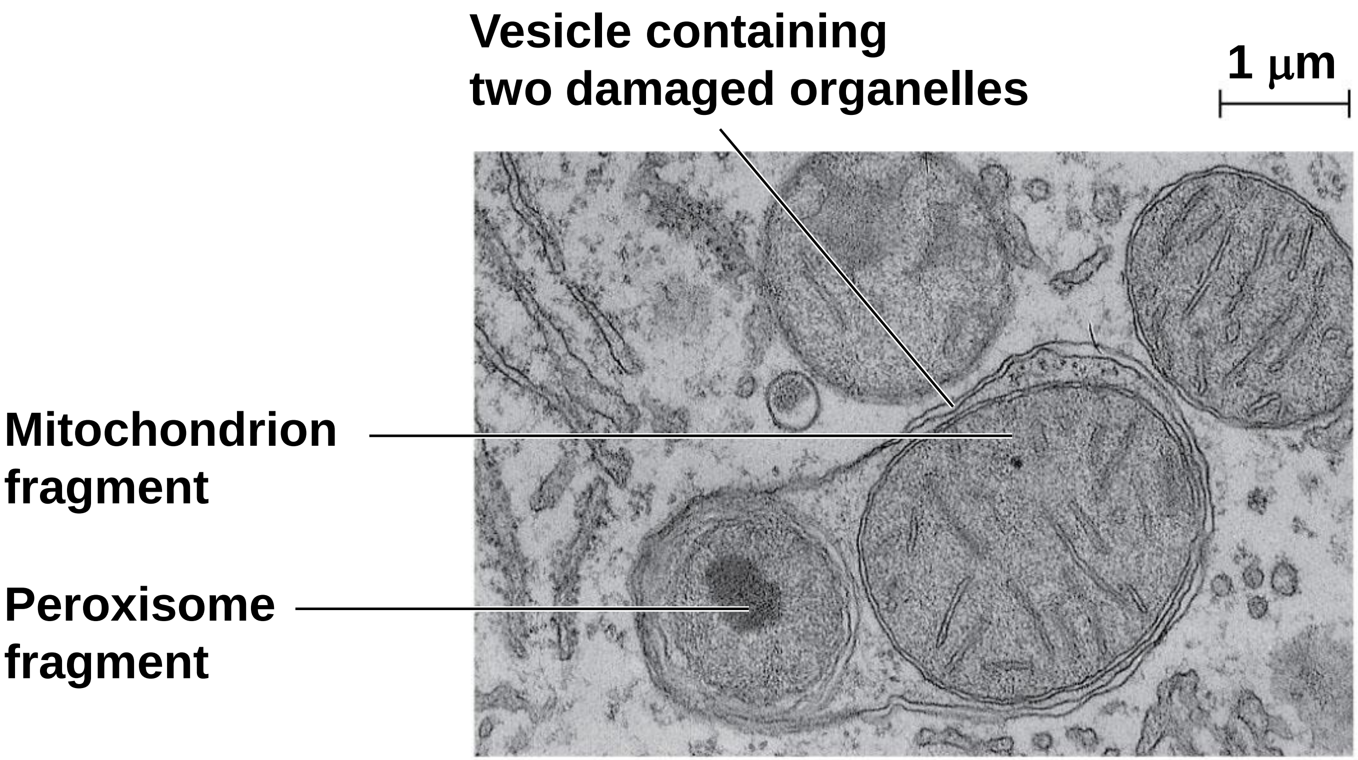

Vesicle containing
two damaged organelles
1 μm
Mitochondrion
fragment
Peroxisome
fragment
Lysosome
Peroxisome
Mitochondrion
Vesicle
Digestion

Figure 4.13-1



Vesicle containing two damaged organelles
1 μm
Mitochondrion fragment
Peroxisome fragment

Vacuoles: Diverse Maintenance Compartments

- **Vacuoles** are large vesicles derived from the endoplasmic reticulum and Golgi apparatus
- The solution inside a vacuole differs in composition from the cytosol

- **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
- Certain vacuoles in plants and fungi carry out enzymatic hydrolysis like lysosomes

Figure 4.14

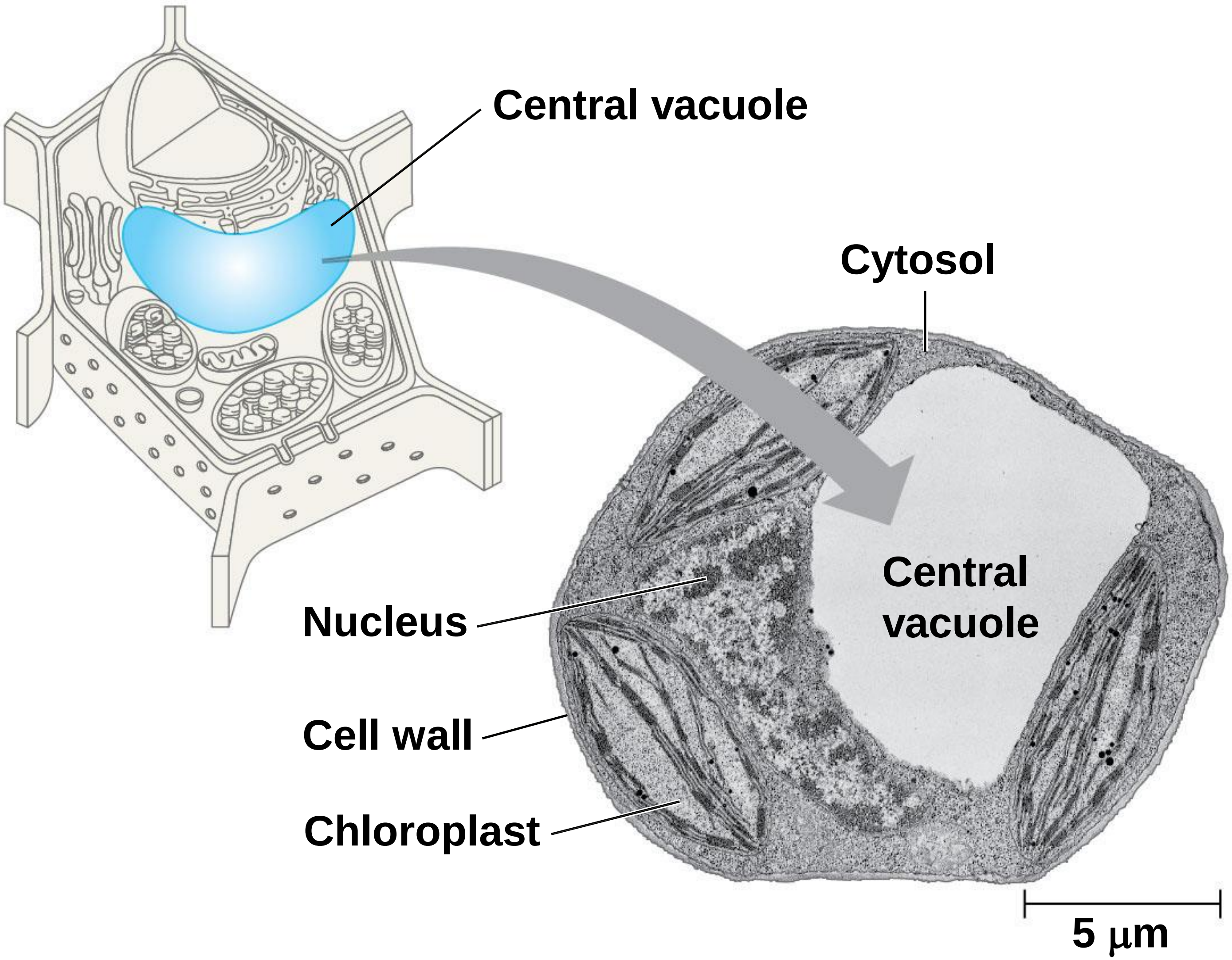
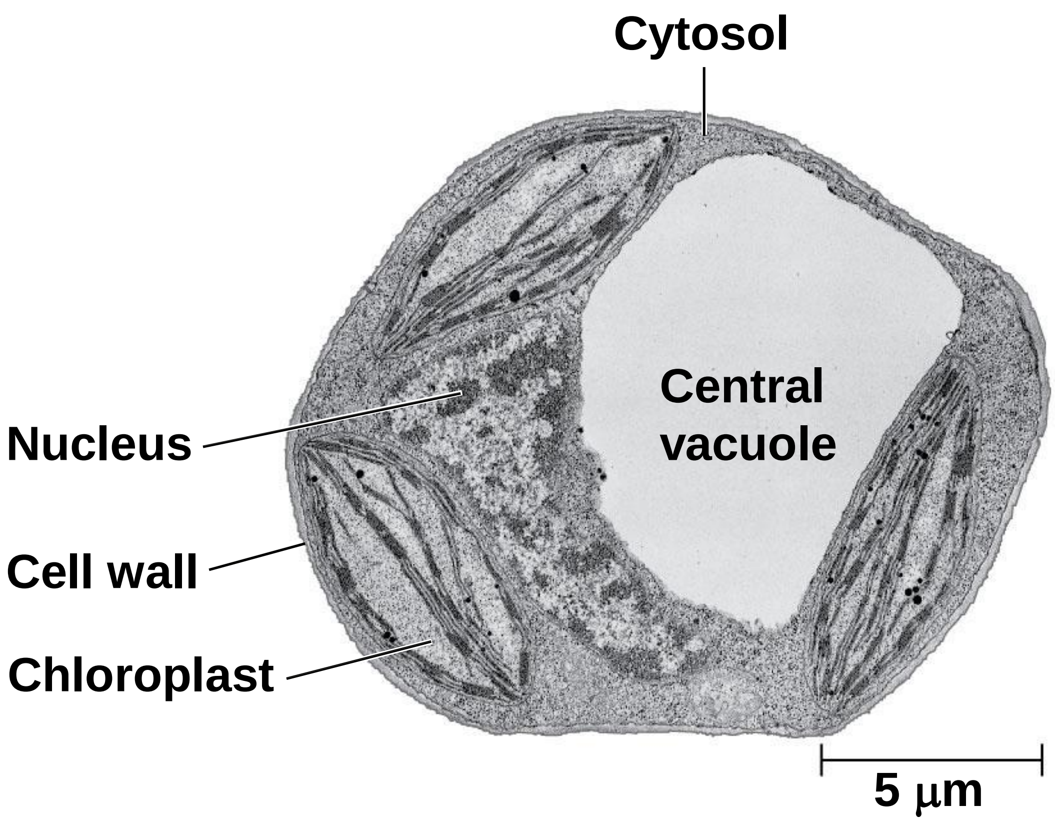

Central vacuole
Cytosol
Central
vacuole
Nucleus
Cell wall
Chloroplast
5 µm

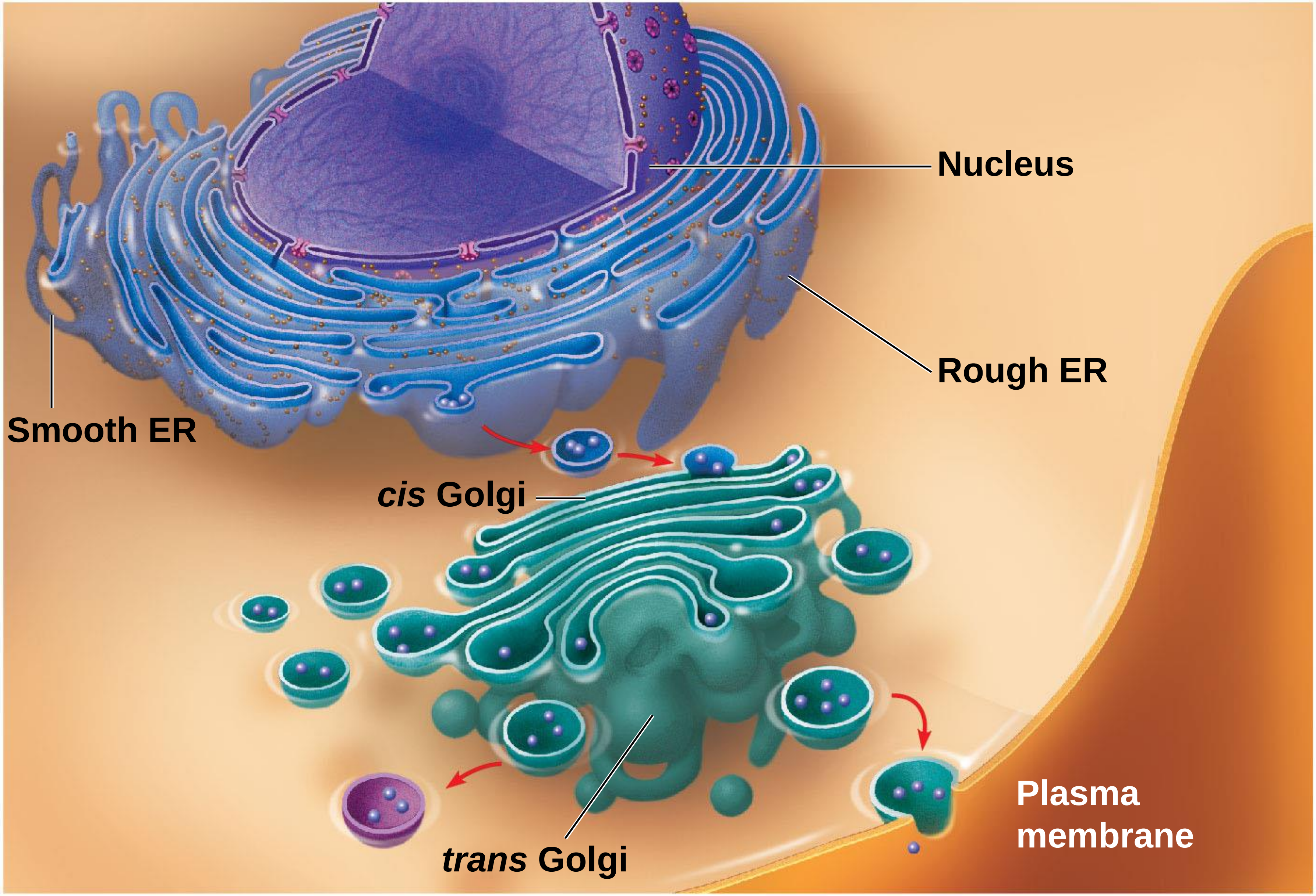
Figure 4.14-1


Cytosol
Central vacuole
Nucleus
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

Figure 4.15



Nucleus
Rough ER
Smooth ER
cis Golgi
trans Golgi
Plasma membrane

Concept 4.5: Mitochondria and chloroplasts change energy from one form to another

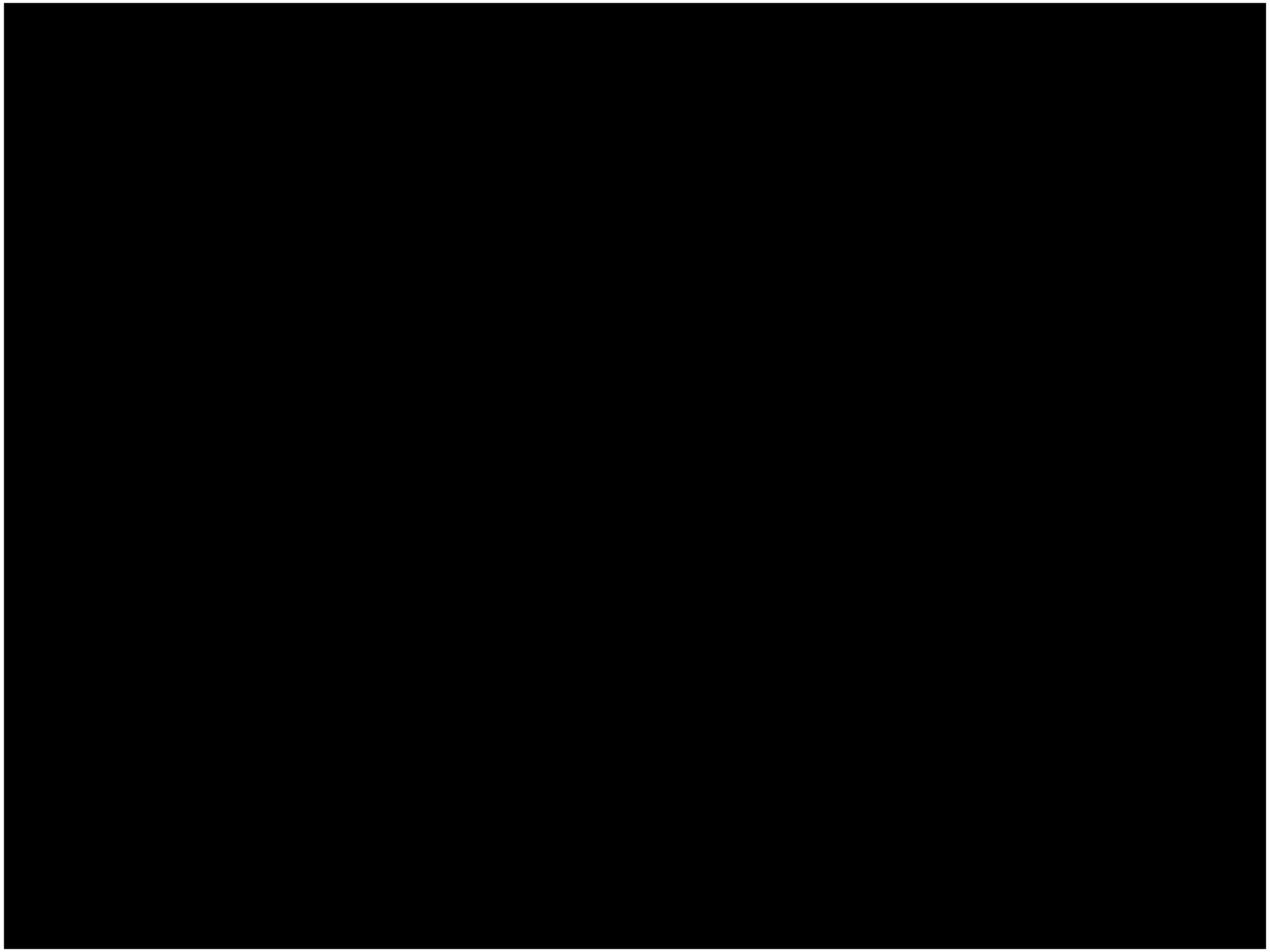
- **Mitochondria** are the sites of cellular respiration, a metabolic process that uses oxygen to generate ATP
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis
- Peroxisomes are oxidative organelles

The Evolutionary Origins of Mitochondria and Chloroplasts

- Mitochondria and chloroplasts display similarities with bacteria
  - Enveloped by a double membrane
  - Contain ribosomes and multiple circular DNA molecules
  - Grow and reproduce somewhat independently in cells

- The **endosymbiont theory**
  - An early ancestor of eukaryotic cells engulfed a nonphotosynthetic prokaryotic cell, which formed an endosymbiont relationship with its host
  - The host cell and endosymbiont merged into a single organism, a eukaryotic cell with a mitochondrion
  - At least one of these cells may have taken up a photosynthetic prokaryote, becoming the ancestor of cells that contain chloroplasts

Video: ER and Mitochondria



Video: Mitochondria 3-D

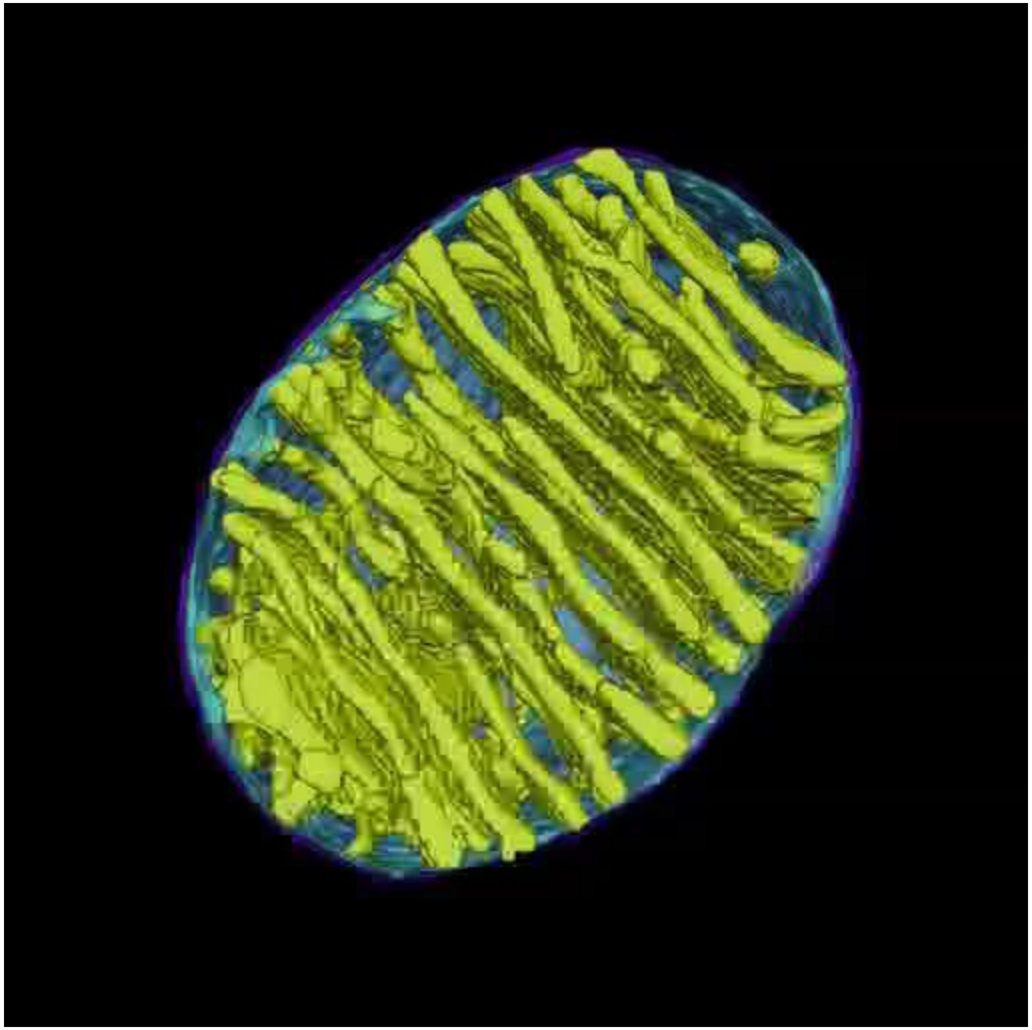
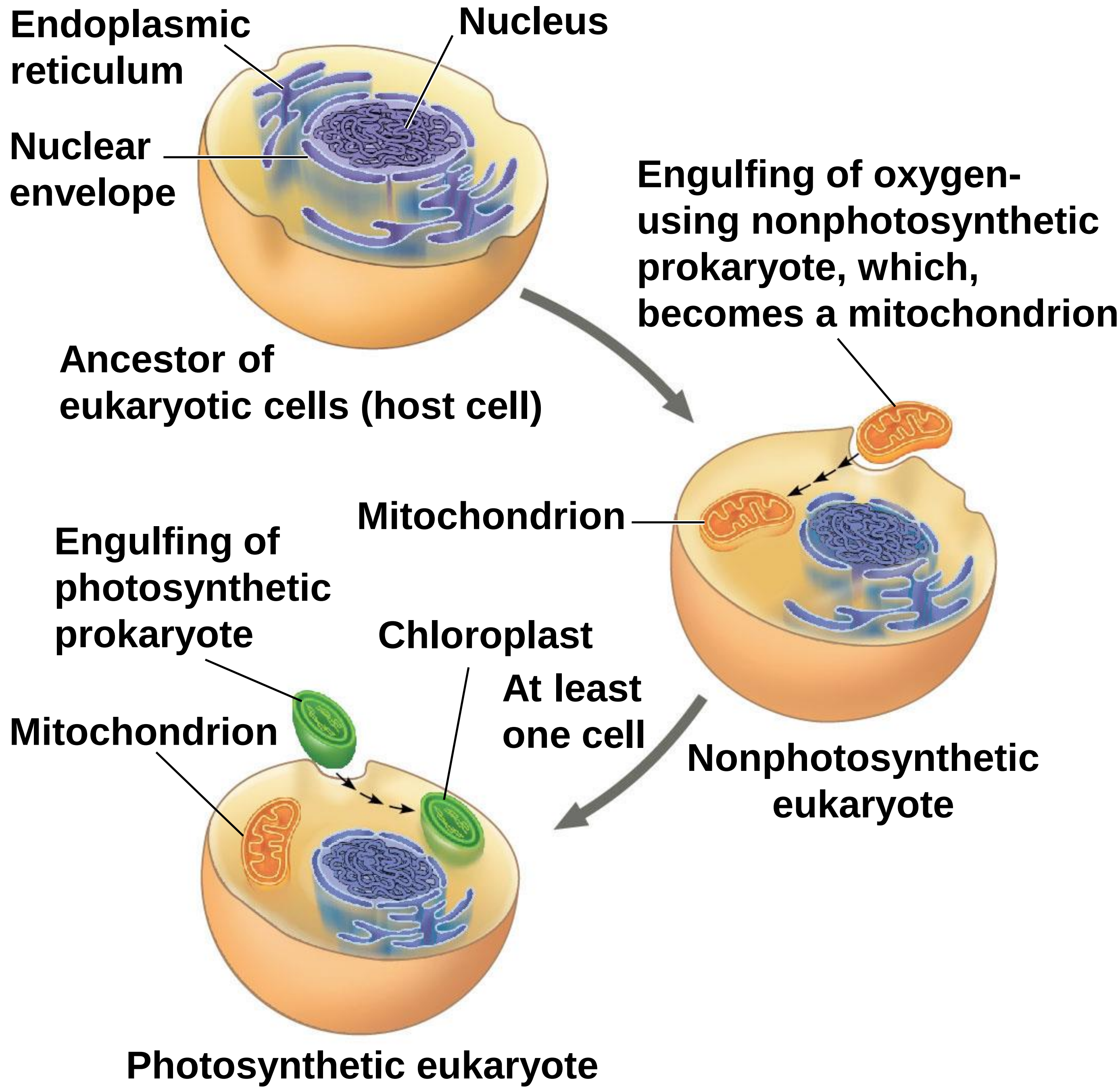


