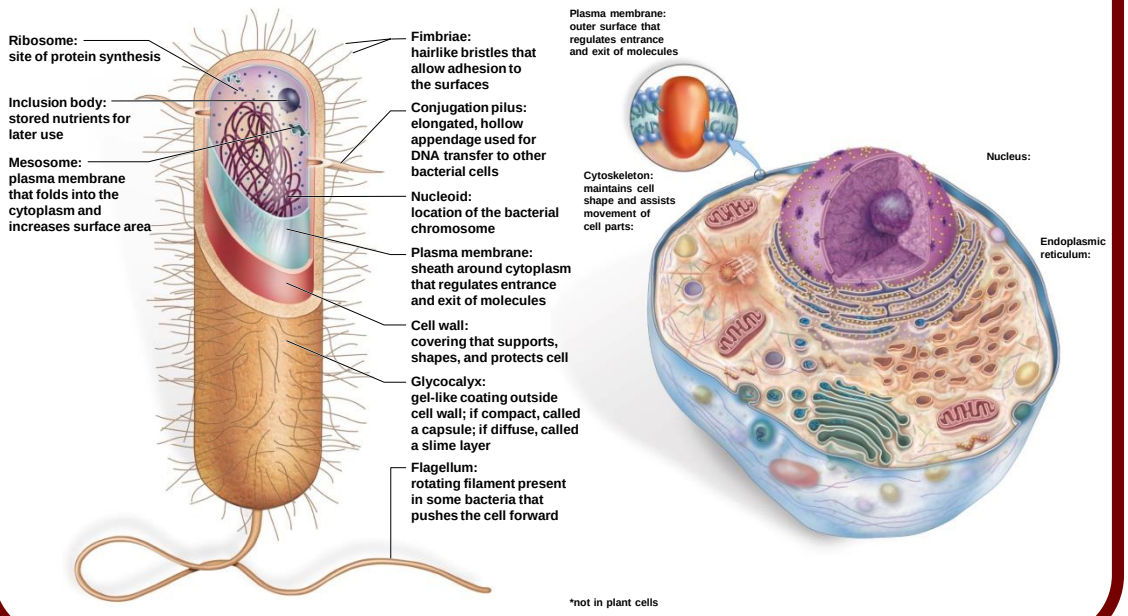
Chapter 4: pp. 59-84

Cell Structure and Function



BIOLOGY

10th Edition

Sylvia S. Mader

PowerPoint® Lecture Slides are prepared by Dr. Isaac Barjis, Biology Instructor

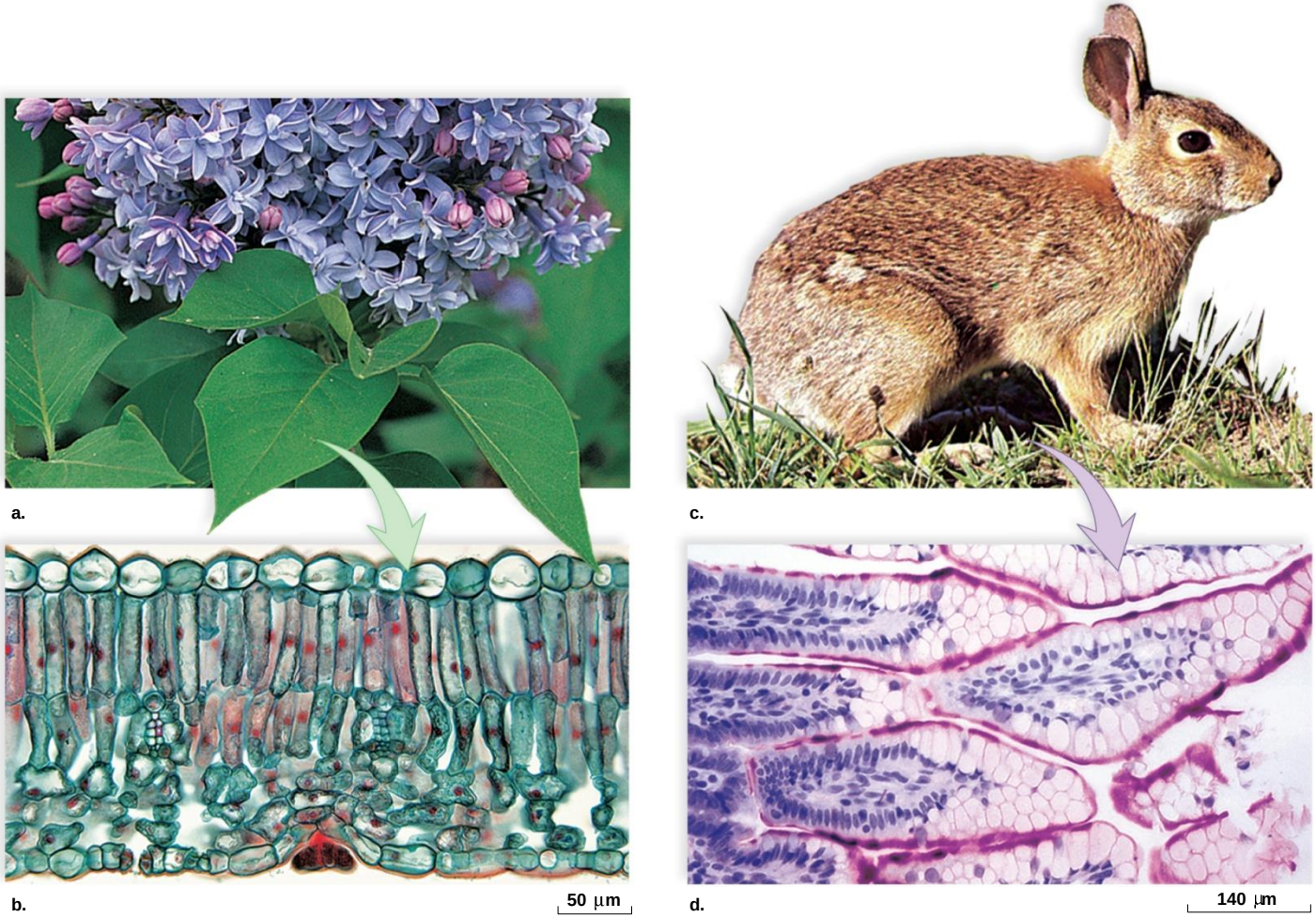
Outline

- Cellular Level of Organization
  - Cell theory
  - Cell size
- Prokaryotic Cells
- Eukaryotic Cells
  - Organelles
- Nucleus and Ribosome
- Endomembrane System
- Other Vesicles and Vacuoles
- Energy related organelles
- Cytoskeleton
    - Centrioles, Cilia, and Flagella

Cell Theory

- Detailed study of the cell began in the 1830s
- A unifying concept in biology
- Originated from the work of biologists Schleiden and Schwann in 1838-9
- States that:
  - All organisms are composed of cells
    - German botanist Matthais Schleiden in 1838
    - German zoologist Theodor Schwann in 1839
  - All cells come only from preexisting cells
    - German physician Rudolph Virchow in 1850's
  - Cells are the smallest structural and functional unit of organisms