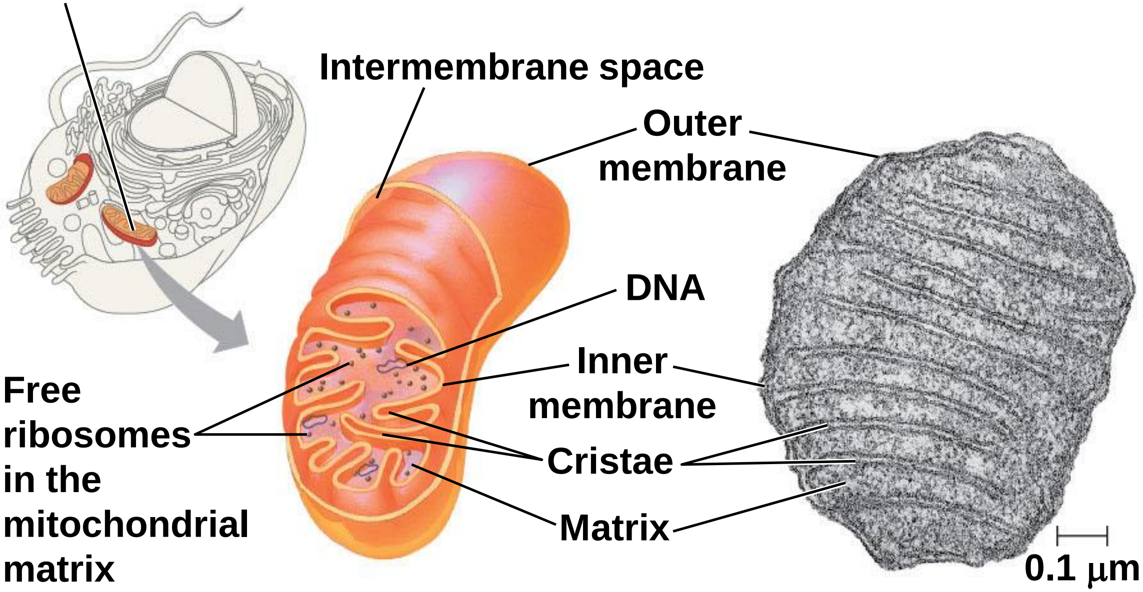
Figure 4.16


Endoplasmic reticulum
Nucleus
Nuclear envelope
Ancestor of eukaryotic cells (host cell)
Engulfing of oxygen-using nonphotosynthetic prokaryote, which, becomes a mitochondrion
Mitochondrion
Nonphotosynthetic eukaryote
At least one cell
Engulfing of photosynthetic prokaryote
Chloroplast
Mitochondrion
Photosynthetic eukaryote

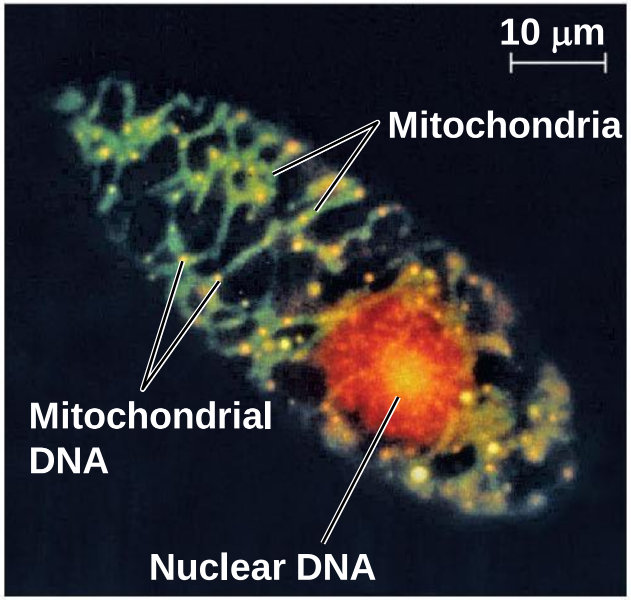
Mitochondria: Chemical Energy Conversion

- 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

Figure 4.17

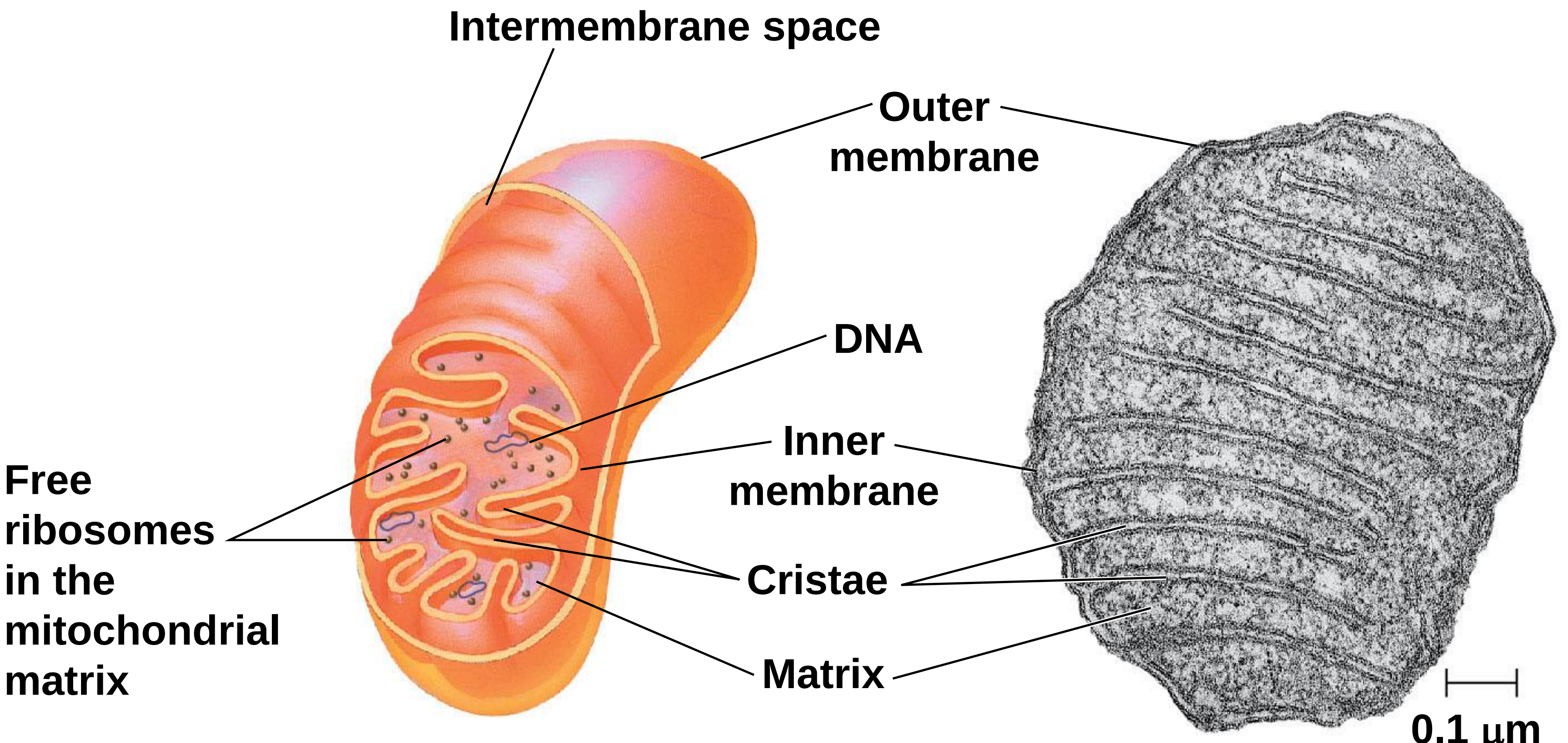


(a) Diagram and TEM of mitochondrion



(b) Network of mitochondria in *Euglena* (LM)

Figure 4.17-1



(a) Diagram and TEM of mitochondrion

Figure 4.17-1a

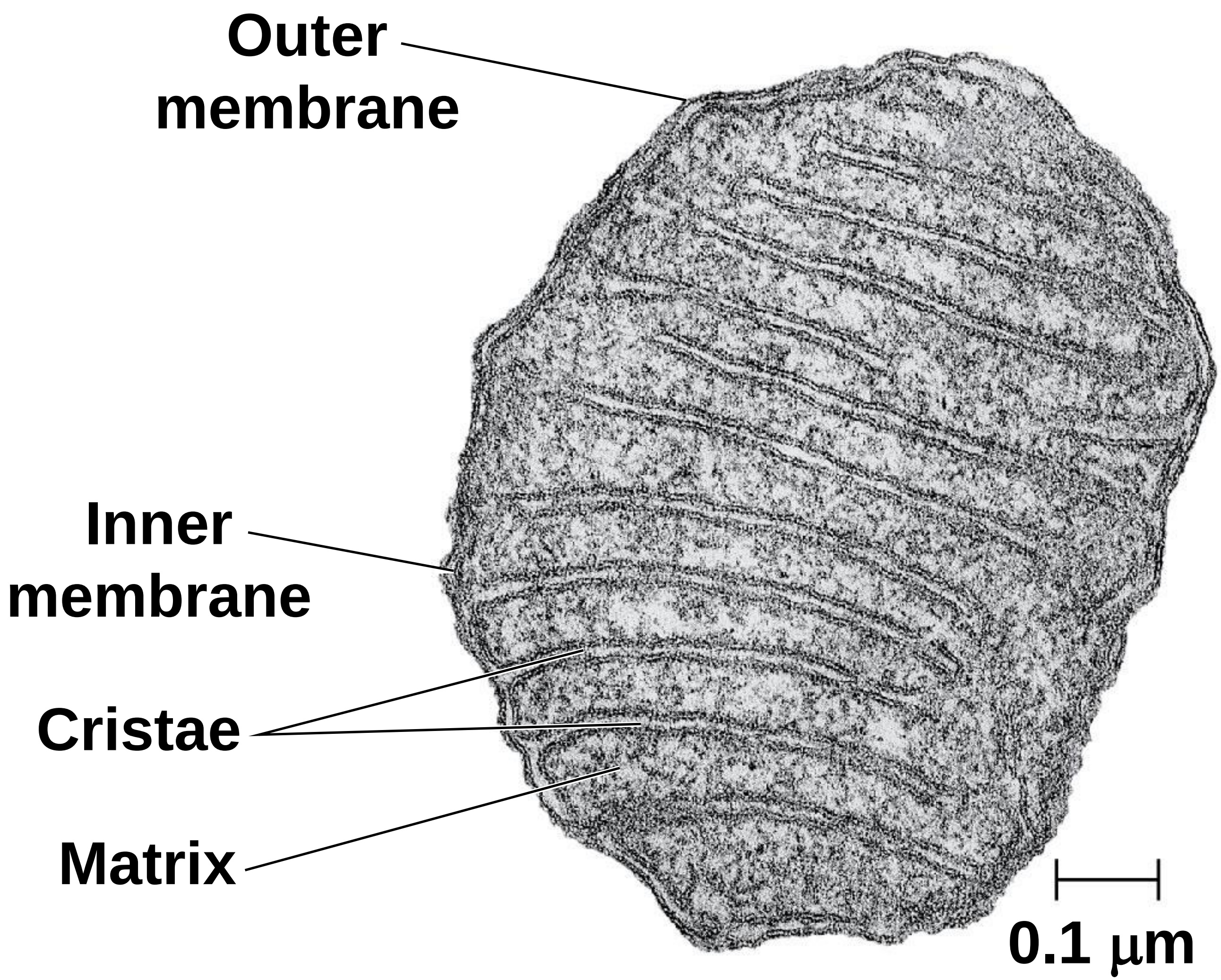
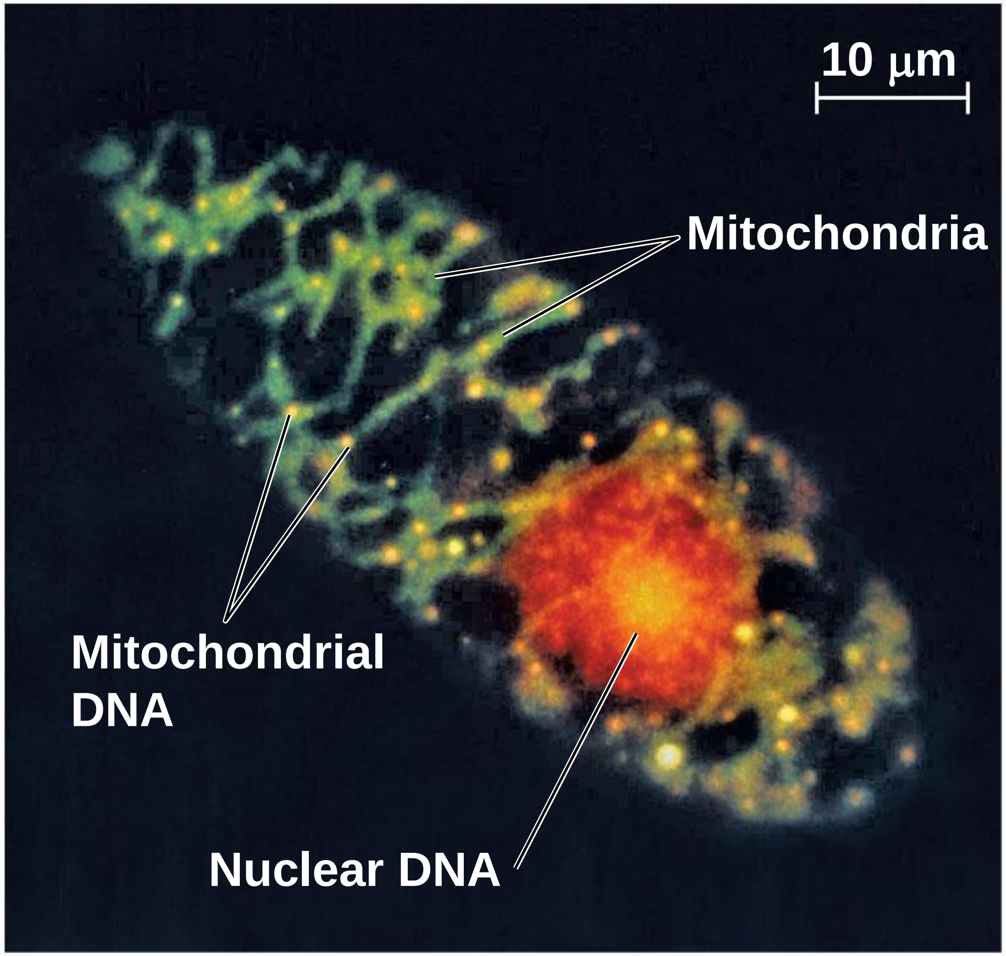


Figure 4.17-2



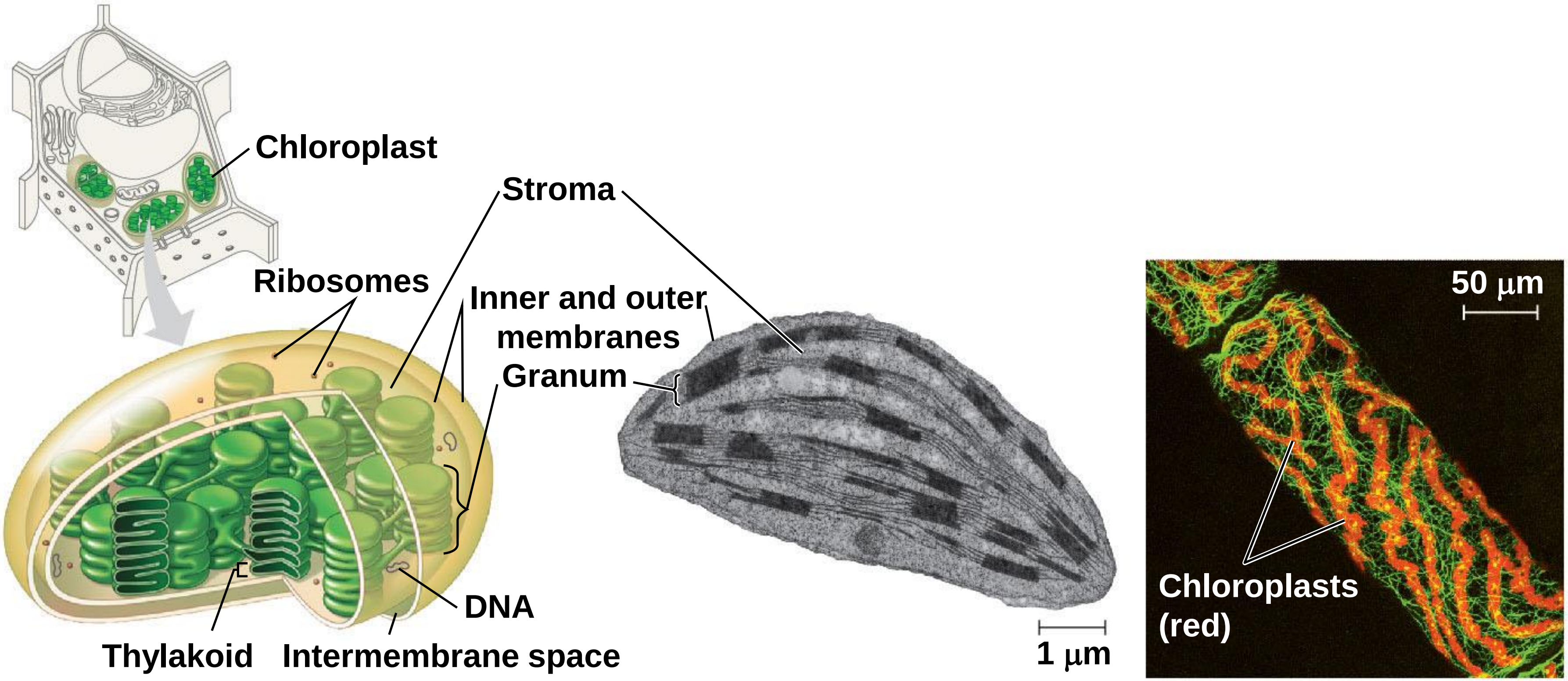
(b) Network of mitochondria in *Euglena* (LM)

Chloroplasts: Capture of Light Energy

- 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
- The chloroplast is one of a group of plant organelles called **plastids**

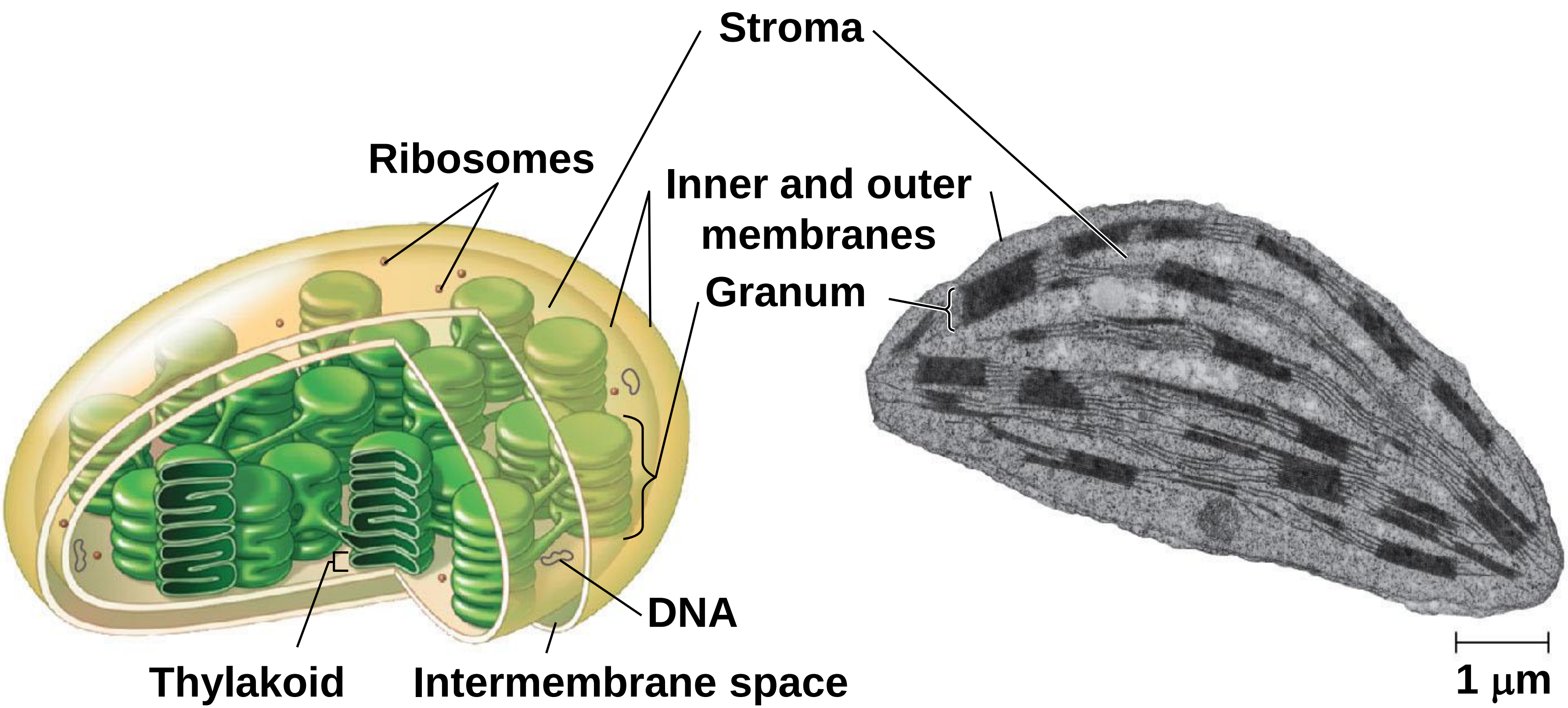
Figure 4.18



(a) Diagram and TEM of chloroplast

(b) Chloroplasts in an algal cell

Figure 4.18-1



(a) Diagram and TEM of chloroplast

Figure 4.18-1a

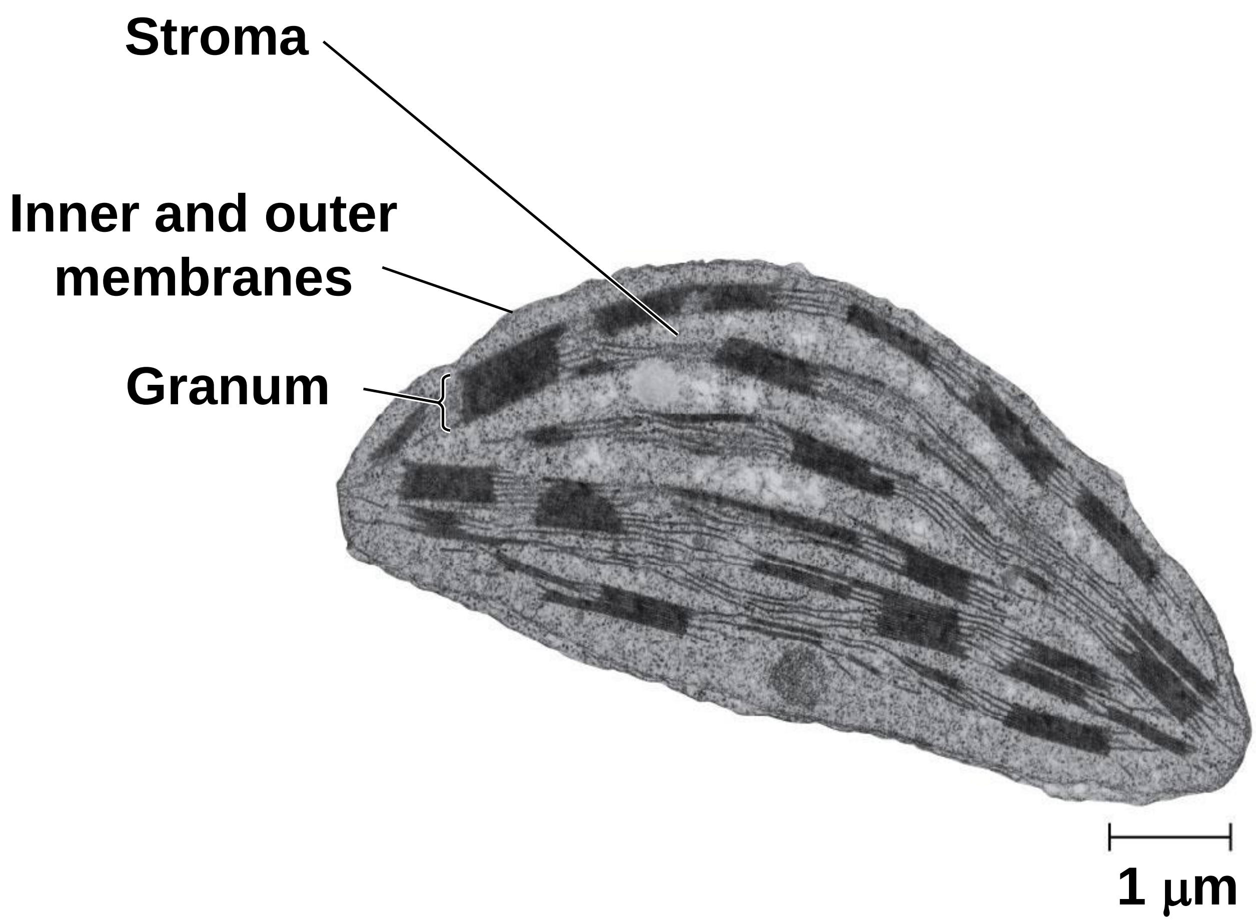
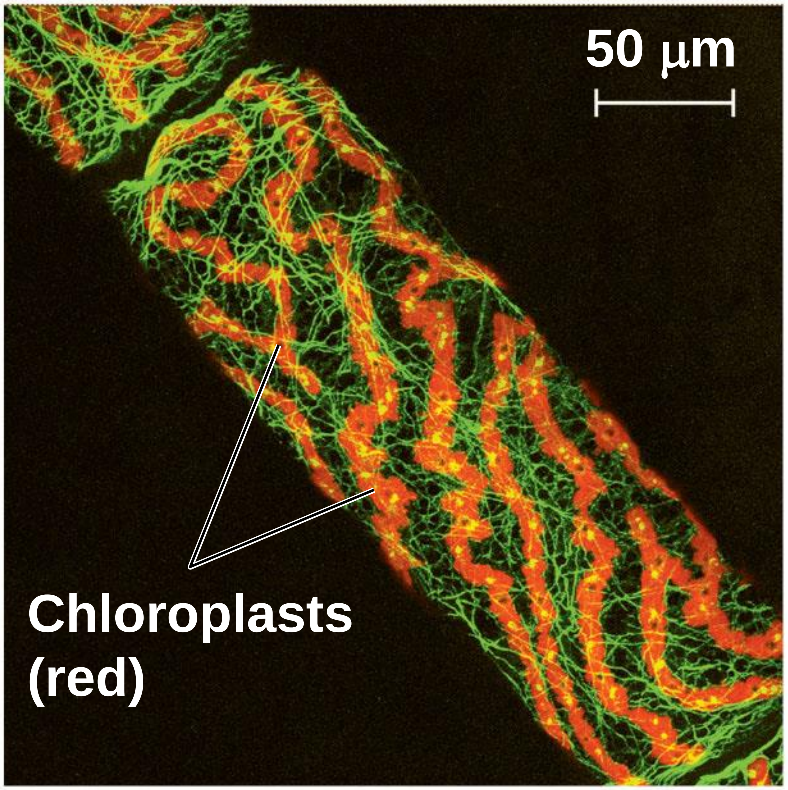


Figure 4.18-2

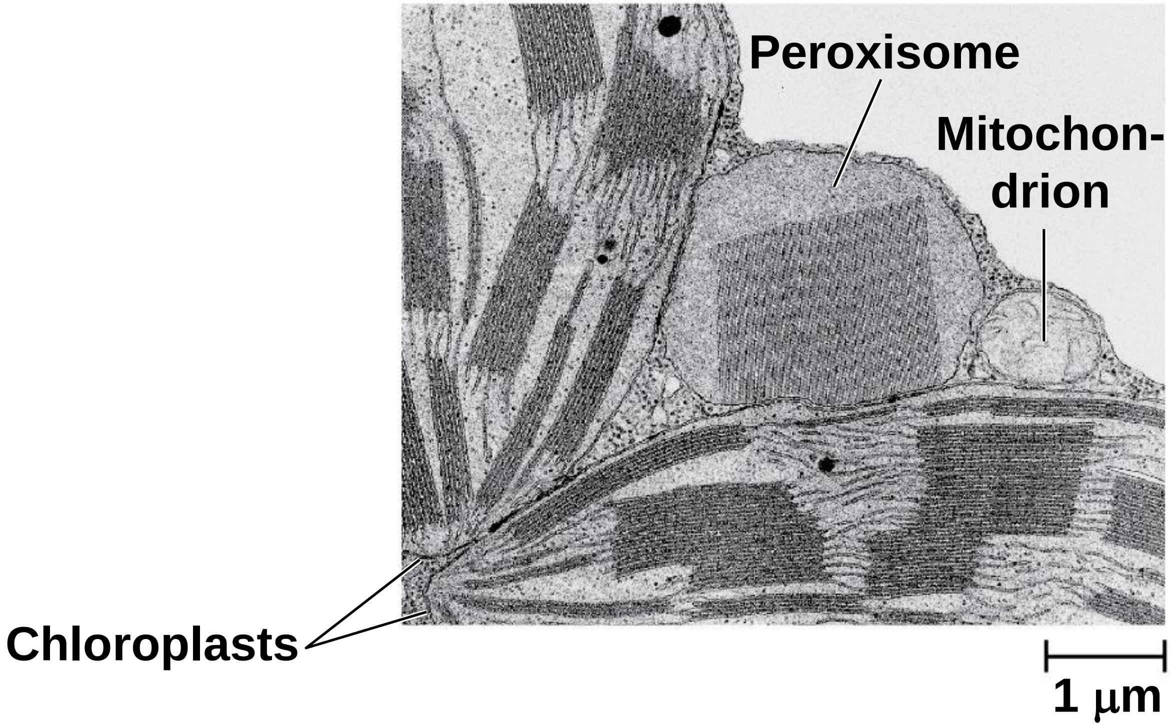


(b) Chloroplasts in an algal cell

Peroxisomes: Oxidation

- **Peroxisomes** are specialized metabolic compartments bounded by a single membrane
- Peroxisomes produce hydrogen peroxide and then convert it to water
- Peroxisomes perform reactions with many different functions

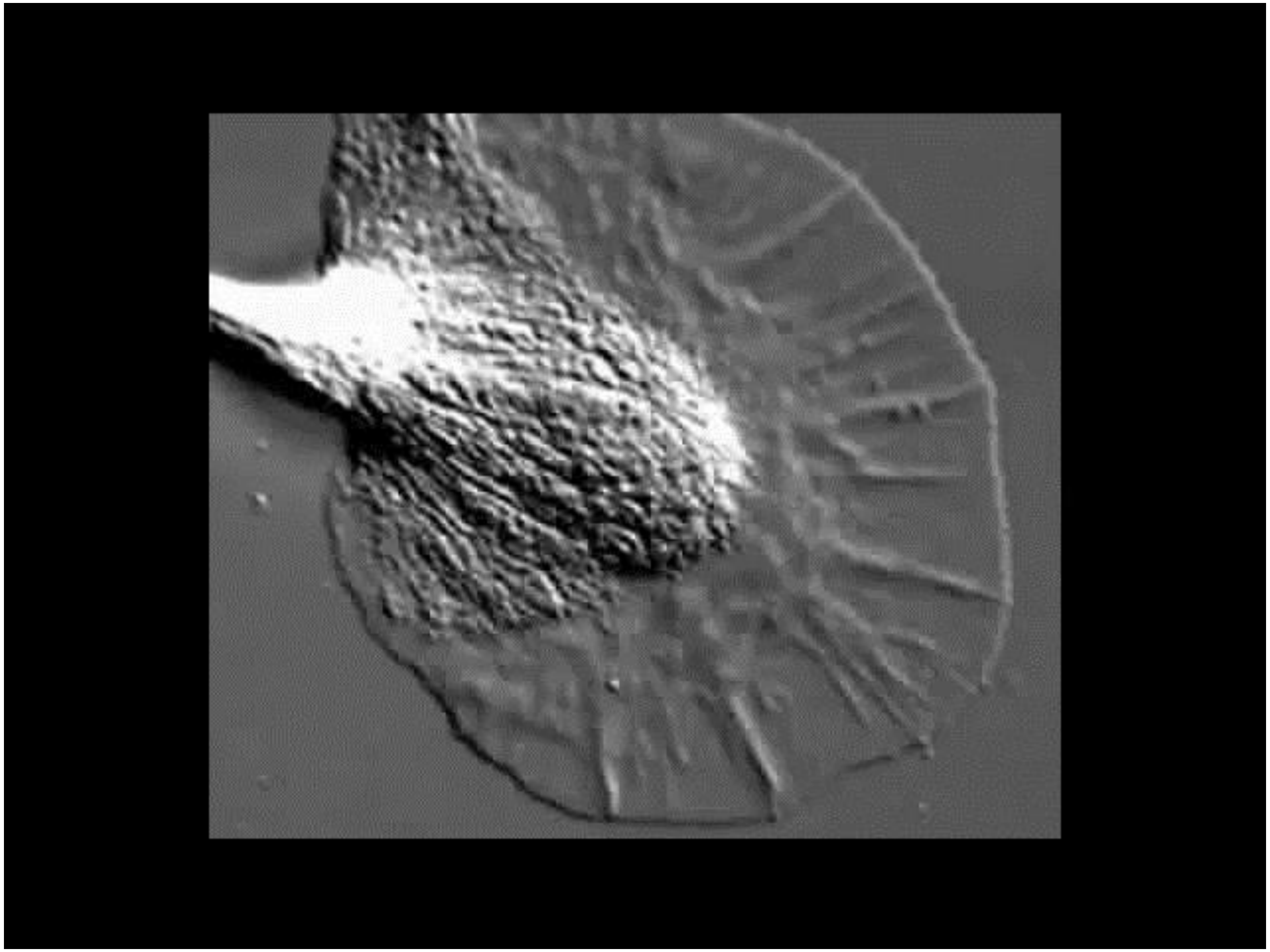
Figure 4.19



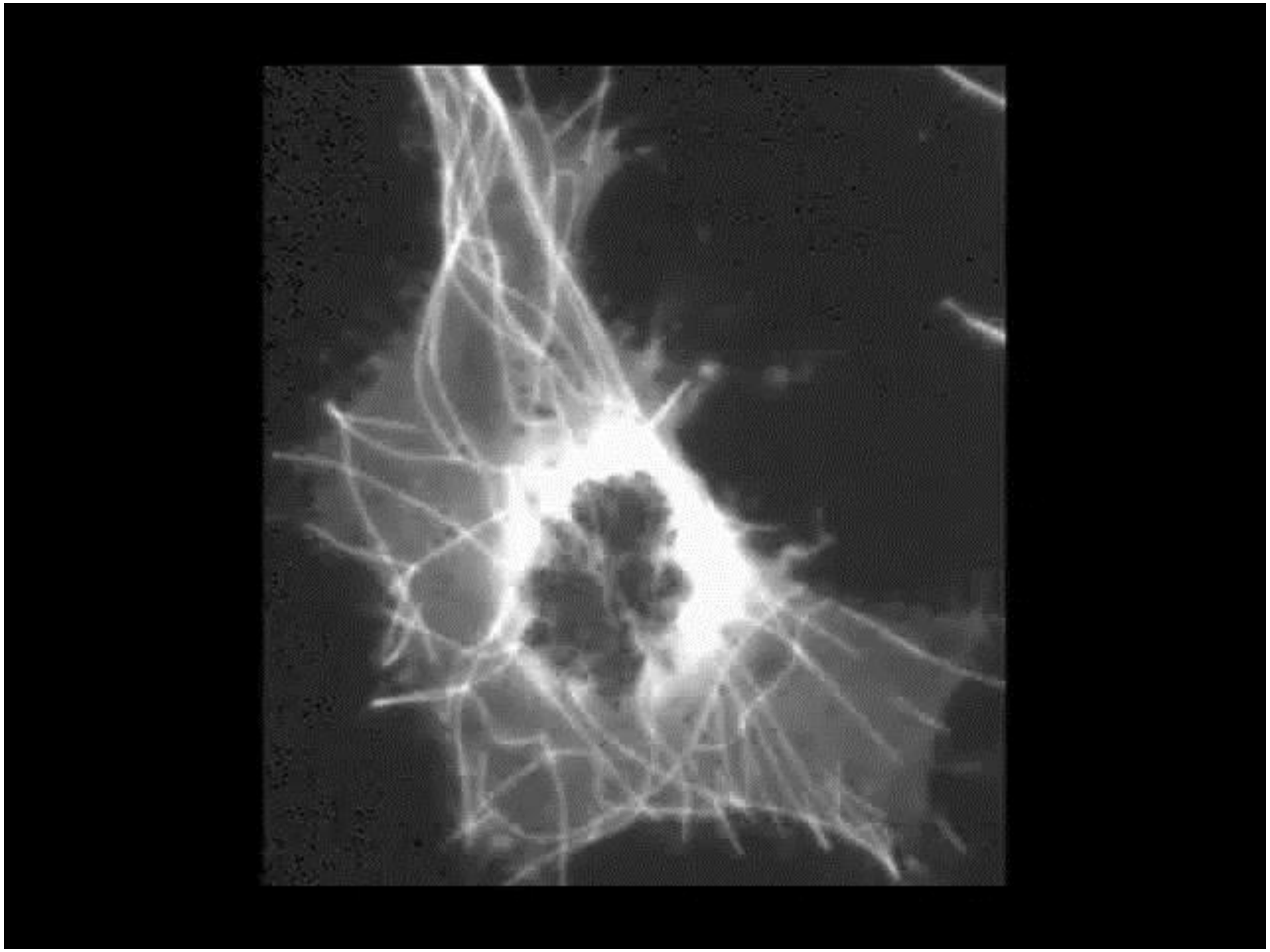
Concept 4.6: The cytoskeleton is a network of fibers that organizes structures and activities in the cell

- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm
- It organizes the cell’s structures and activities

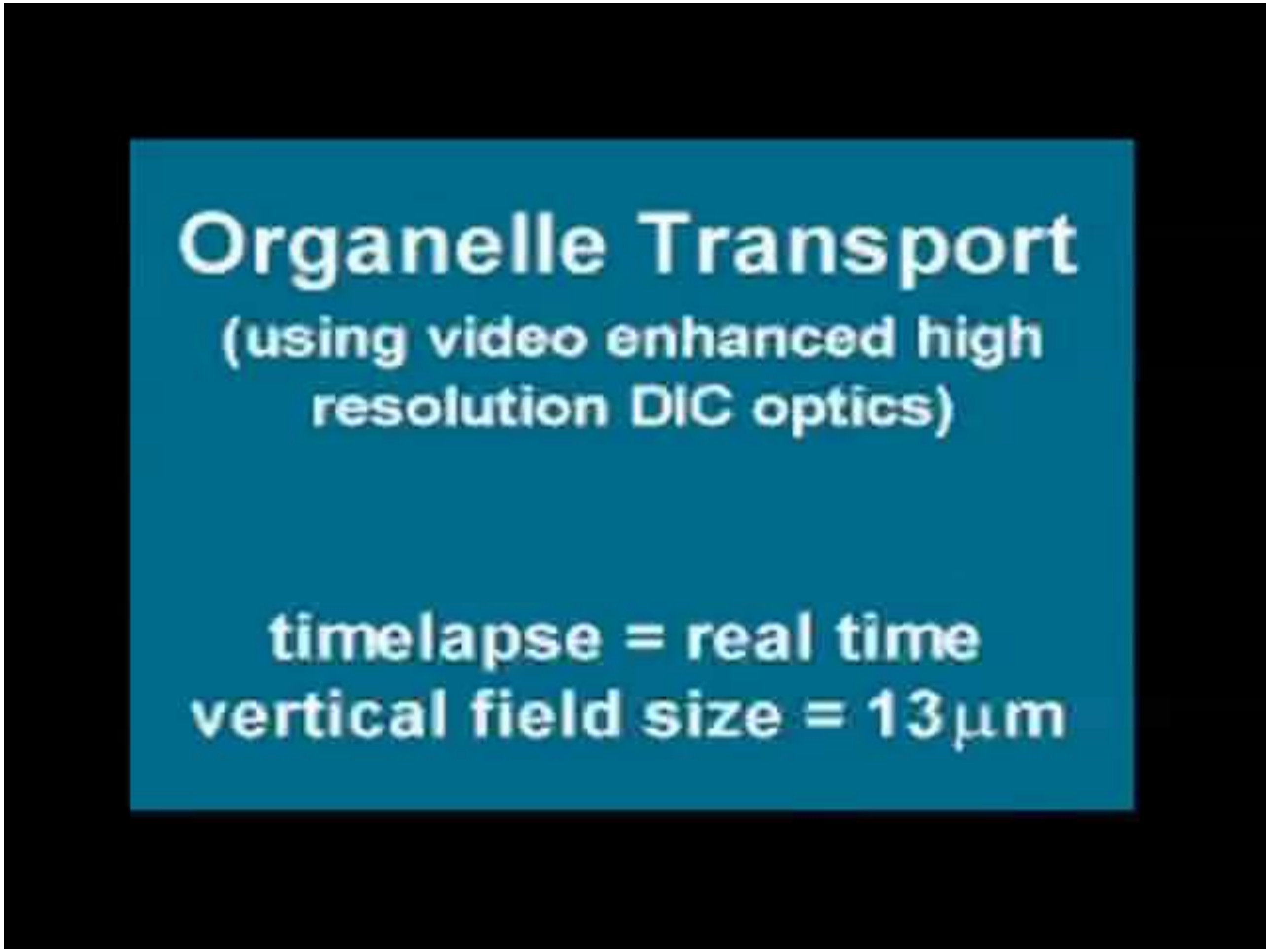
Video: Cytoskeleton in Neuron



Video: Microtubule Transport

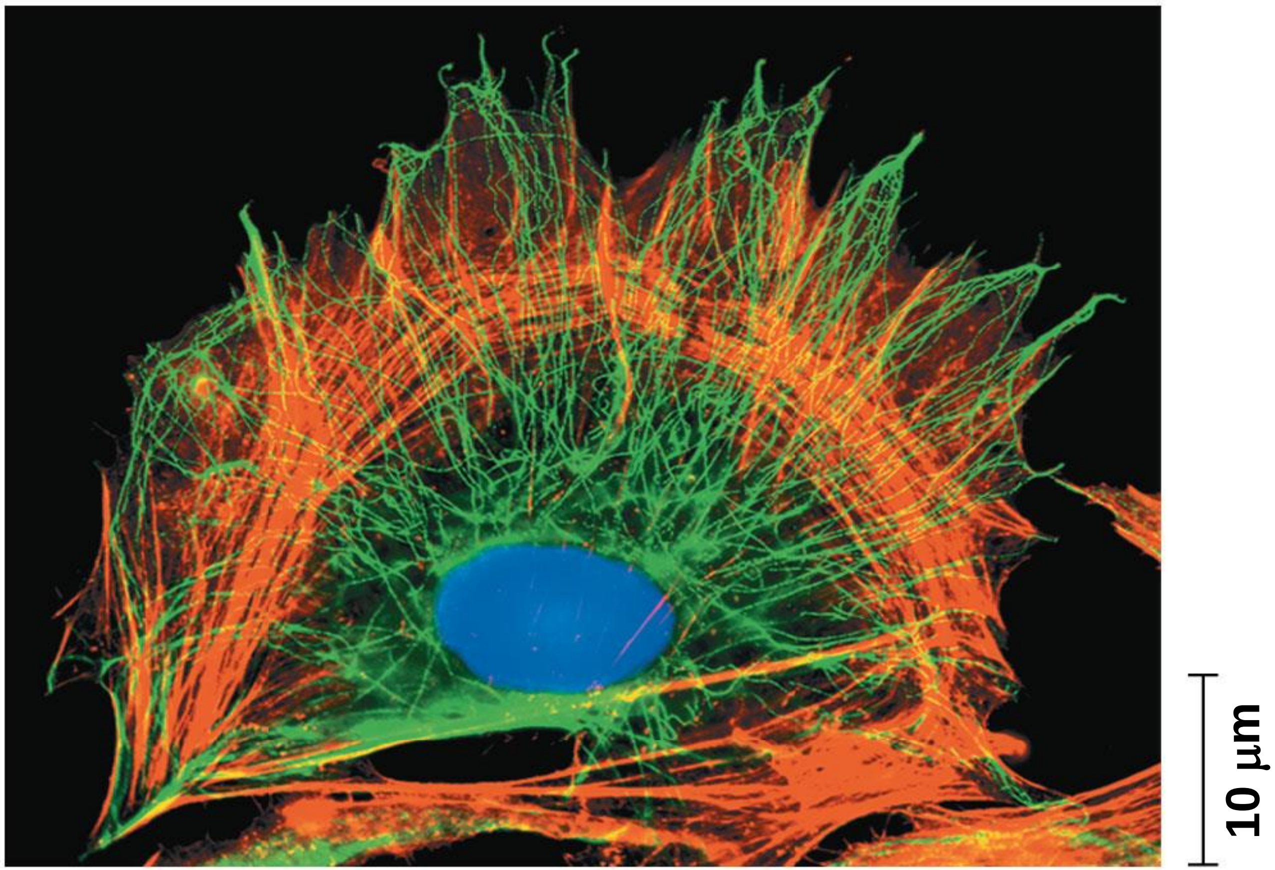


Video: Organelle Movement



Video: Organelle Transport

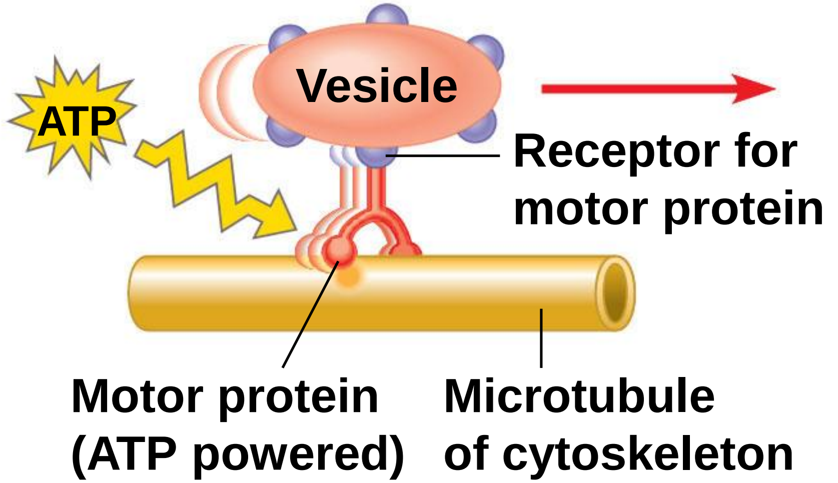
Figure 4.20



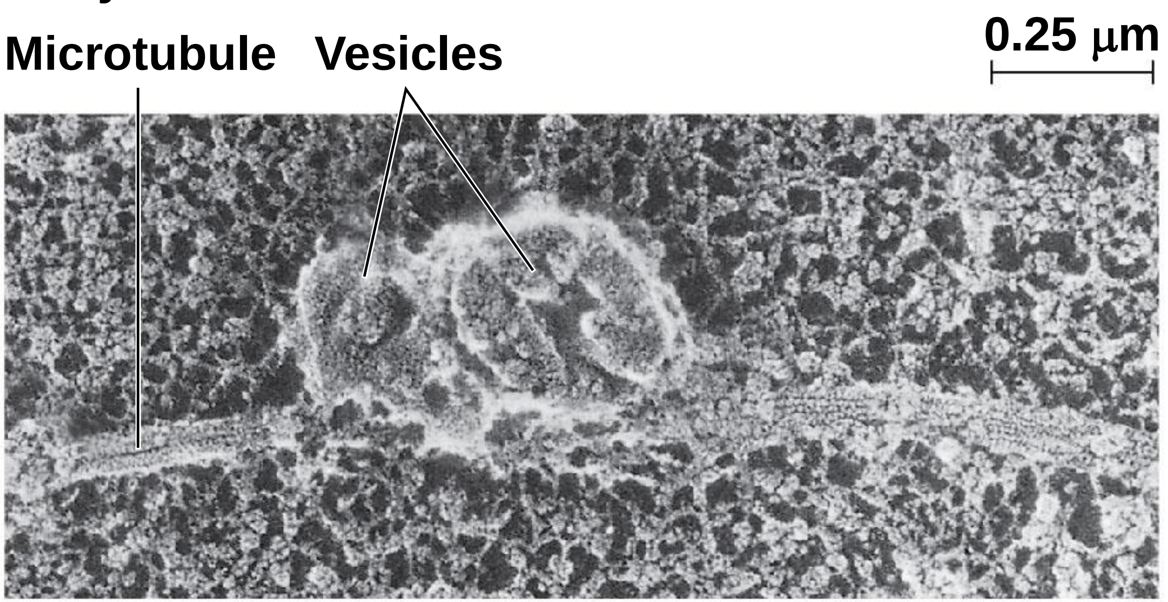
Roles of the Cytoskeleton: Support and Motility

- The cytoskeleton helps to support the cell and maintain its shape
- It provides anchorage for many organelles and molecules
- It interacts with **motor proteins** to produce motility
- Inside the cell, vesicles and other organelles can “walk” along the tracks provided by the cytoskeleton

Figure 4.21

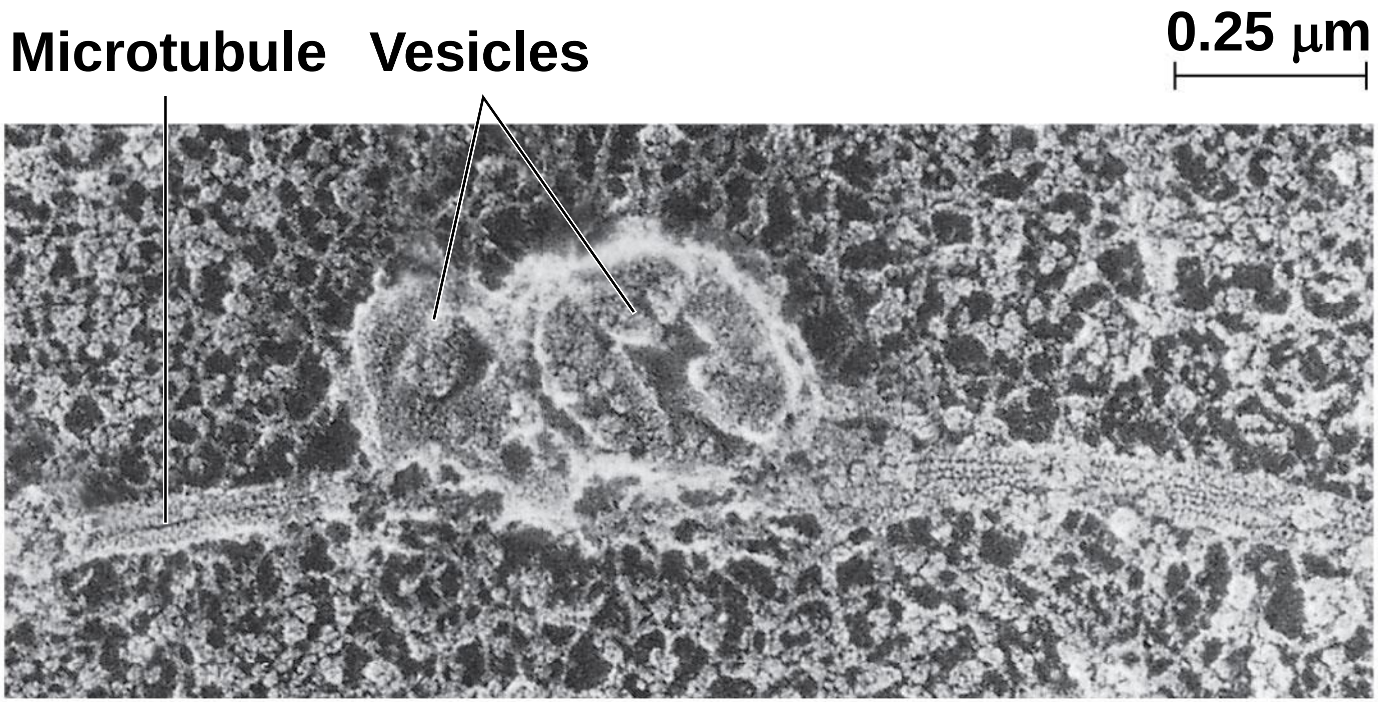


(a) Motor proteins "walk" vesicles along cytoskeletal fibers.



(b) Two vesicles move toward the tip of a nerve cell extension called an axon (SEM)

Figure 4.21-1

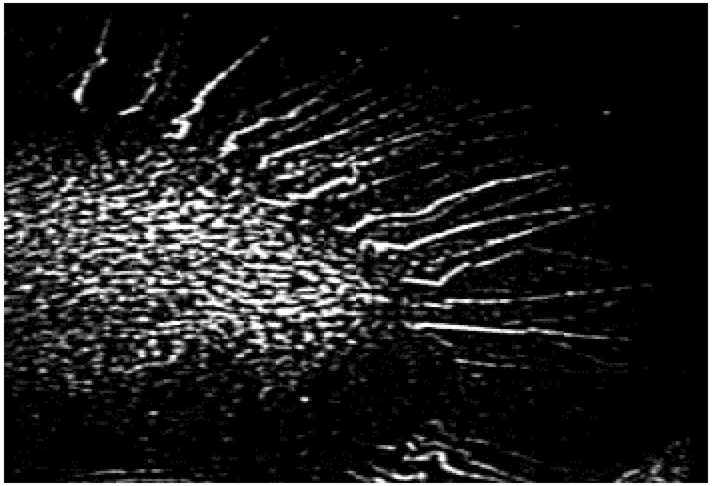


(b) Two vesicles move toward the tip of a nerve cell extension called an axon (SEM)

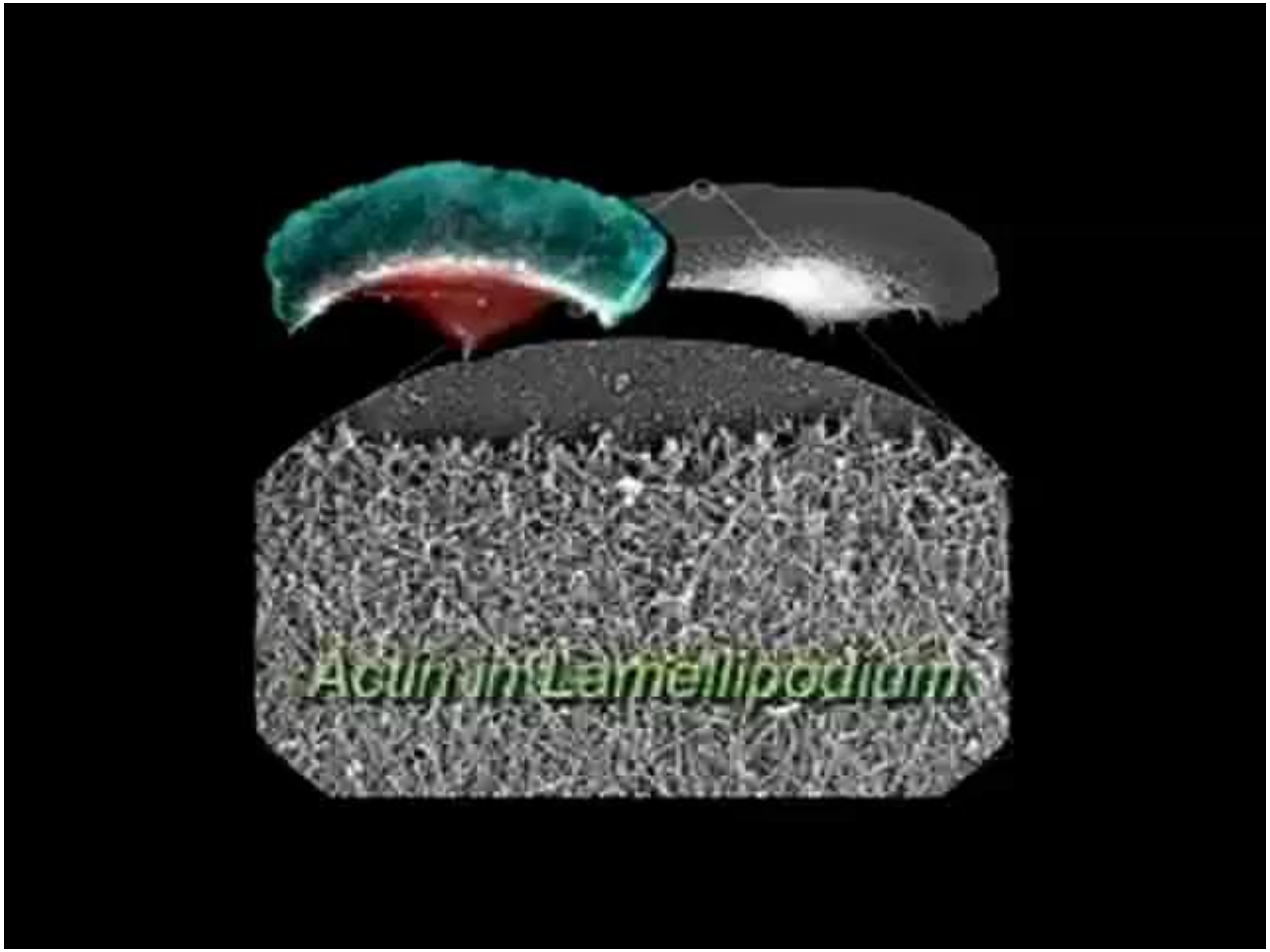
Components of the Cytoskeleton

- 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

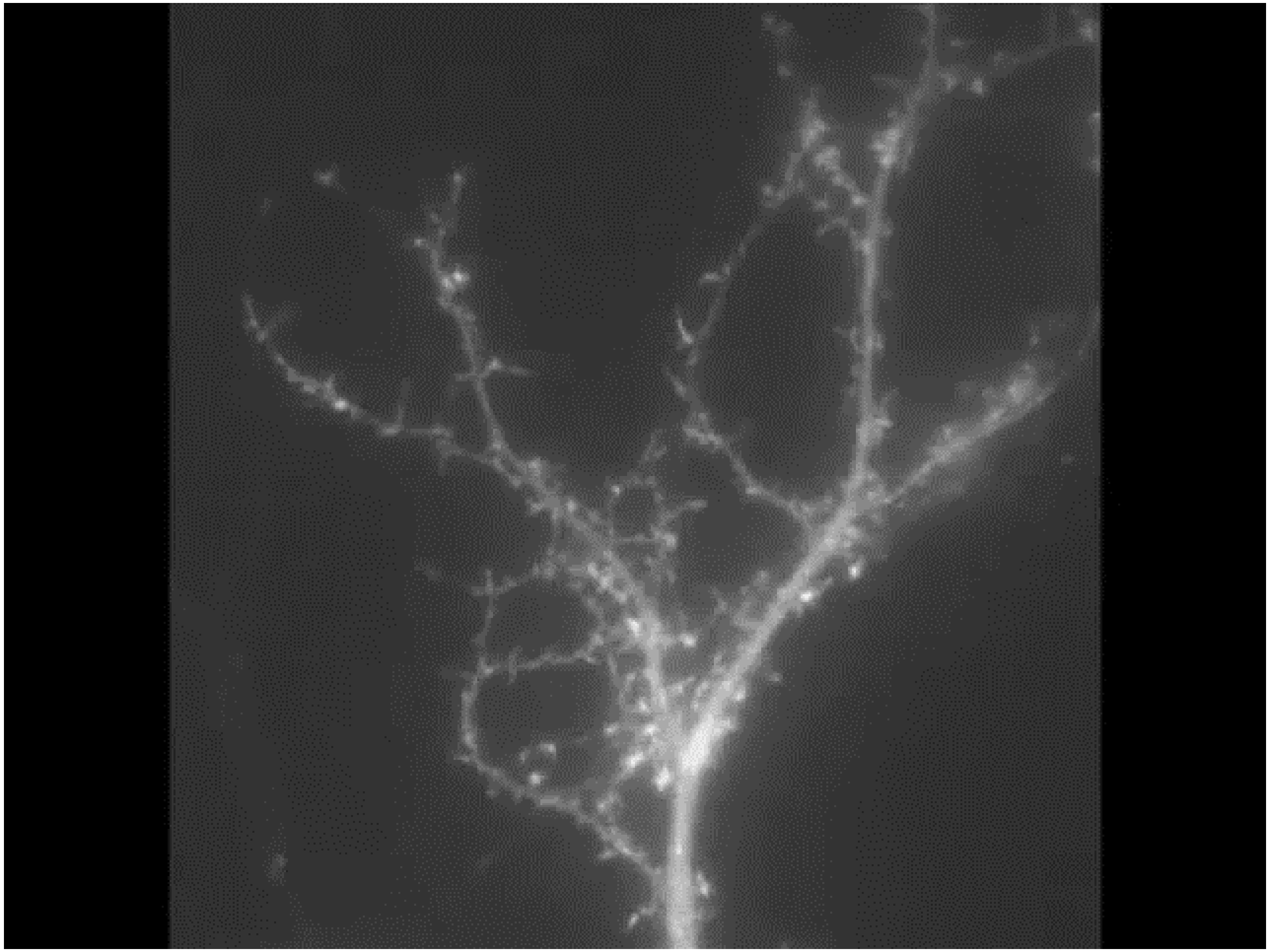
Video: Actin Cytoskeleton



Video: Actin in Crawling Cell

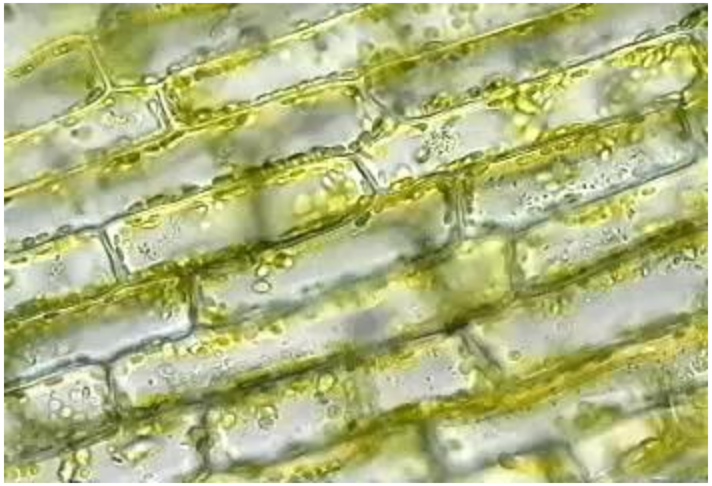


Video: Actin in Neuron

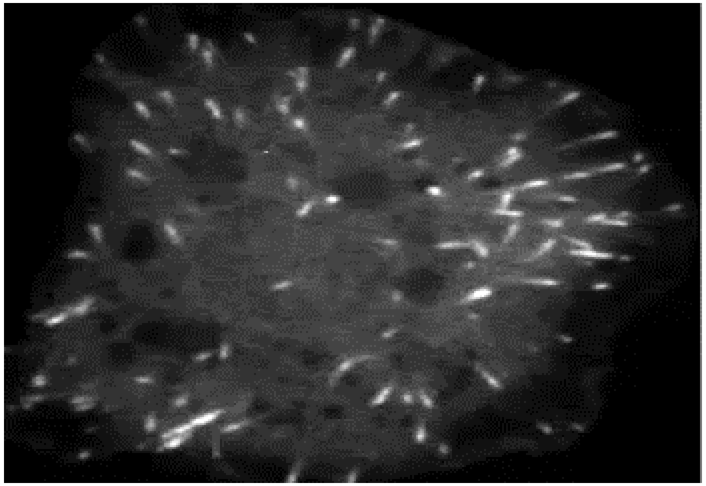


Video: Chloroplast Movement

Video: Cytoplasmic Stream



Video: Microtubule Movement



Video: Microtubules

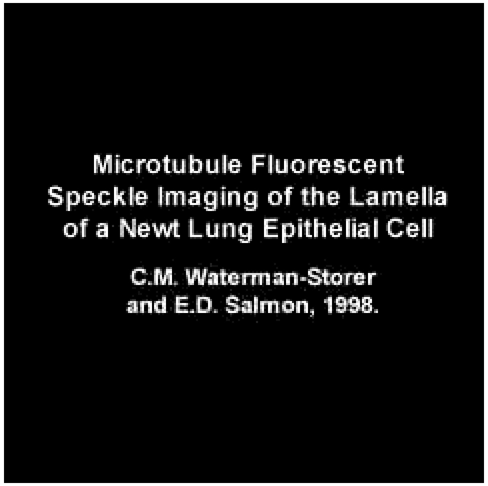


Figure 4.T01

Table 4.1 The Structure and Function of the Cytoskeleton

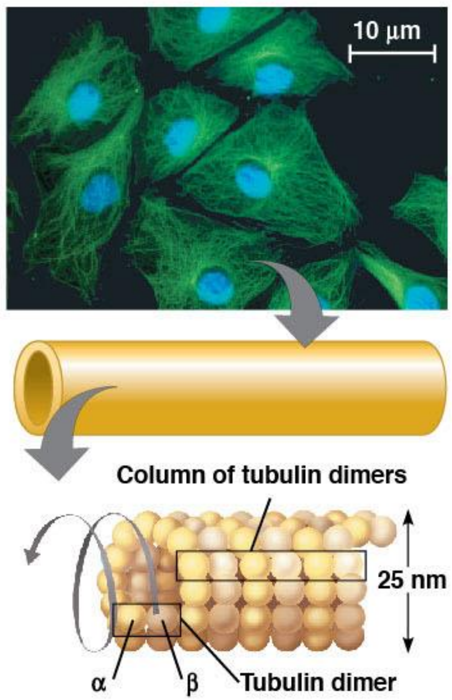
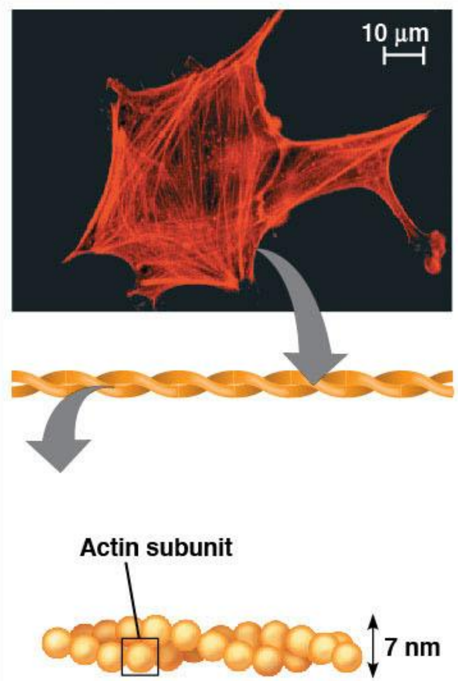
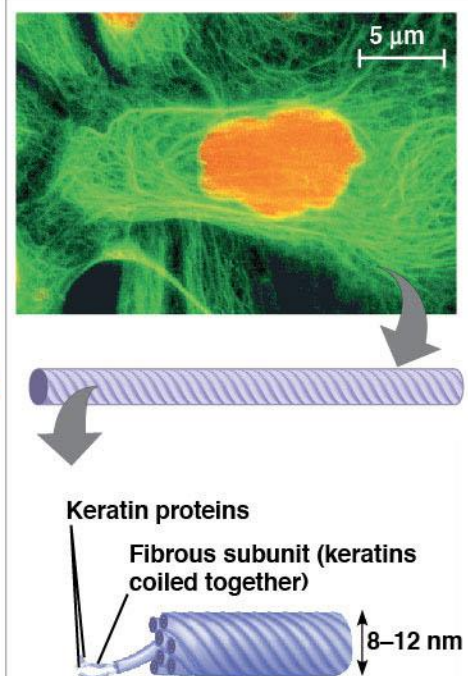
Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes	Two intertwined strands of actin	Fibrous proteins coiled into cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, a dimer consisting of α-tubulin and β-tubulin	Actin	One of several different proteins (such as keratins)
Main functions	Maintenance of cell shape; cell motility; chromosome movements in cell division; organelle movements	Maintenance of cell shape; changes in cell shape; muscle contraction; cytoplasmic streaming (plant cells); cell motility; cell division (animal cells)	Maintenance of cell shape; anchorage of nucleus and certain other organelles; formation of nuclear lamina
Fluorescence micrographs of fibroblasts. Fibroblasts are a favorite cell type for cell biology studies because they spread out flat and their internal structures are easy to see. In each, the structure of interest has been tagged with fluorescent molecules. The DNA in the nucleus has also been tagged in the first micrograph (blue) and third micrograph (orange).			

Figure 4.T01-1

Microtubules (Tubulin Polymers)
Hollow tubes
25 nm with 15-nm lumen
Tubulin, a dimer consisting of α-tubulin and β-tubulin
Maintenance of cell shape; cell motility; chromosome movements in cell division; organelle movements

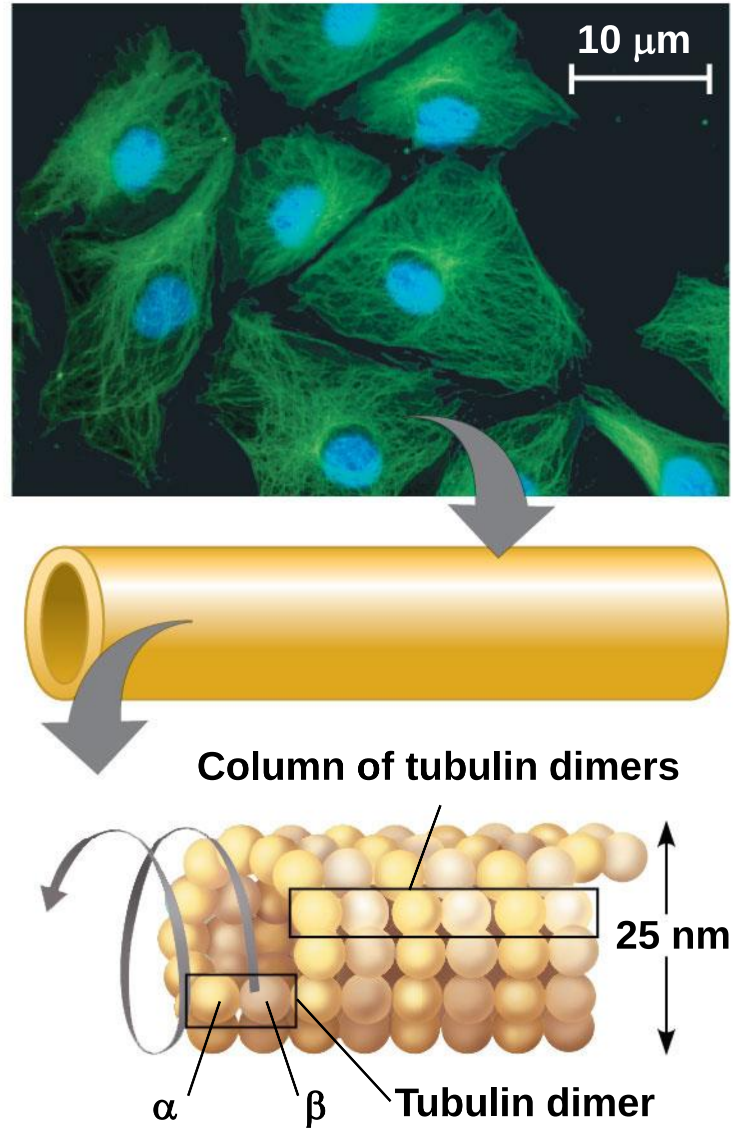


Figure 4.T01-1a

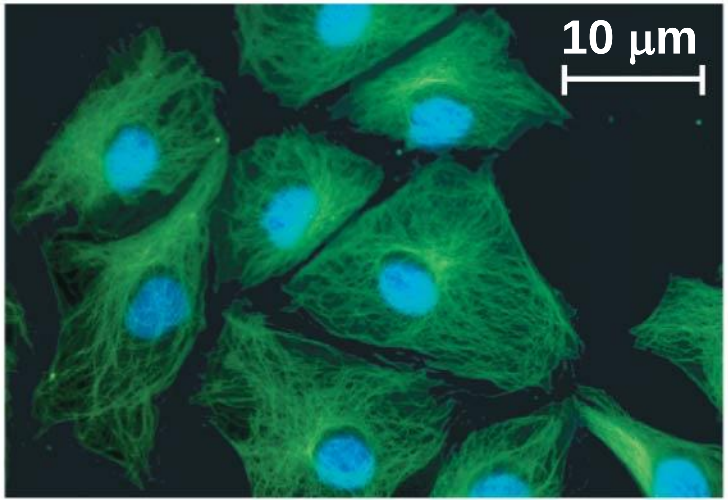


Figure 4.T01-2

Microfilaments (Actin Filaments)
Two intertwined strands of actin
7 nm
Actin
Maintenance of cell shape; changes in cell shape; muscle contraction; cy-toplasmic streaming (plant cells); cell motility; cell division (animal cells)

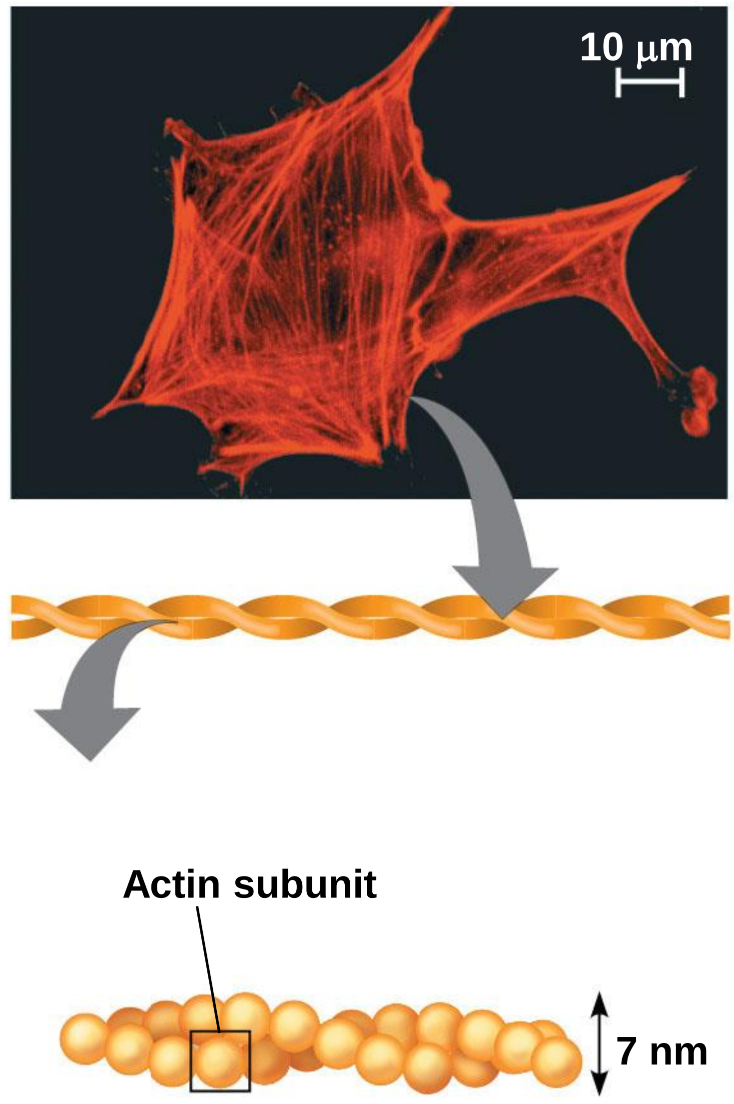


Figure 4.T01-2a

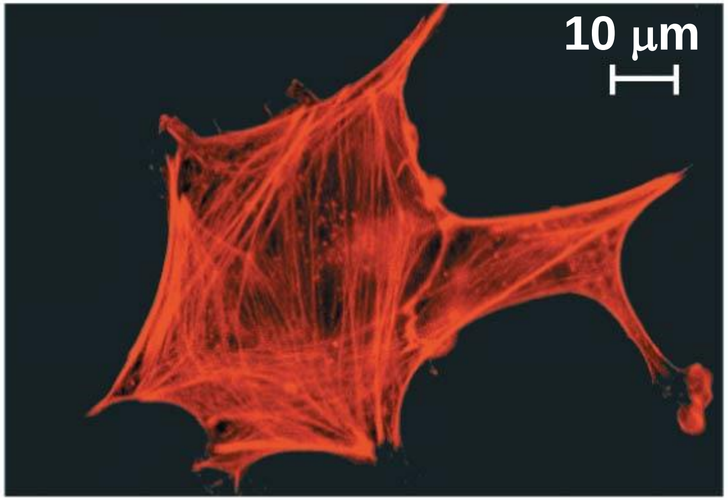


Figure 4.T01-3

Intermediate Filaments
Fibrous proteins coiled into cables
8–12 nm
One of several different proteins (such as keratins)
Maintenance of cell shape; anchorage of nucleus and certain other organelles; formation of nuclear lamina

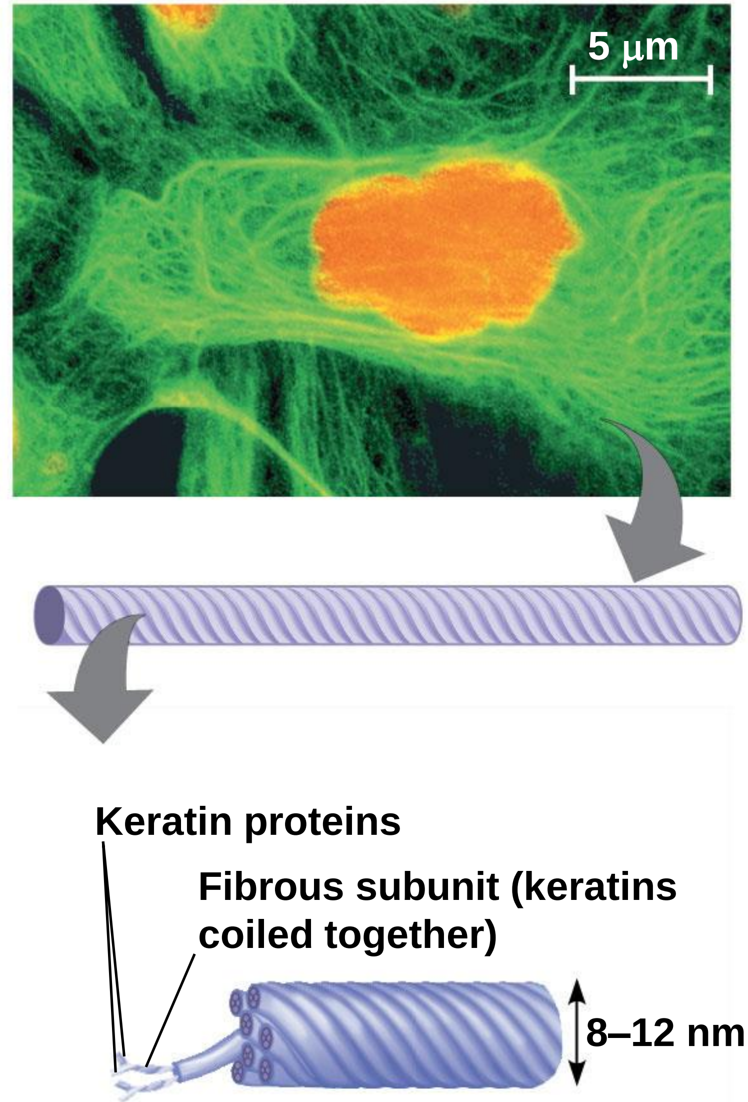
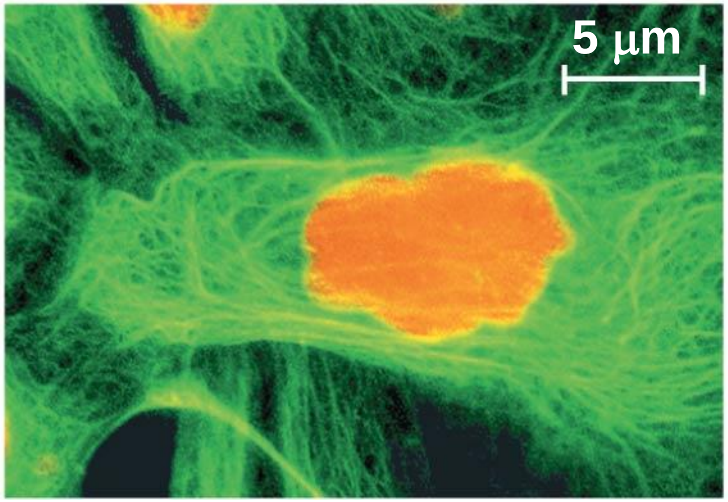


Figure 4.T01-3a



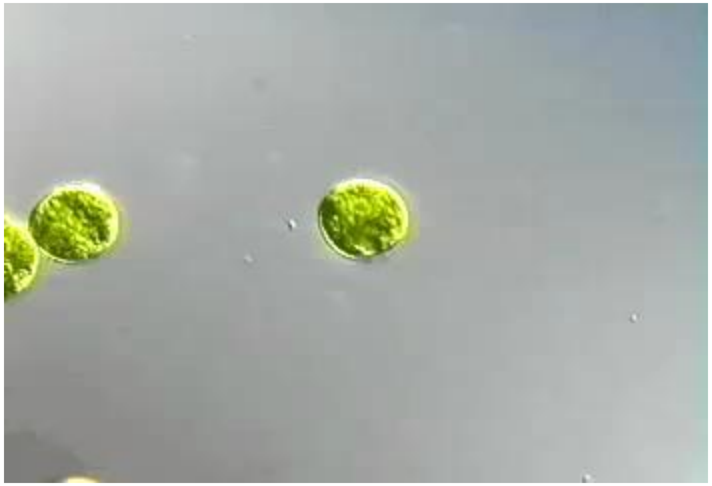
Microtubules

- **Microtubules** are hollow rods constructed from globular protein dimers called tubulin
- Functions of microtubules
  - Shape and support the cell
  - Guide movement of organelles
  - Separate chromosomes during cell division

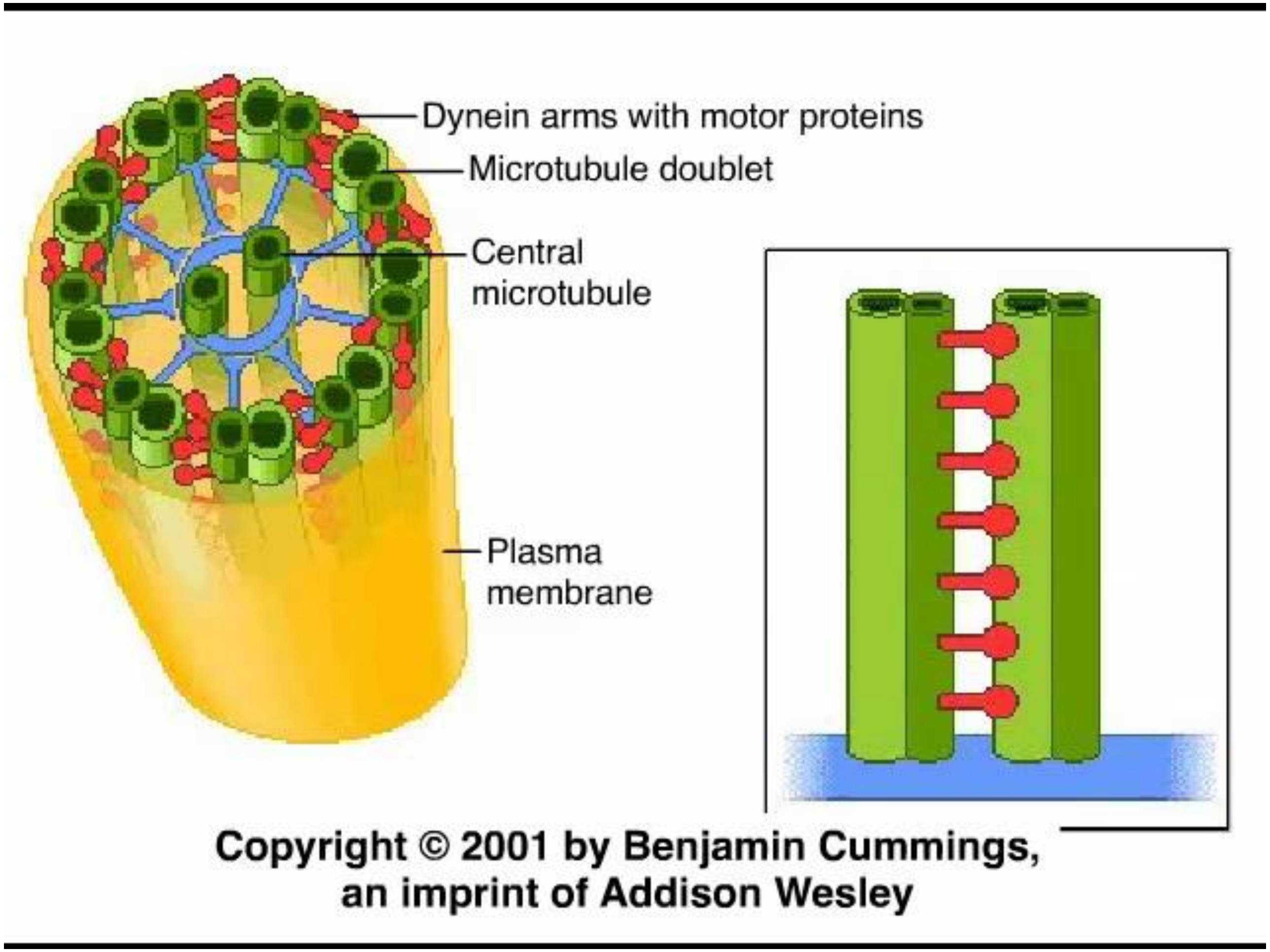
Centrosomes and Centrioles

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

Video: *Chlamydomonas*

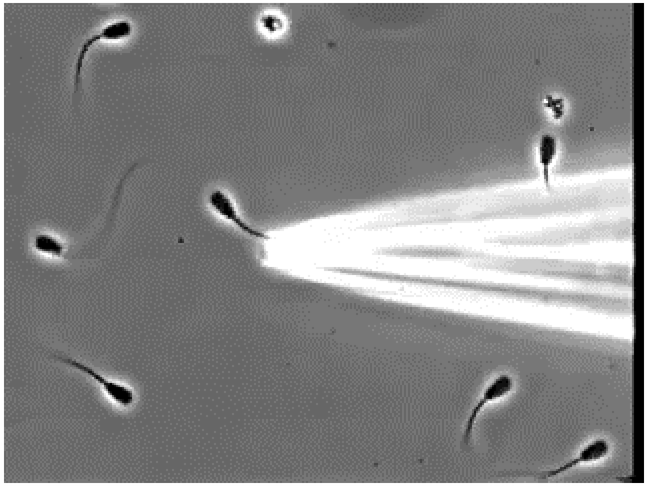


Animation: Cilia Flagella

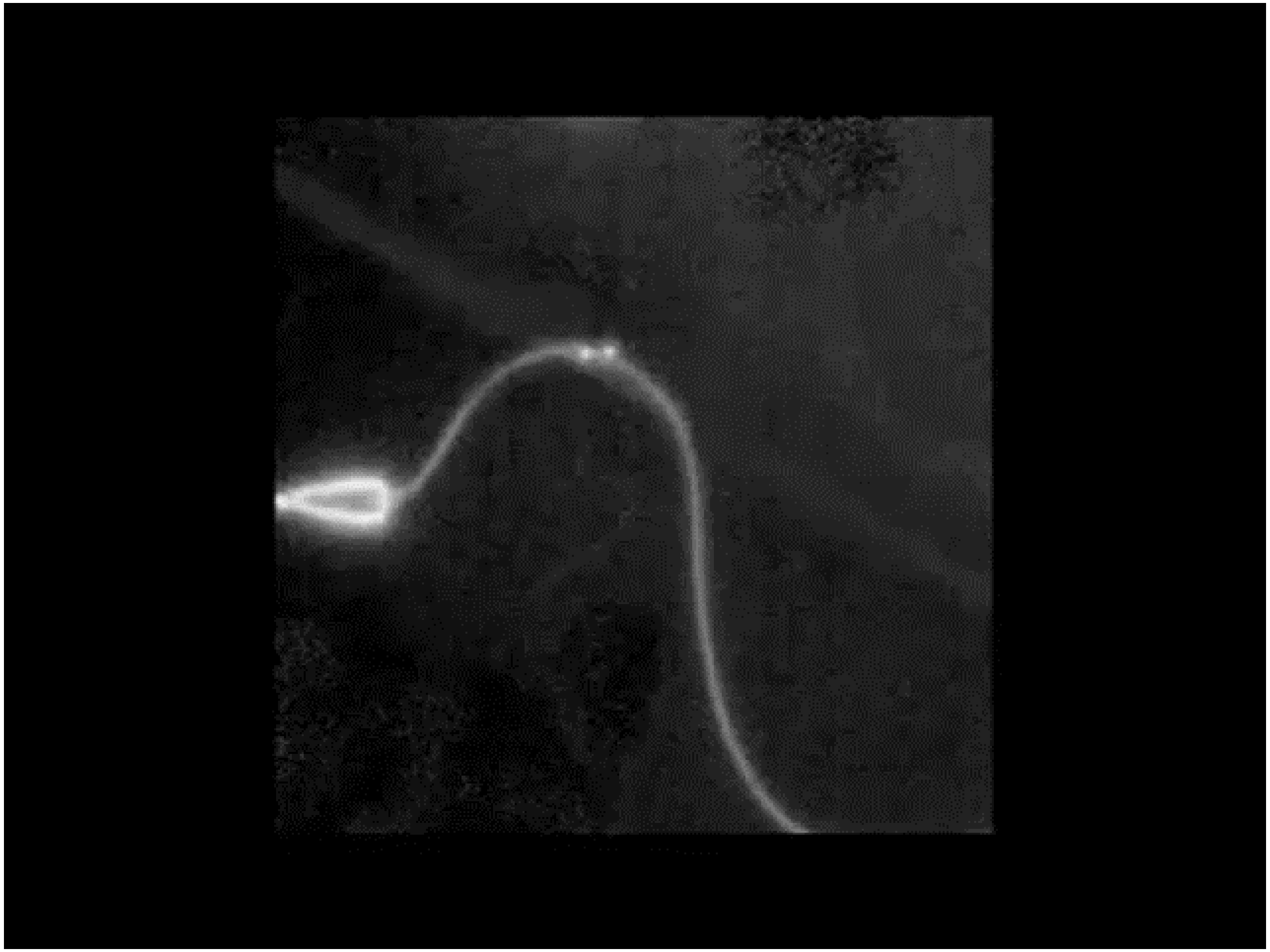


Video: Ciliary Motion

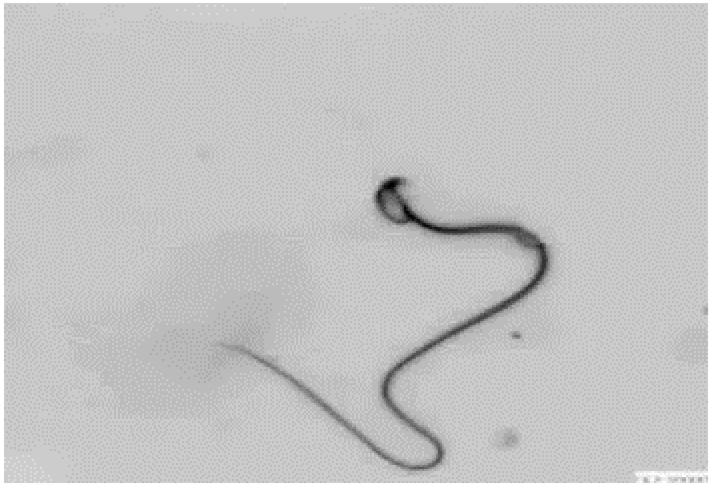
Video: Flagella in Sperm



Video: Flagellum Microtubule

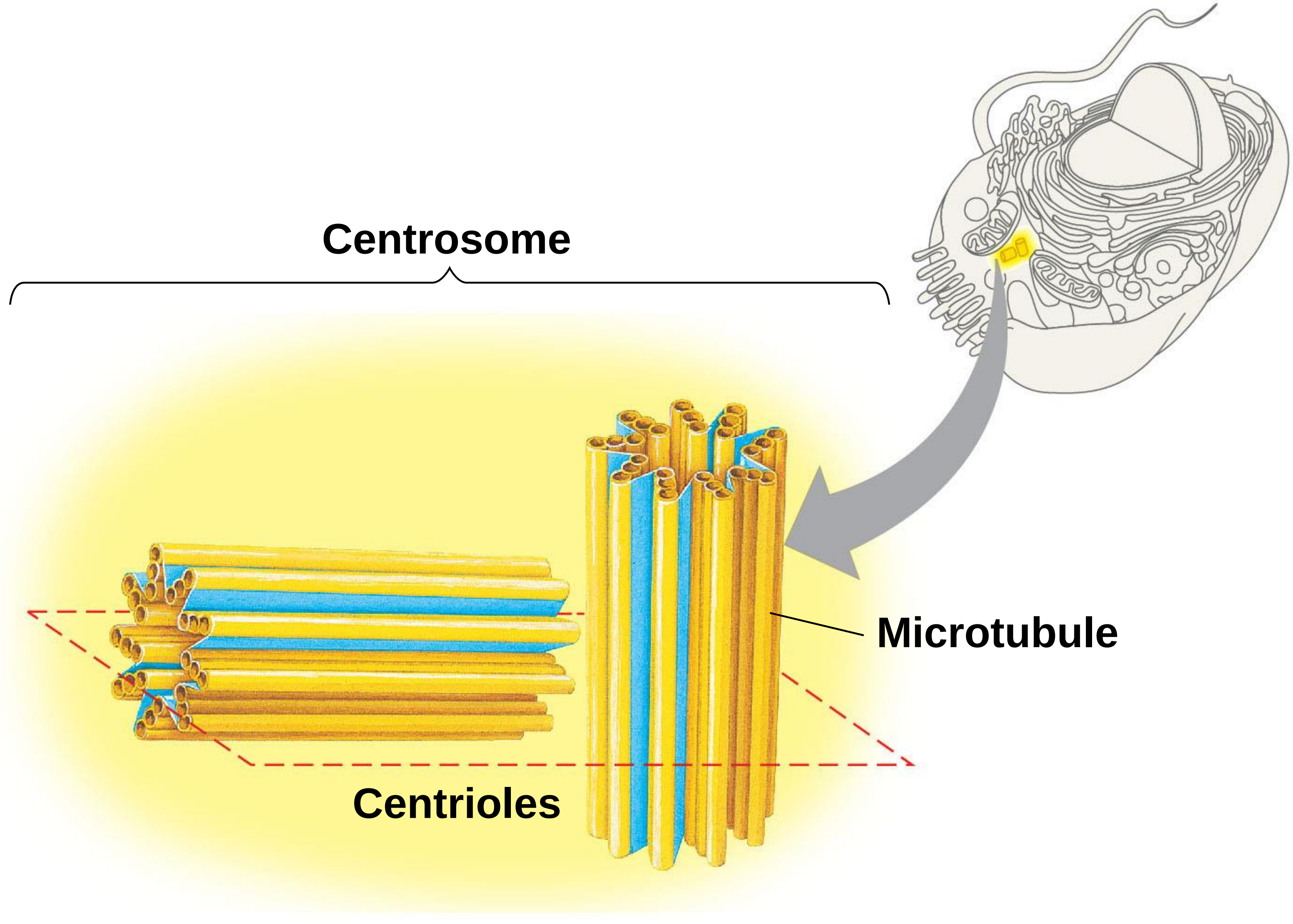


Video: Sperm Flagellum



Video: *Paramecium* Cilia

Figure 4.22

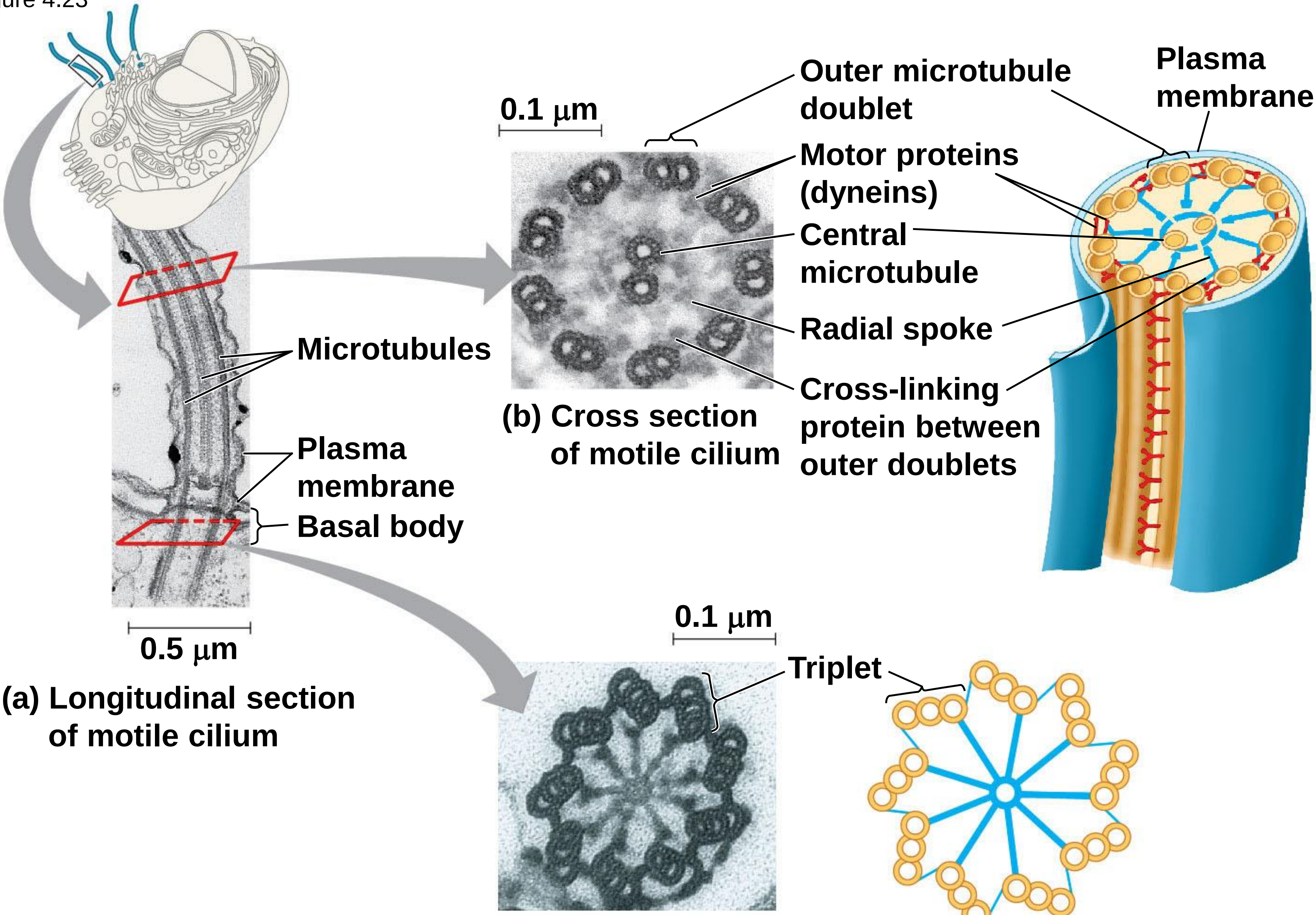


Cilia and Flagella

- Microtubules control the beating of **cilia** and **flagella**, microtubule-containing extensions projecting from some cells
- Flagella are limited to one or a few per cell, while cilia occur in large numbers on cell surfaces
- Cilia and flagella also differ in their beating patterns

- Cilia and flagella share a common structure
  - A group 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

Figure 4.23

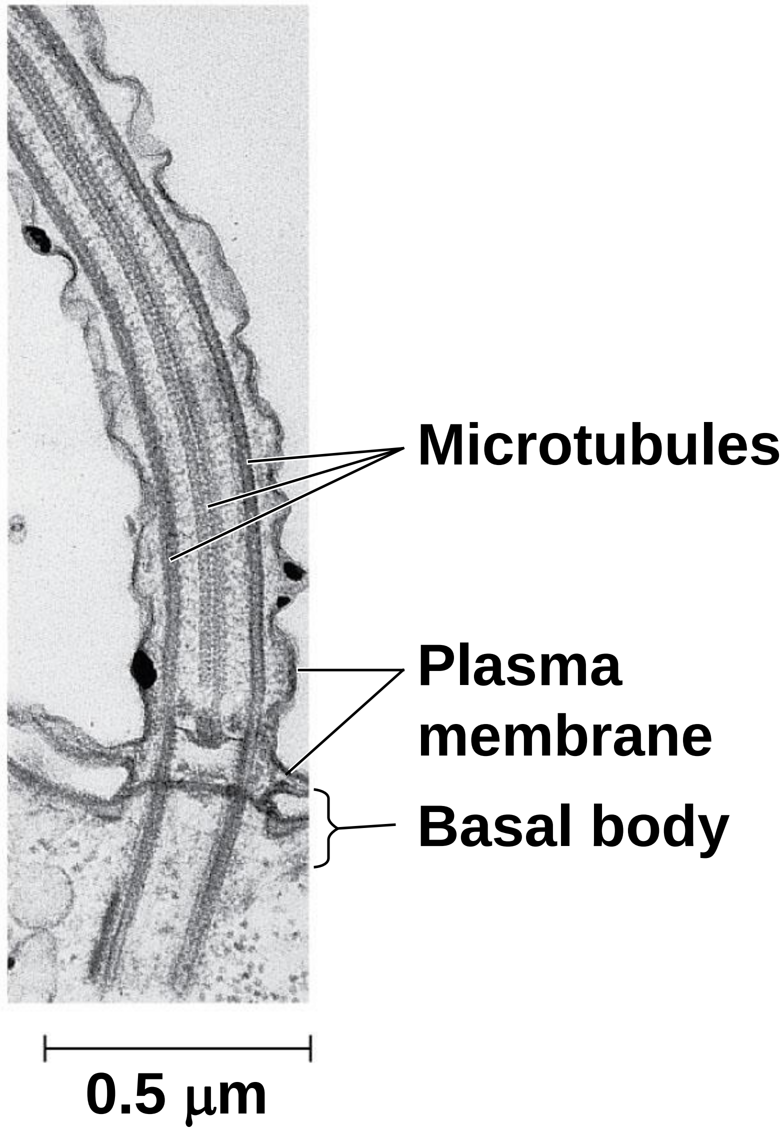


(a) Longitudinal section of motile cilium

(b) Cross section of motile cilium

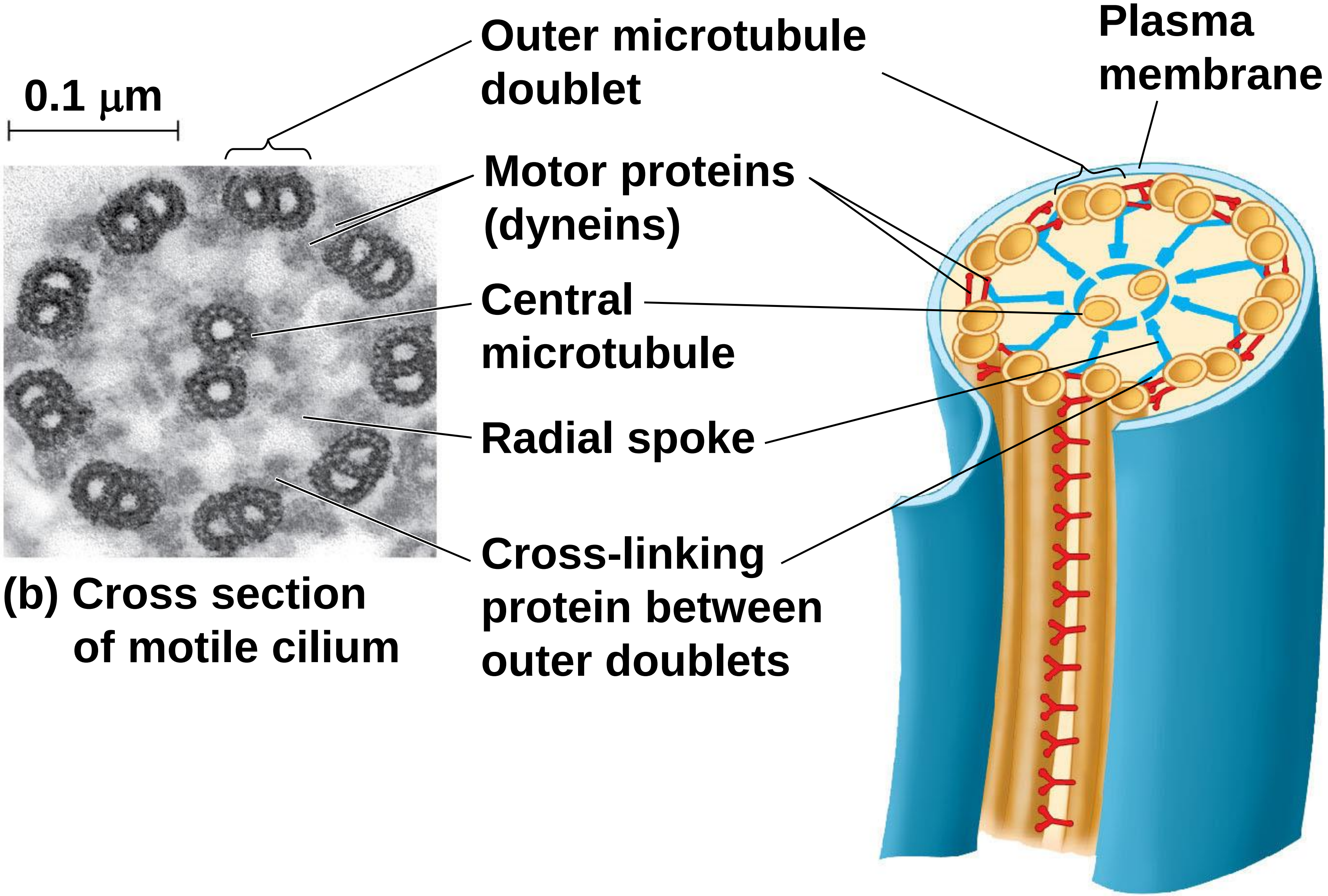
(c) Cross section of basal body

Figure 4.23-1

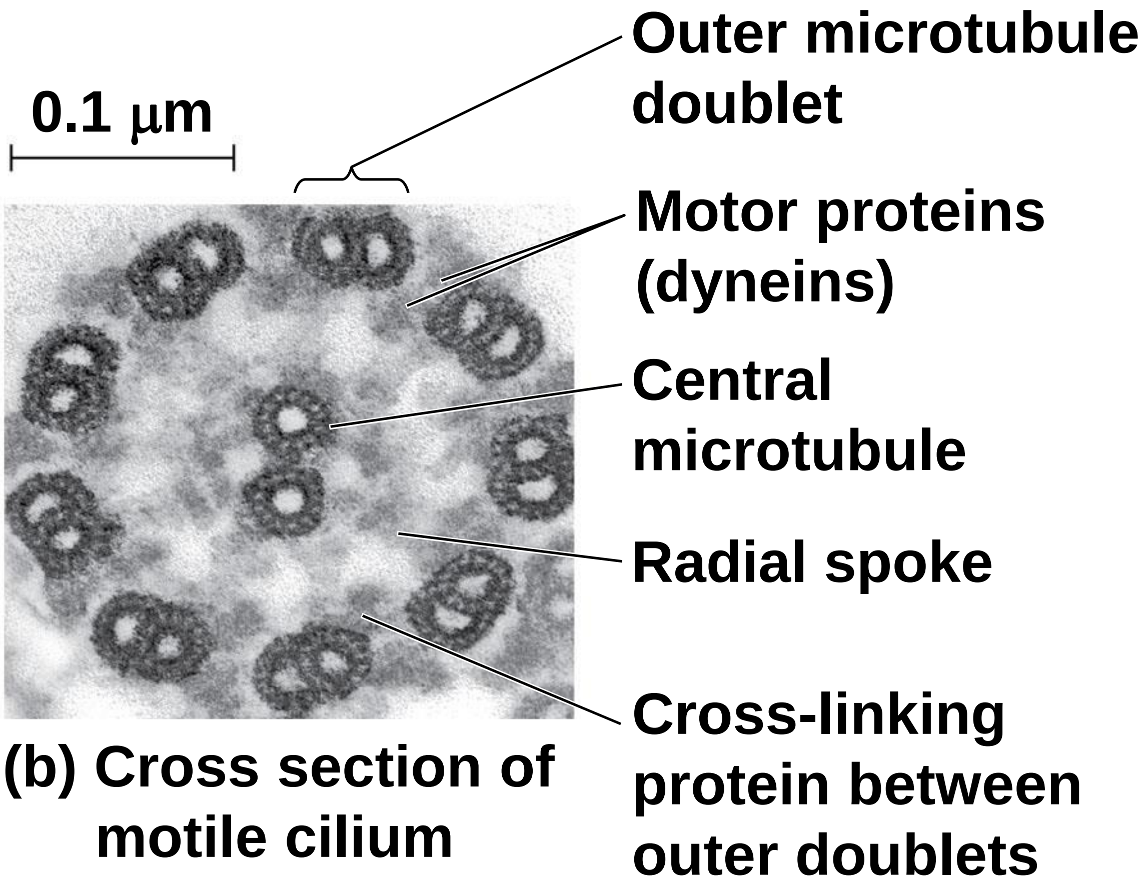


(a) Longitudinal section of motile cilium

Figure 4.23-2

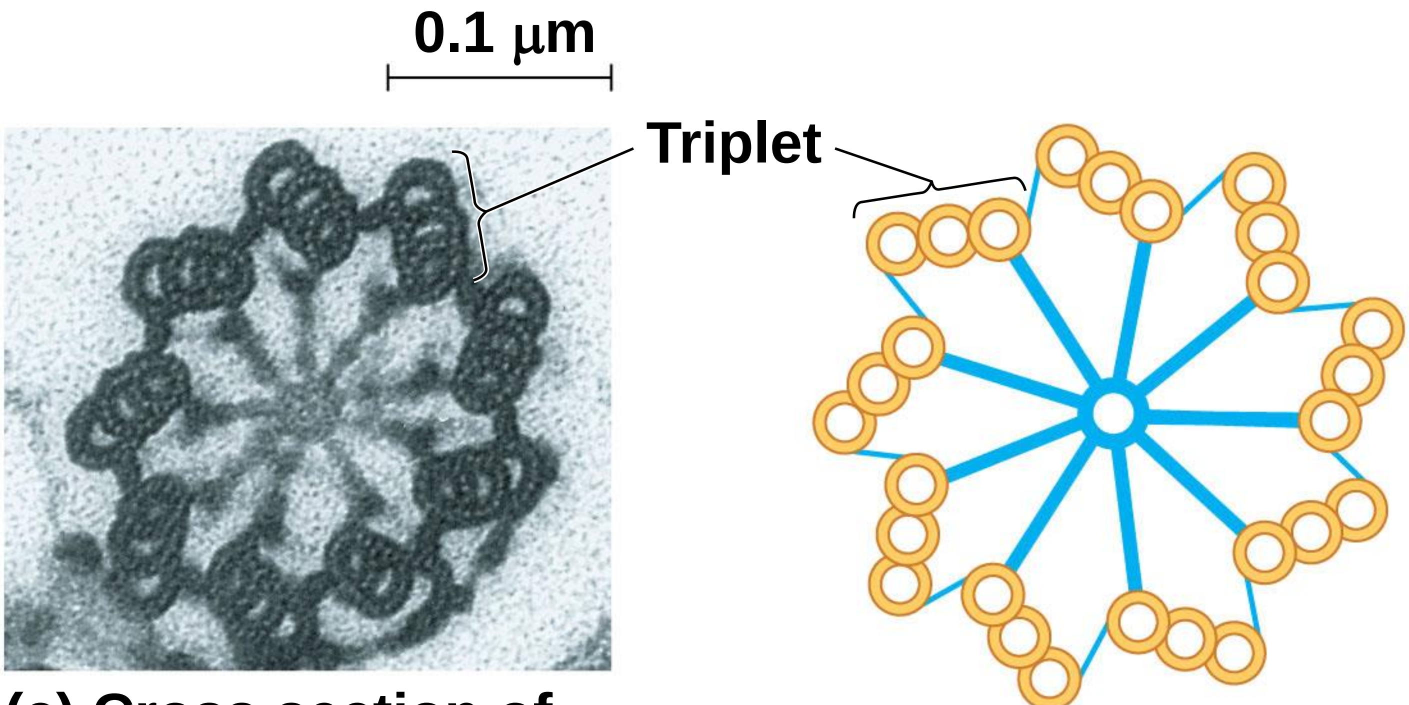


(b) Cross section of motile cilium



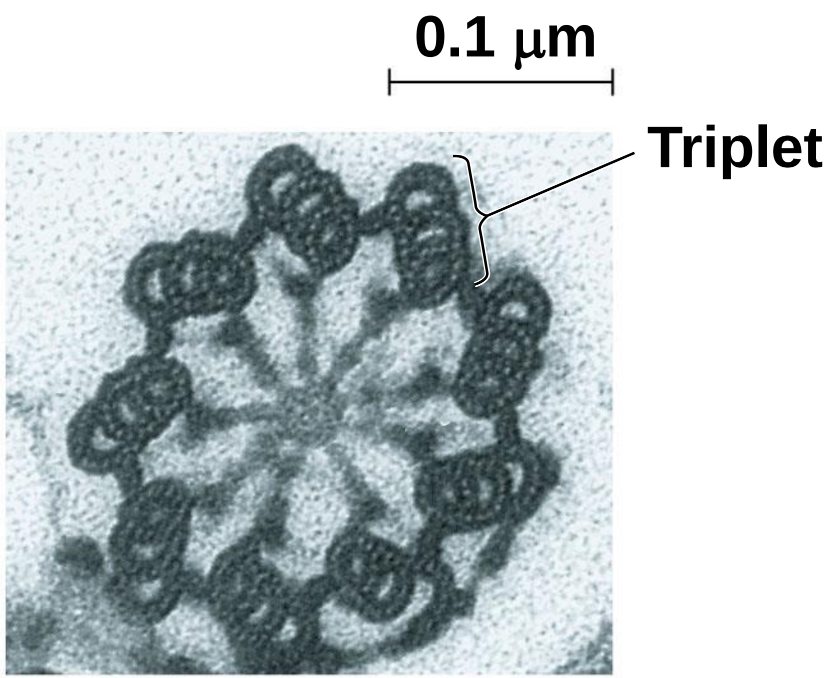
(b) Cross section of motile cilium

Figure 4.23-3



(c) Cross section of basal body

Figure 4.23-3a



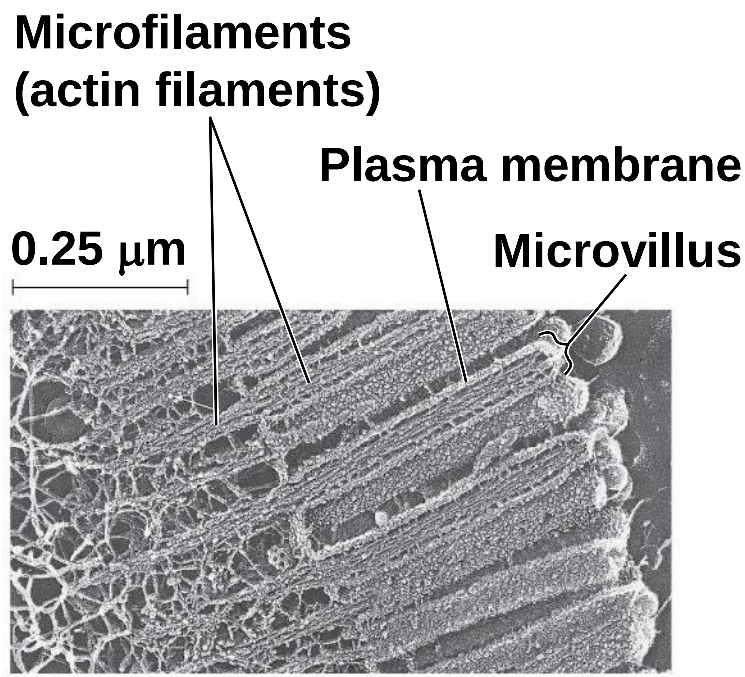
(c) Cross section of basal body

- How dynein “walking” moves flagella and cilia
  - Dynein arms alternately contact, move, and release the outer microtubules
  - The outer doublets and central microtubules are held together by flexible cross-linking proteins
  - Movements of the doublet arms cause the cilium or flagellum to bend

Microfilaments (Actin Filaments)

- **Microfilaments** are thin solid rods, built from molecules of globular **actin** subunits
- The structural role of microfilaments is to bear tension, resisting pulling forces within the cell
- Bundles of microfilaments make up the core of microvilli of intestinal cells

Figure 4.24



Microfilaments
(actin filaments)
Plasma membrane
0.25 μm
Microvillus

- Microfilaments that function in cellular motility interact with the motor protein **myosin**
- For example, actin and myosin interact to cause muscle contraction, amoeboid movement of white blood cells, and cytoplasmic streaming in plant cells

Intermediate Filaments

- **Intermediate filaments** are larger than microfilaments but smaller than microtubules
- Intermediate filaments are only found in the cells of some animals, including vertebrates
- They support cell shape and fix organelles in place
- Intermediate filaments are more permanent cytoskeleton elements than the other two classes

Concept 4.7: Extracellular components and connections between cells help coordinate cellular activities

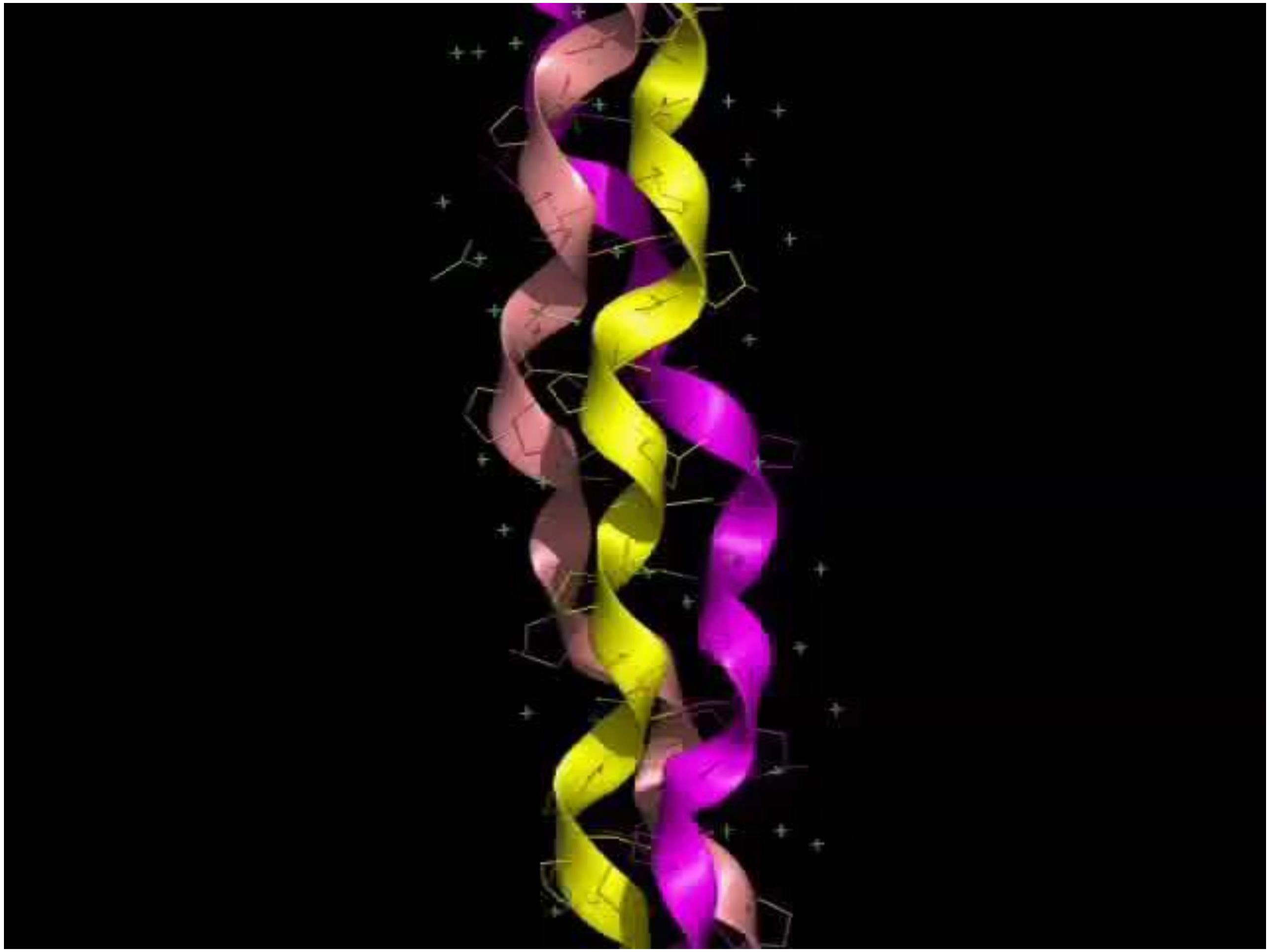
- Most cells synthesize and secrete materials that are external to the plasma membrane
- These extracellular materials are involved in many cellular functions

Cell Walls of Plants

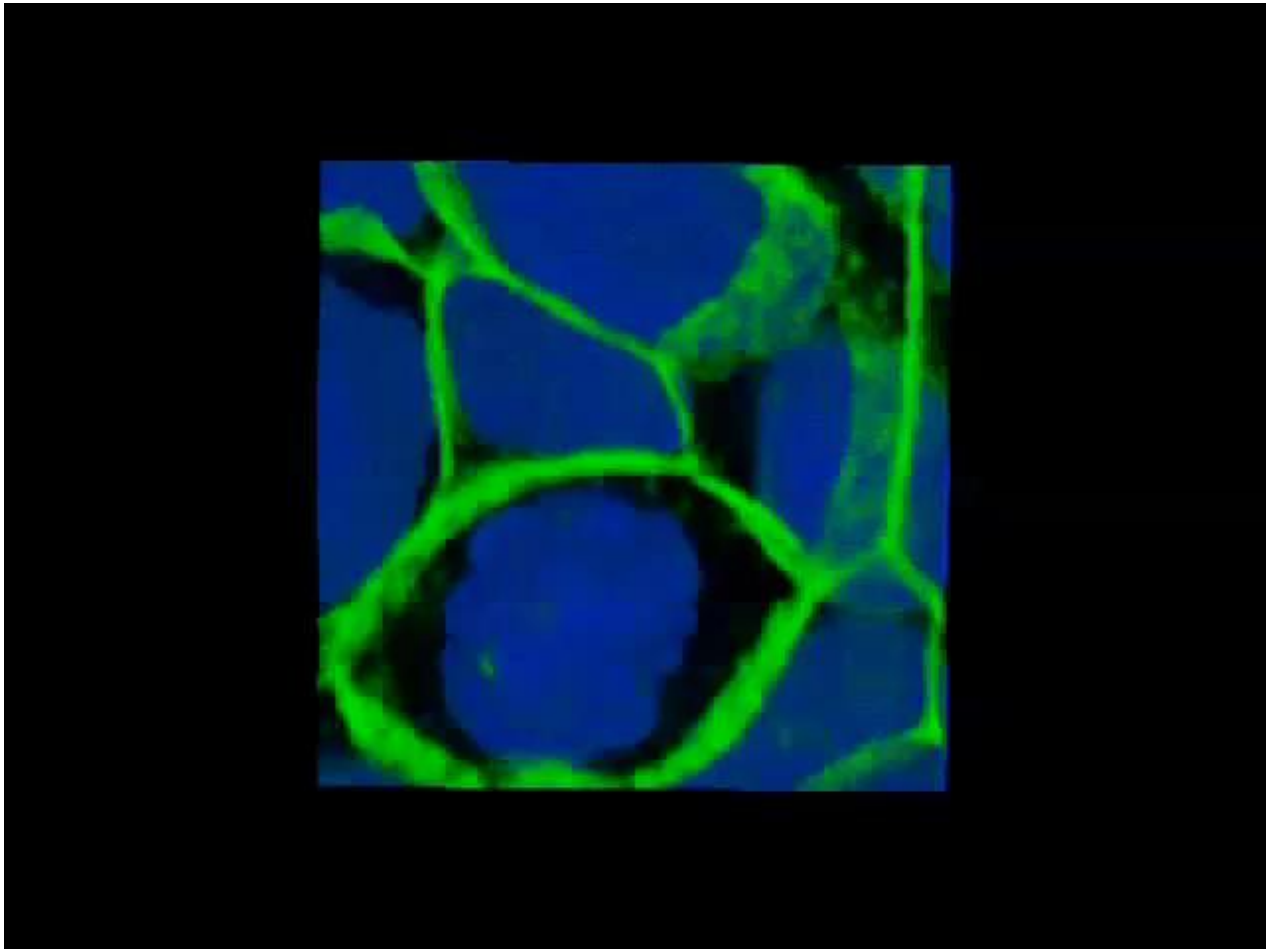
- The **cell wall** is an extracellular structure that distinguishes plant cells from animal cells
- The cell wall protects the plant cell, maintains its shape, and prevents excessive uptake of water
- Plant cell walls are made of cellulose fibers embedded in other polysaccharides and protein

- 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

Video: Collagen Model



Video: Extracellular Matrix



Video: Fibronectin

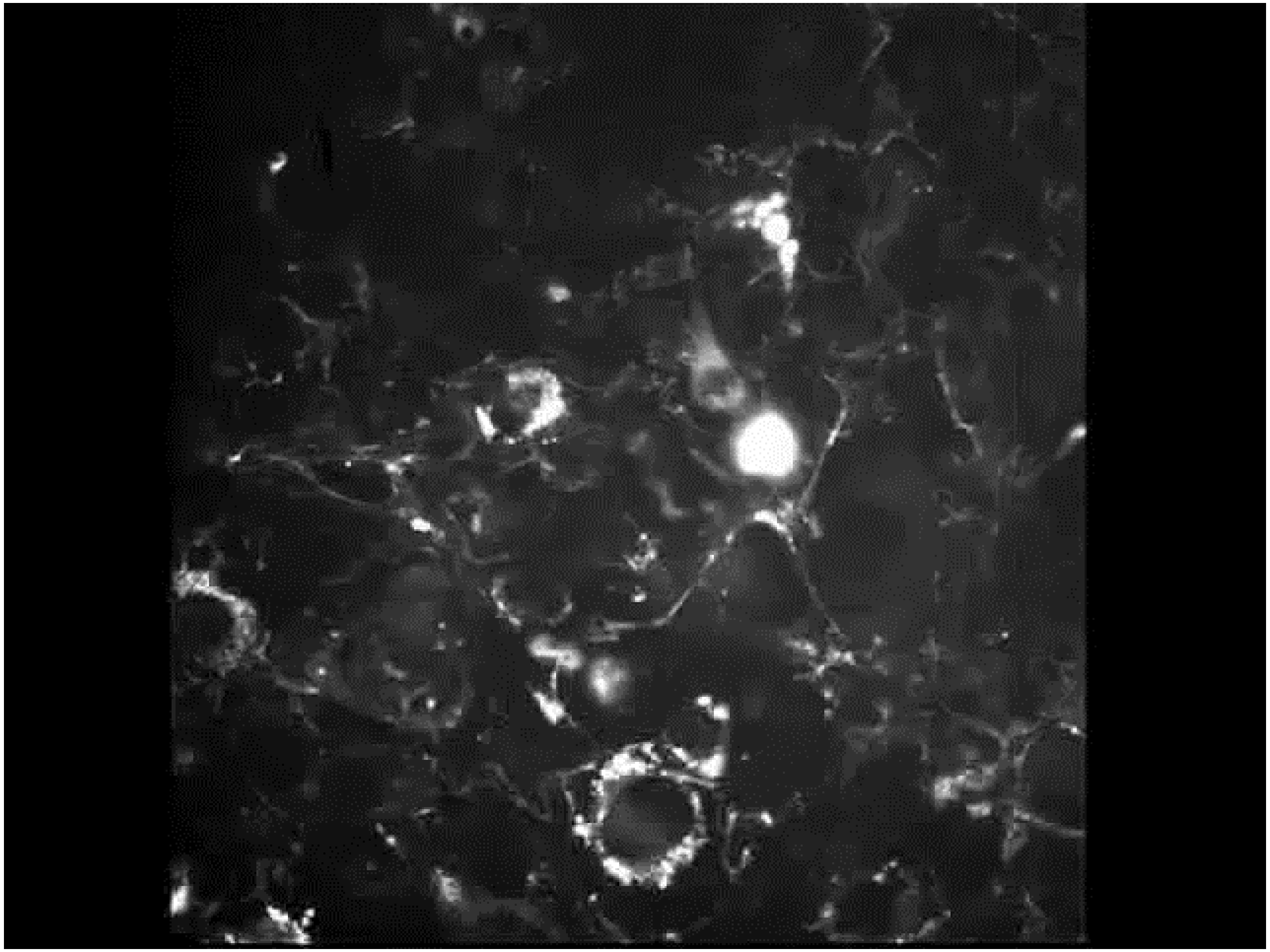
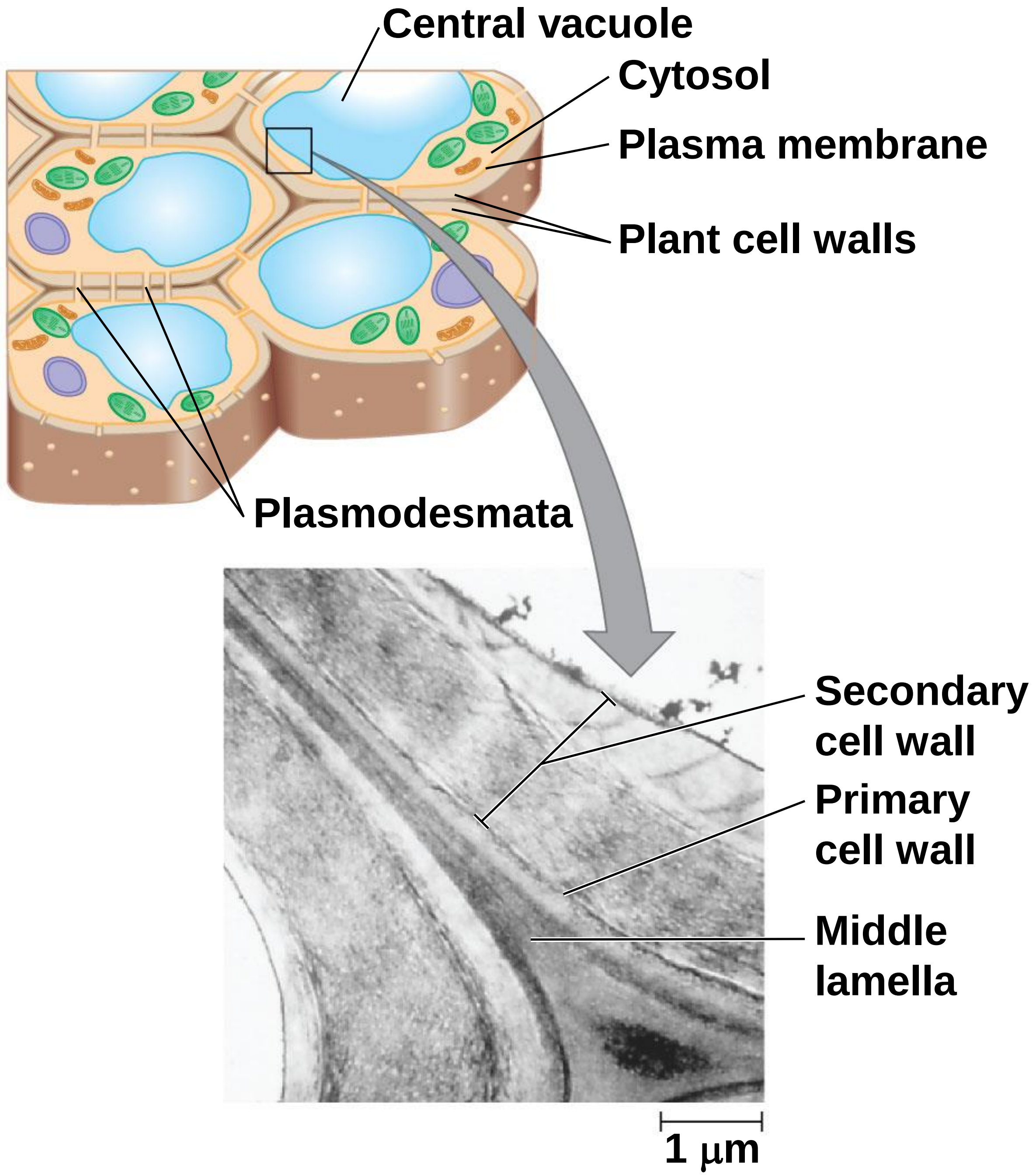
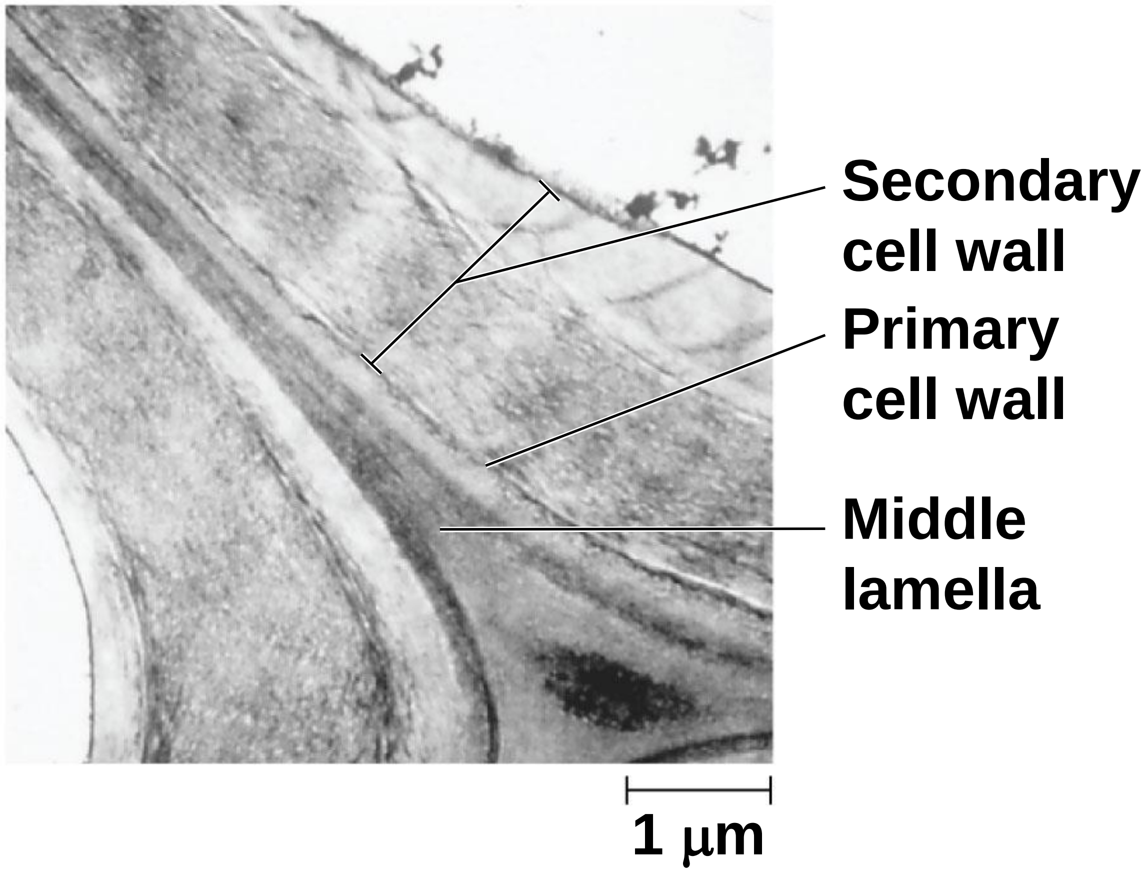


Figure 4.25



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

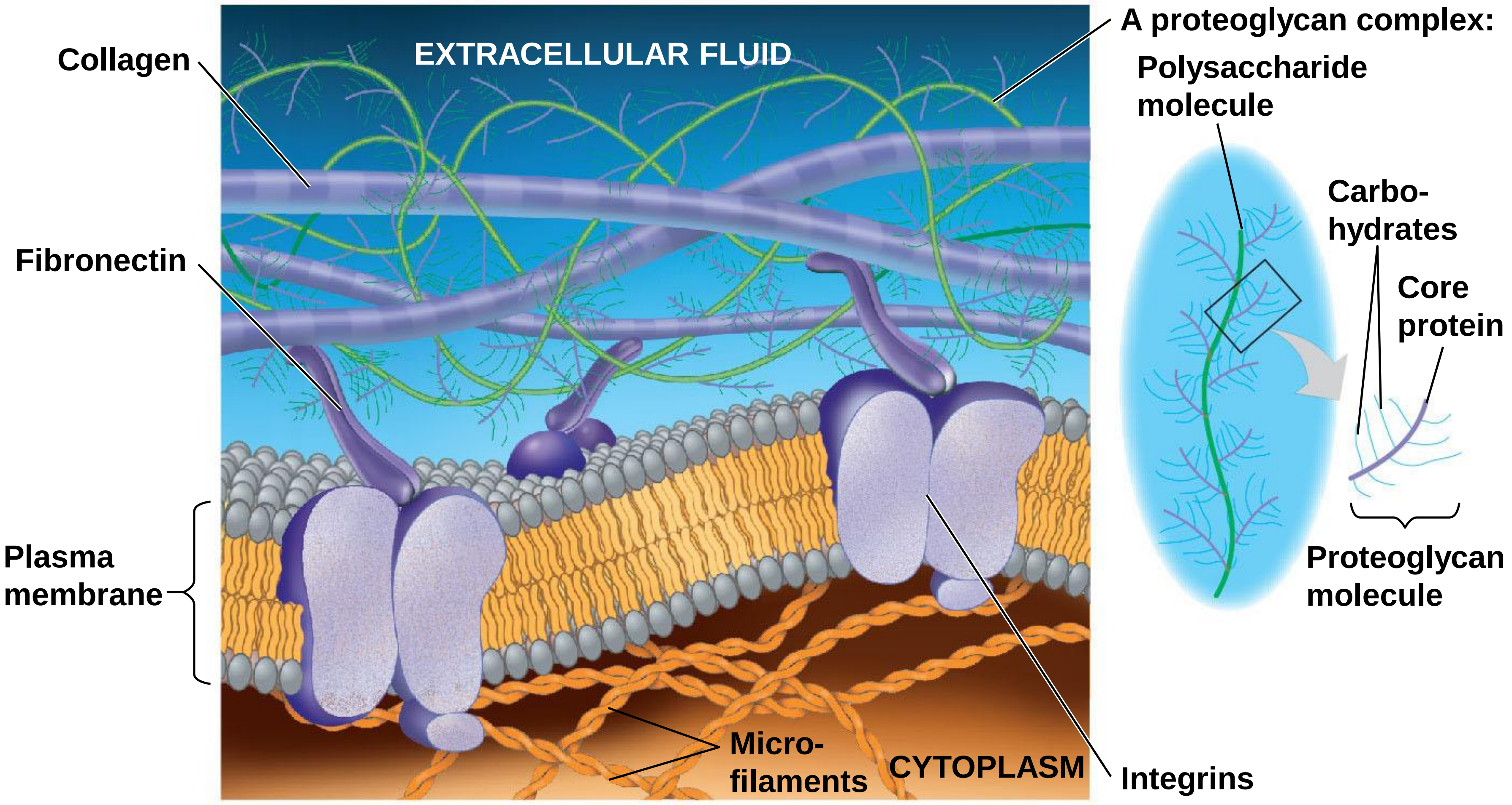
Figure 4.25-1



The Extracellular Matrix (ECM) of Animal Cells

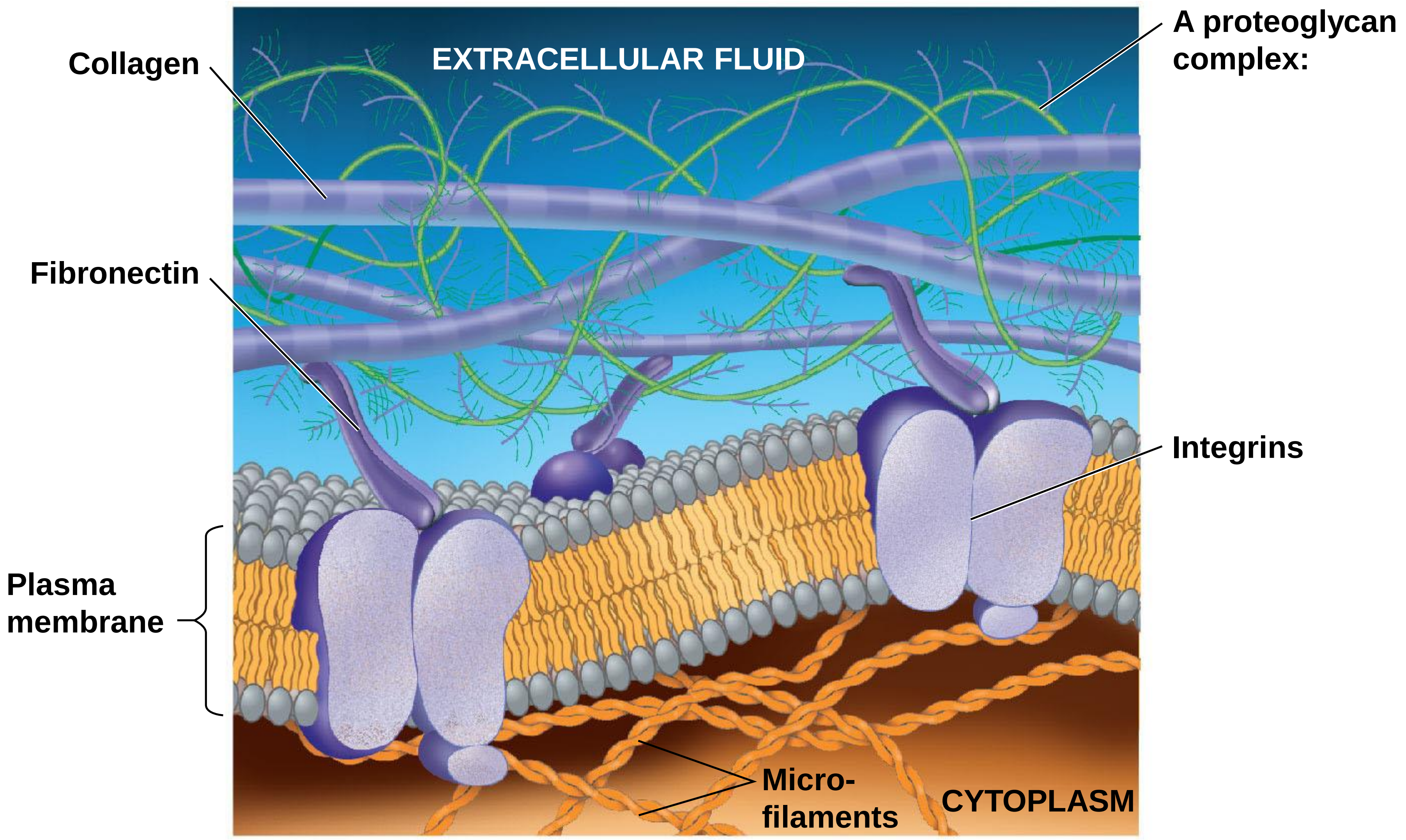
- Animal cells lack cell walls but are covered by an elaborate **extracellular matrix** (**ECM**)
- The ECM is made up of glycoproteins such as **collagen**, **proteoglycans**, and **fibronectin**
- ECM proteins bind to receptor proteins in the plasma membrane called **integrins**

Figure 4.26



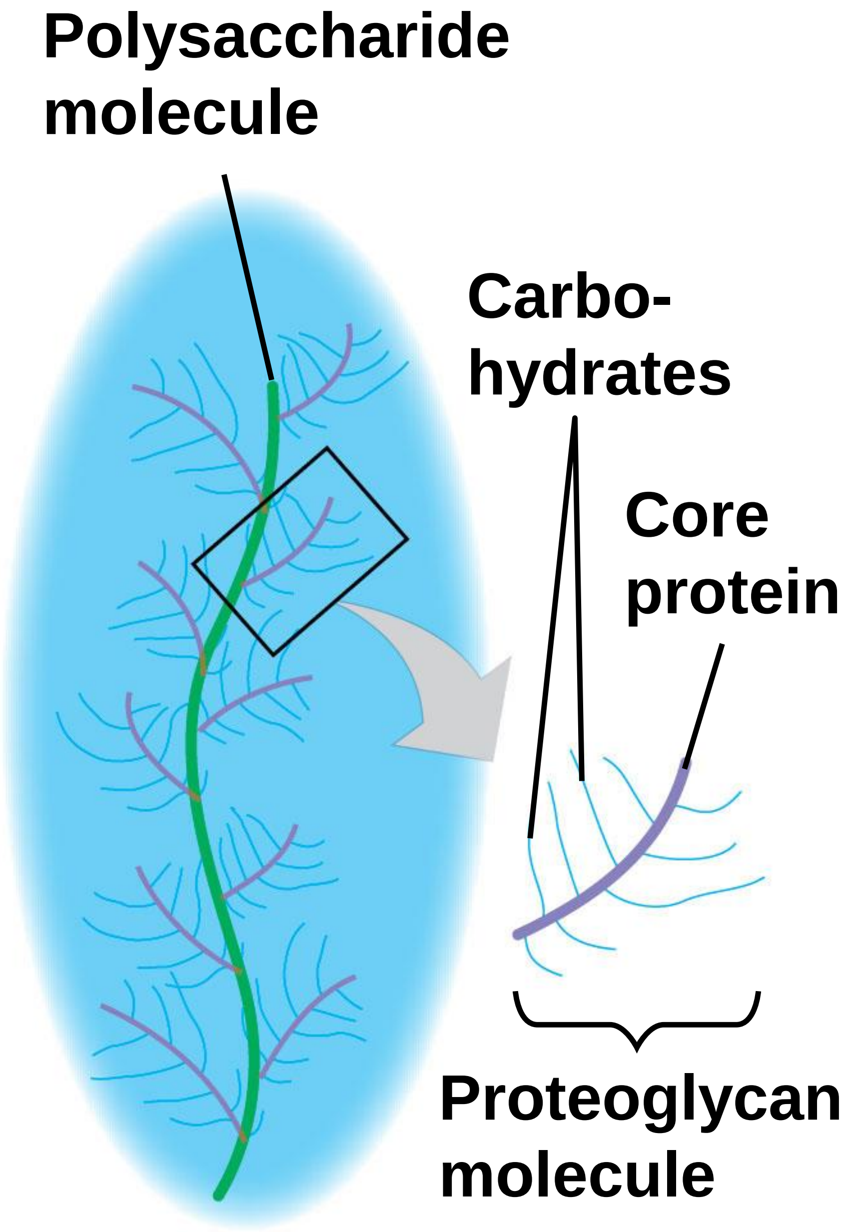
EXTRACELLULAR FLUID
Collagen
Fibronectin
Plasma membrane
Micro-filaments
CYTOPLASM
Integrins
A proteoglycan complex:
Polysaccharide molecule
Carbo-hydrates
Core protein
Proteoglycan molecule

Figure 4.26-1



Collagen
EXTRACELLULAR FLUID
A proteoglycan
complex:
Fibronectin
Integrins
Plasma
membrane
Micro-
filaments
CYTOPLASM

Figure 4.26-2



Polysaccharide
molecule
Carbo-
hydrates
Core
protein
Proteoglycan
molecule

Cell Junctions

- Neighboring cells in an animal or plant often adhere, interact, and communicate through direct physical contact
- There are several types of intercellular junctions that facilitate this
  - Plasmodesmata
  - Tight junctions
  - Desmosomes
  - Gap junctions

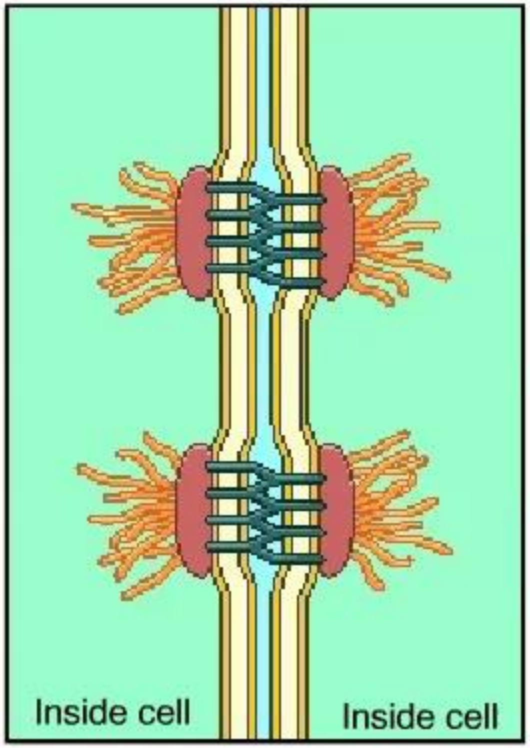
Plasmodesmata in Plant Cells

- **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

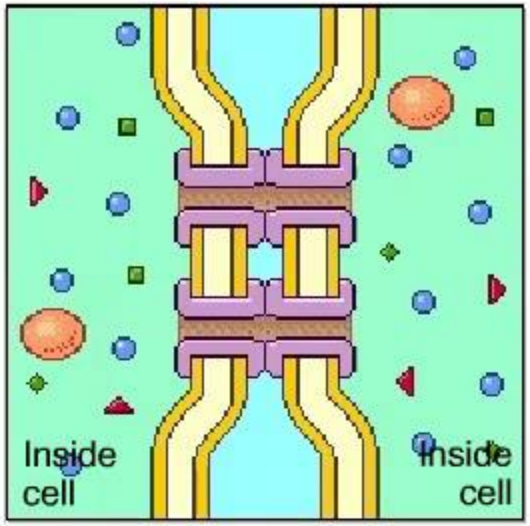
Tight Junctions, Desmosomes, and Gap Junctions in Animal Cells

- Animal cells have three main types of cell junctions
  - Tight junctions
  - Desmosomes
  - Gap junctions
- All are especially common in epithelial tissue

Animation: Desmosomes



Animation: Gap Junctions



Animation: Tight Junctions

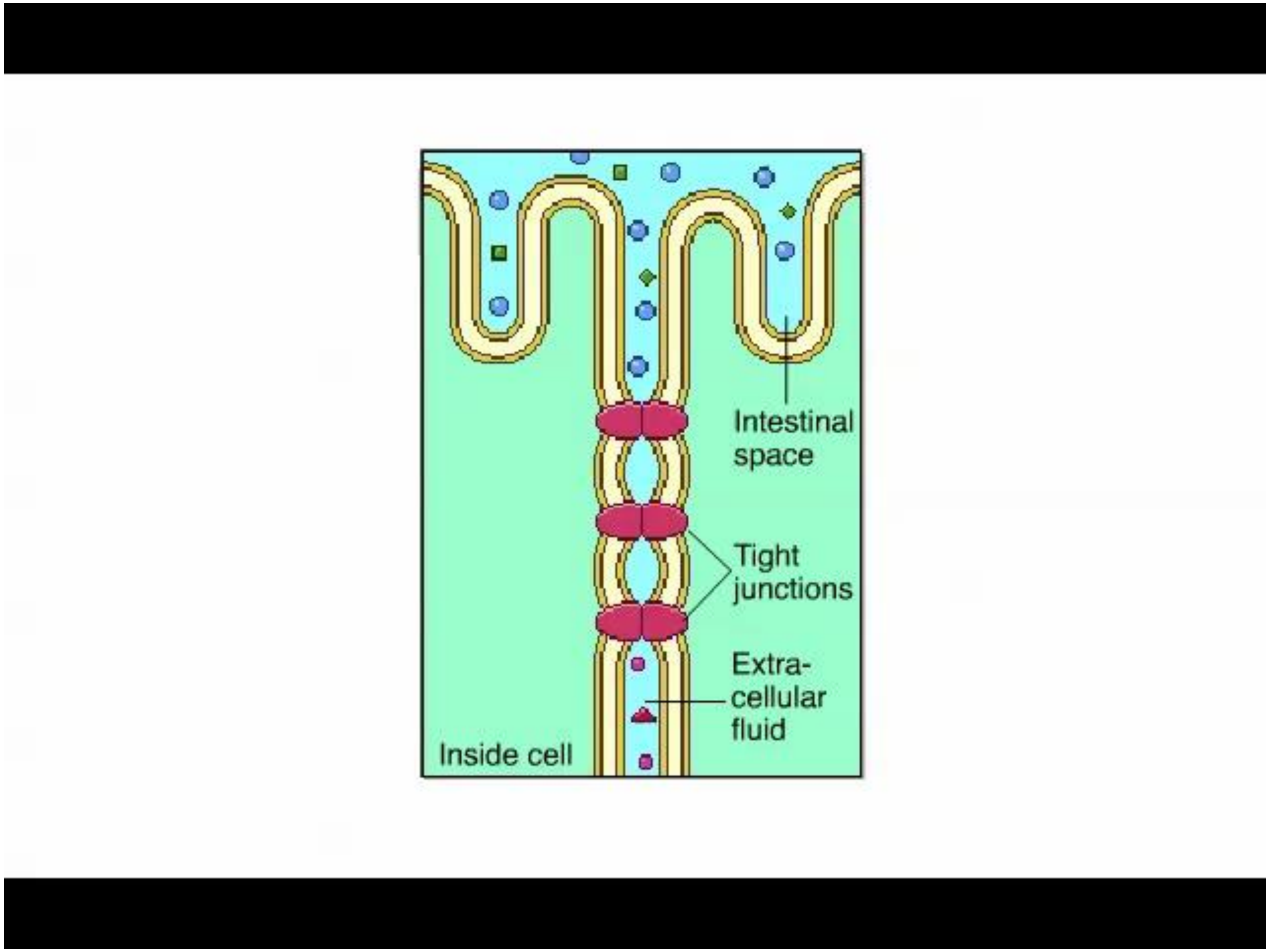
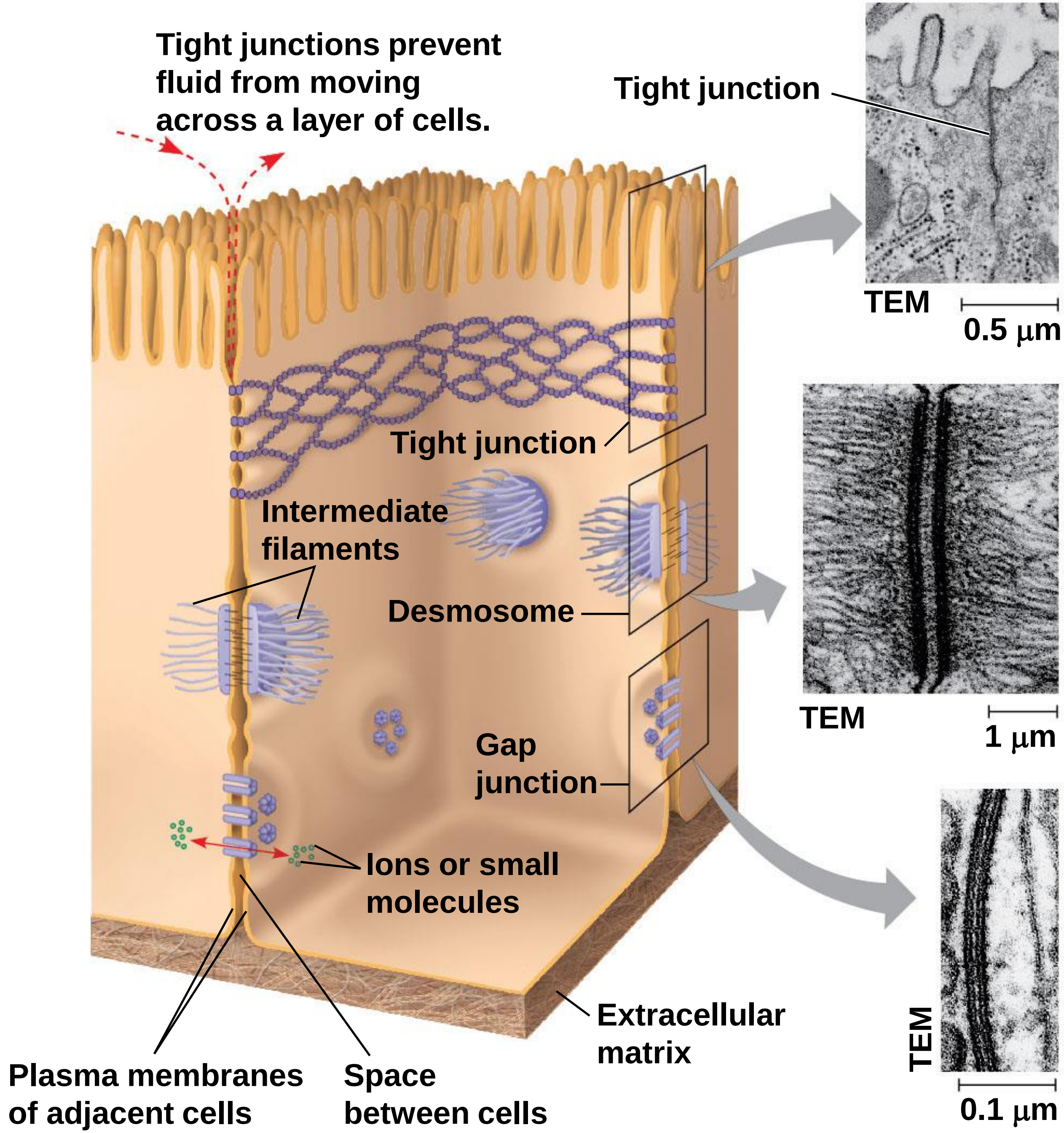


Figure 4.27



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

Figure 4.27-1

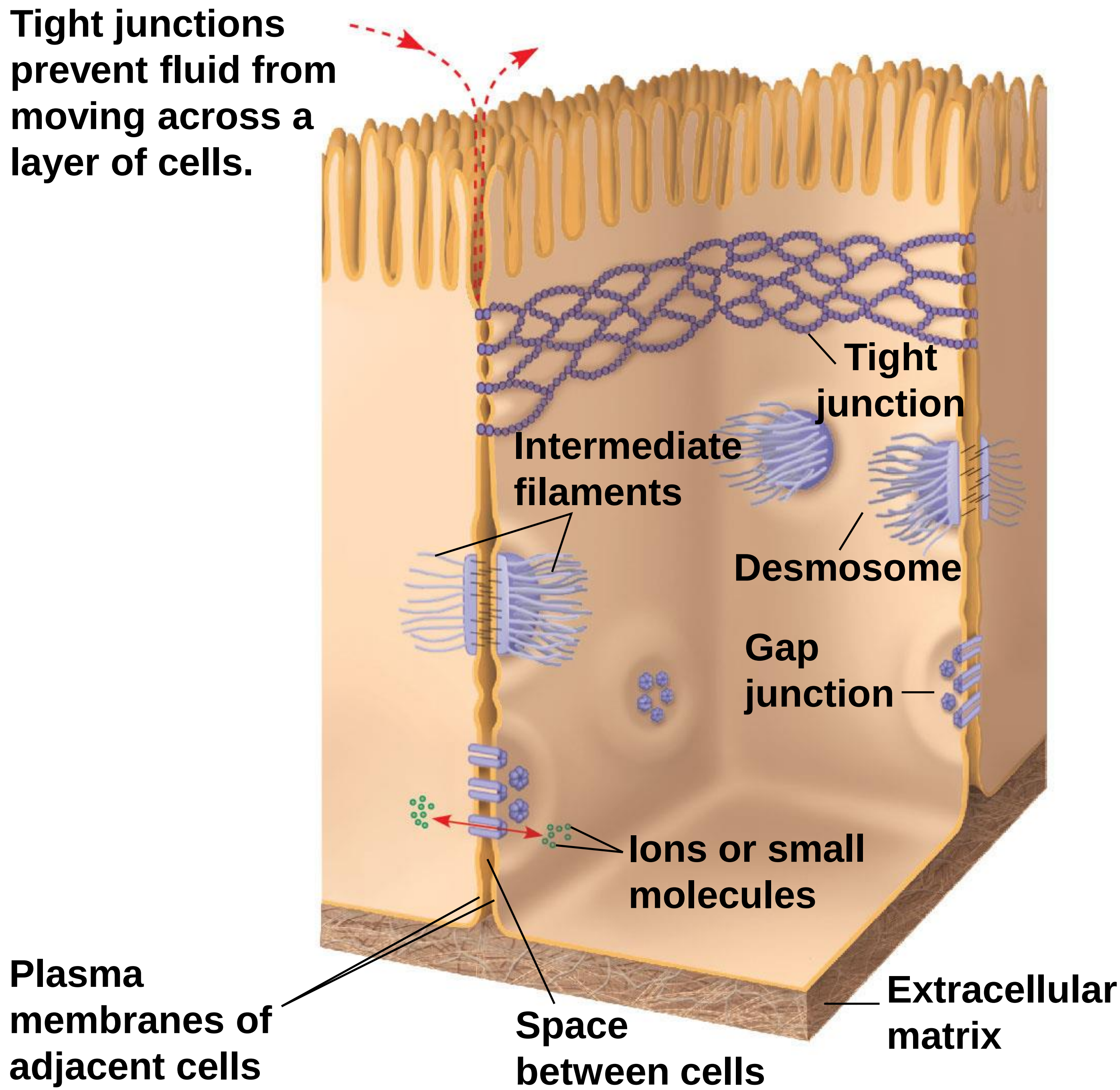

Tight junctions prevent fluid from moving across a layer of cells.
Tight junction
Intermediate filaments
Desmosome
Gap junction
Ions or small molecules
Plasma membranes of adjacent cells
Space between cells
Extracellular matrix

Figure 4.27-2

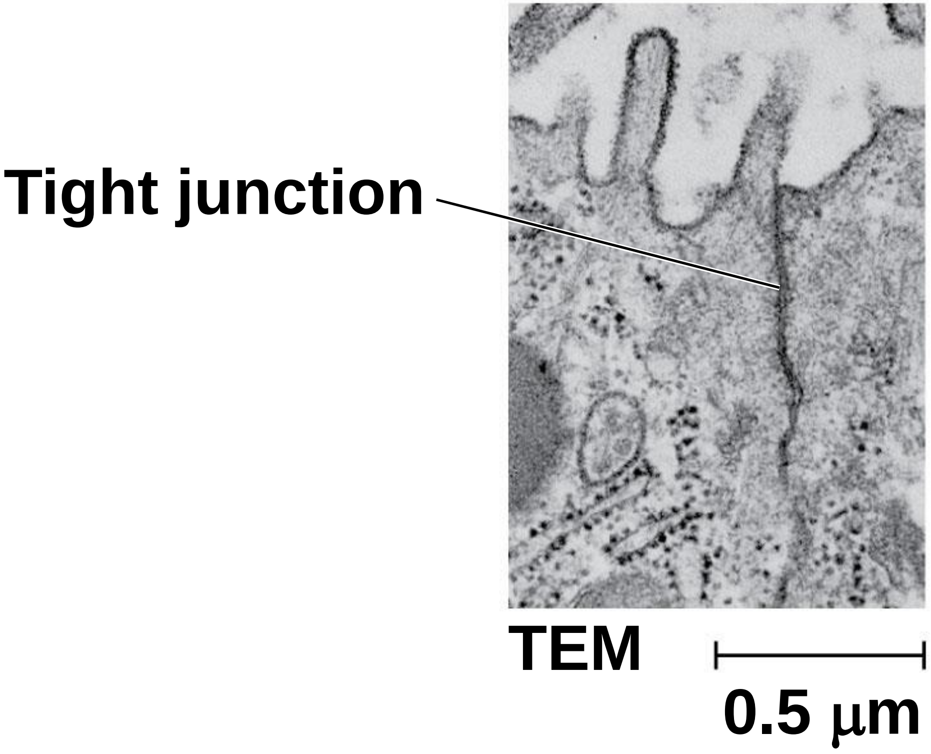
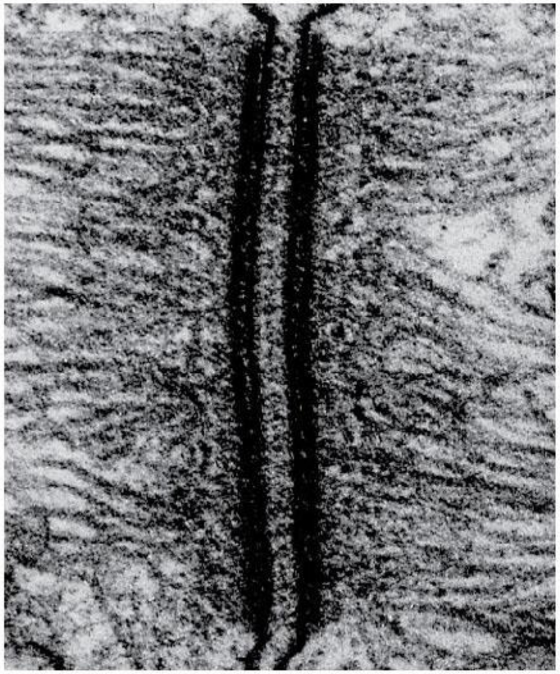
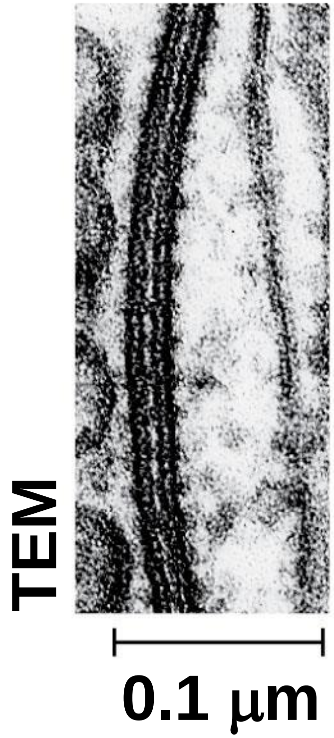


Figure 4.27-3

Desmosome



Gap junction



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

- None of the components of a cell work alone
- For example, a macrophage’s ability to destroy bacteria involves the whole cell, coordinating components such as the cytoskeleton, lysosomes, and plasma membrane
- Cellular functions arise from cellular order

Figure 4.28

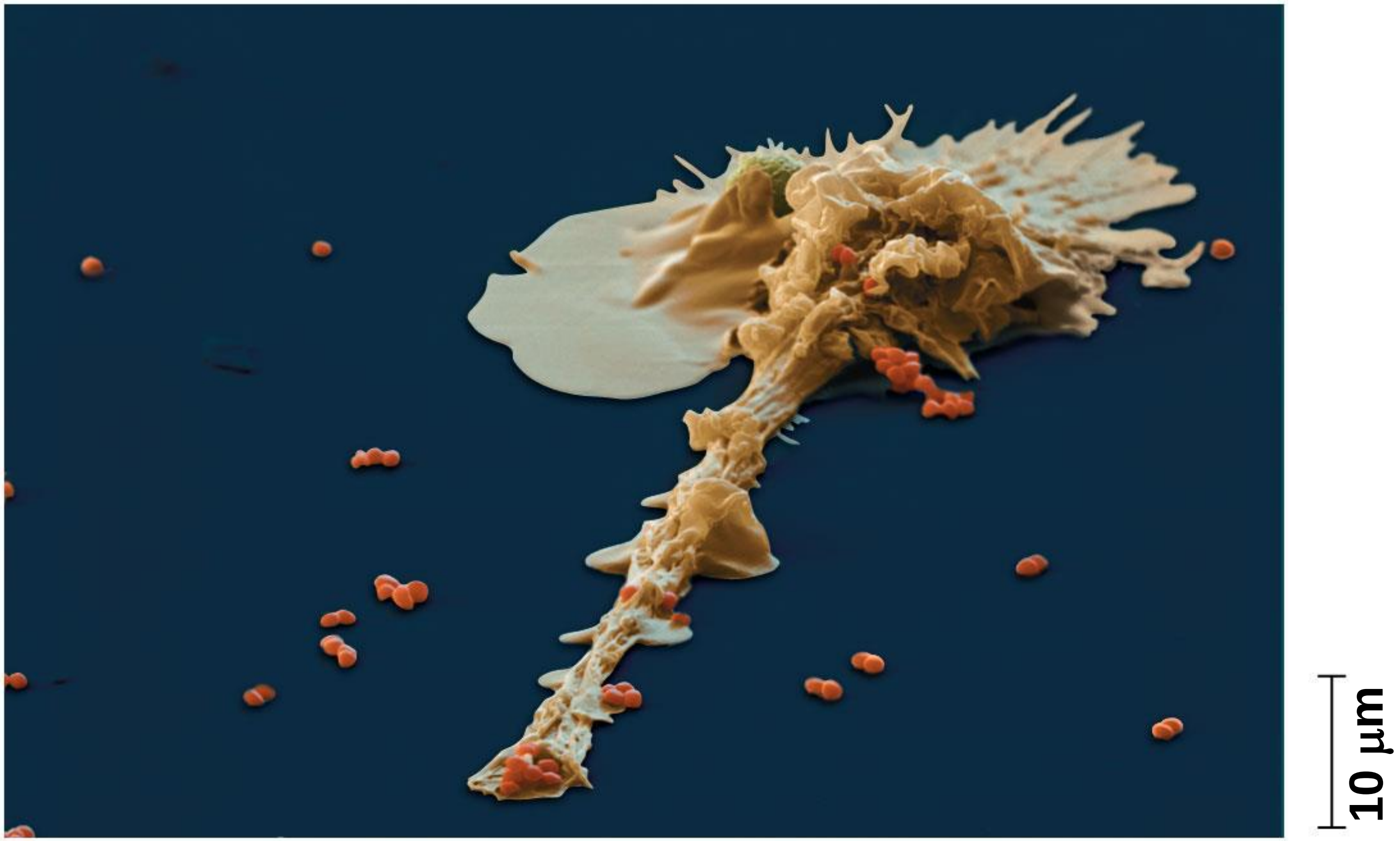


Figure 4.UN01-1

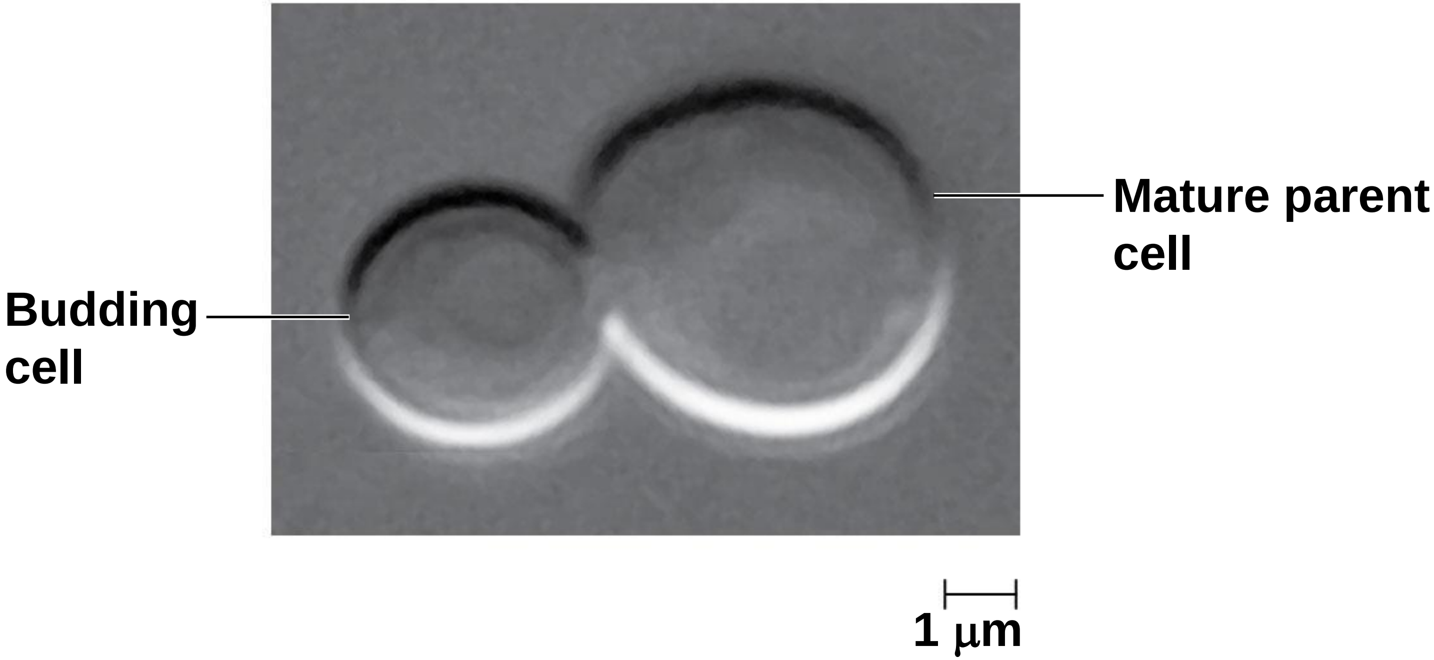


Figure 4.UN01-2

$$V = \frac{4}{3}\pi r^3$$

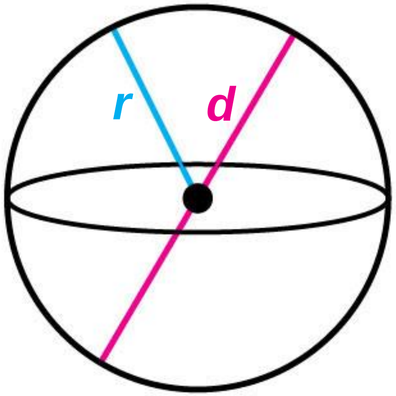


Figure 4.UN02

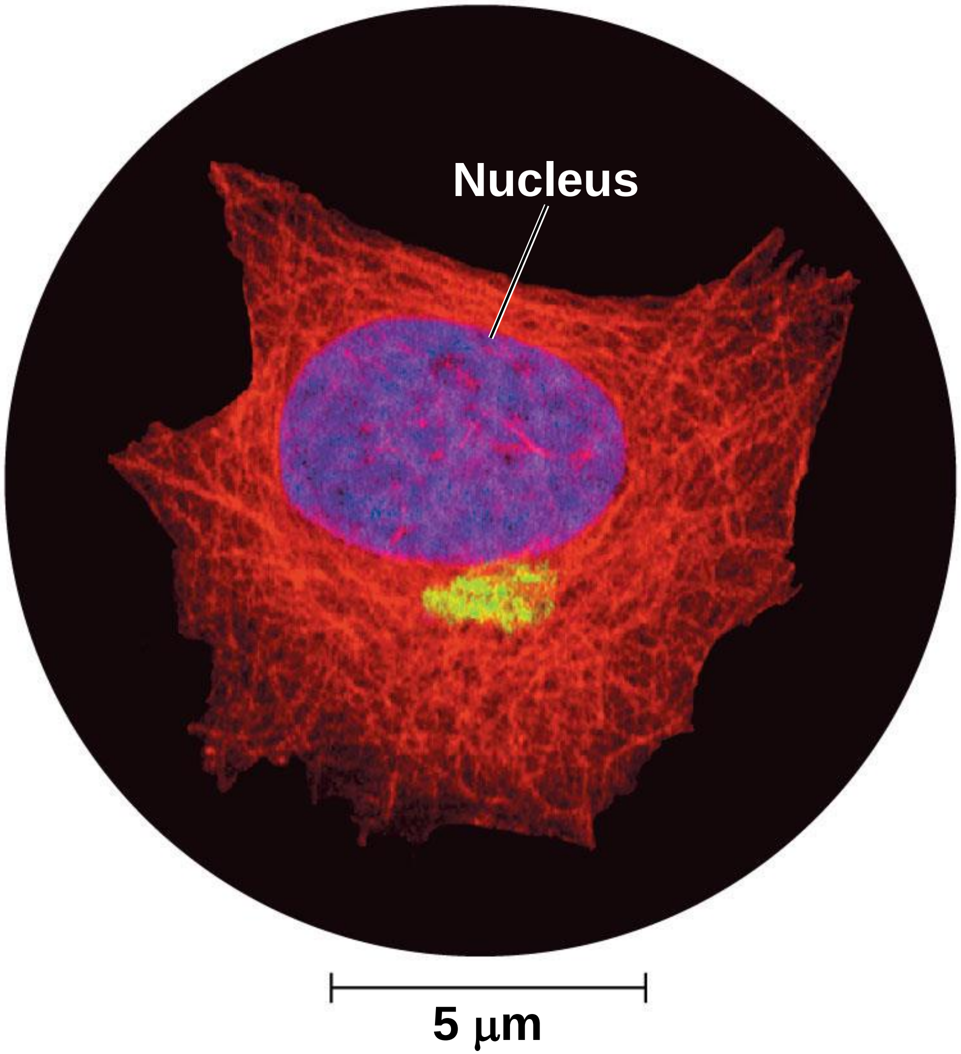


Figure 4.UN03

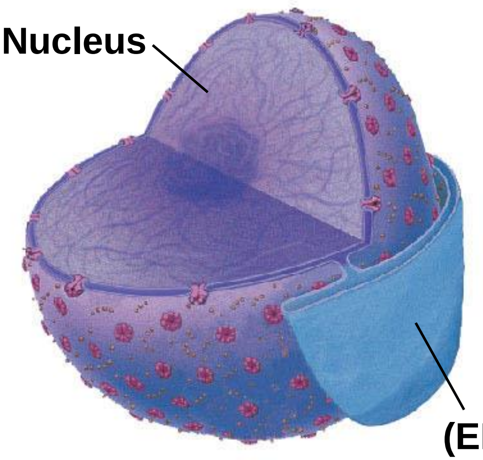
Cell Component	Structure	Function
	Surrounded by nuclear envelope (double membrane) perforated by nuclear pores; nuclear envelope continuous with endoplasmic reticulum (ER)	Houses chromosomes, which are made of chromatin (DNA and proteins); contains nucleoli, where ribosomal subunits are made; pores regulate entry and exit of materials
Ribosome 	Two subunits made of ribosomal RNA and proteins; can be free in cytosol or bound to ER	Protein synthesis

Figure 4.UN04

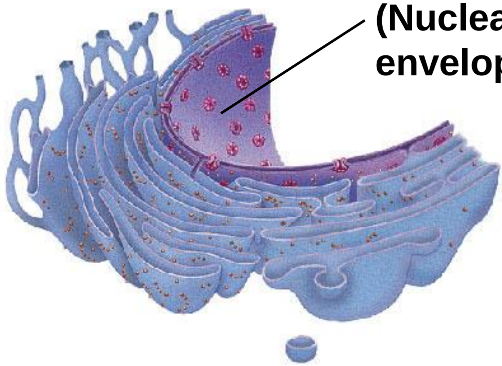
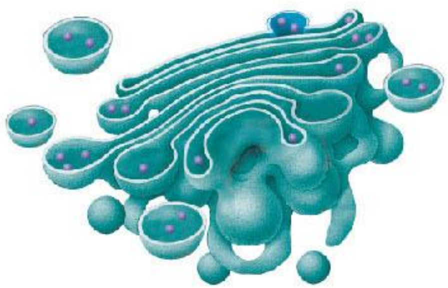
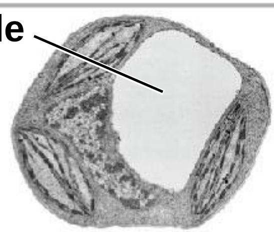
Cell Component	Structure	Function
Endoplasmic reticulum 	**Extensive network of membrane-bounded tubules and sacs; membrane separates lumen from cytosol; continuous with nuclear envelope**	**Smooth ER: synthesis of lipids, metabolism of carbohydrates, Ca^{2+} storage, detoxification of drugs and poisons** **Rough ER: aids in synthesis of secretory and other proteins from bound ribosomes; adds carbohydrates to proteins to make glycoproteins; produces new membrane**
Golgi apparatus 	**Stacks of flattened membranous sacs; has polarity (*cis* and *trans* faces)**	**Modification of proteins, carbohydrates on proteins, and phospholipids; synthesis of many polysaccharides; sorting of Golgi products, which are then released in vesicles**
Lysosome 	**Membranous sac of hydrolytic enzymes (in animal cells)**	**Breakdown of ingested substances, cell macromolecules, and damaged organelles for recycling**
Vacuole 	**Large membrane-bounded vesicle**	**Digestion, storage, waste disposal, water balance, plant cell growth and protection**

Figure 4.UN05

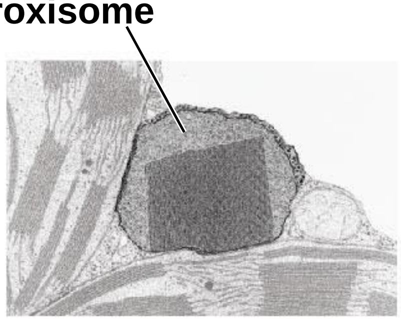
Cell Component	Structure	Function
Mitochondrion 	Bounded by double membrane; inner membrane has infoldings (cristae)	Cellular respiration
Chloroplast 	Typically two membranes around fluid stroma, which contains thylakoids stacked into grana (in cells of photosynthetic eukaryotes, including plants)	Photosynthesis
Peroxisome 	Specialized metabolic compartment bounded by a single membrane	Contains enzymes that transfer hydrogen atoms from certain molecules to oxygen, producing hydrogen peroxide (H_2O_2) as a by-product; H_2O_2 is converted to water by another enzyme

Figure 4.UN06