Organisms and Cells



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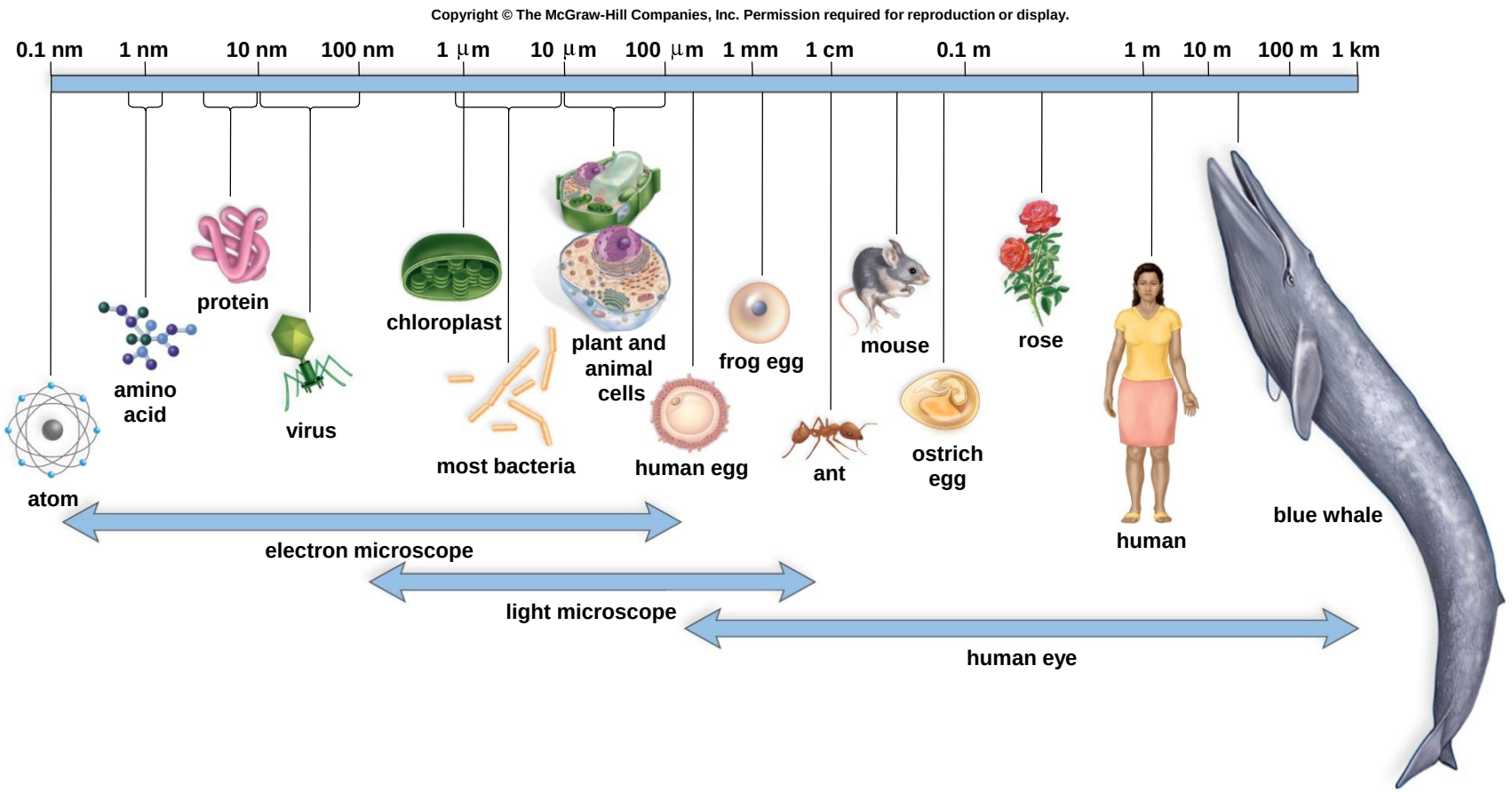
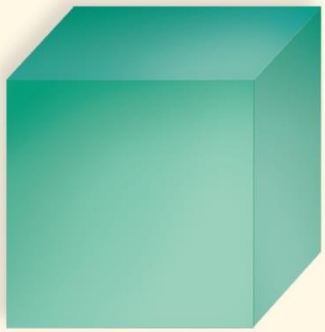
Sizes of Living Things



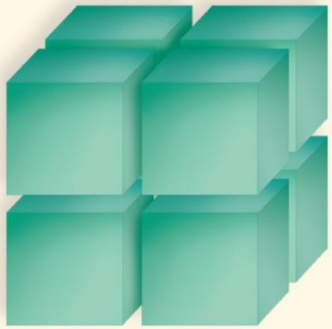
Cell Size

- Cells range in size from one millimeter down to one micrometer
- Cells need a large surface area of plasma membrane to adequately exchange materials.
- The **surface-area-to-volume ratio** requires that cells be small
  - Large cells - surface area relative to volume decreases
  - Volume is living cytoplasm, which demands nutrients and produces wastes
  - Cells specialized in absorption utilize membrane modifications such as microvilli to greatly increase surface area per unit volume

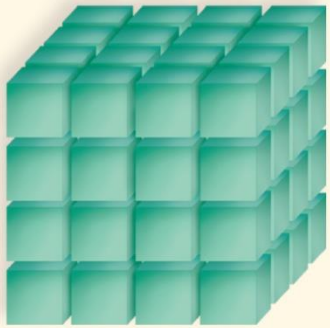
Surface to Volume Ratio



One 4-cm cube



Eight 2-cm cubes



Sixty-four 1-cm cubes

Total surface area (height × width × number of sides × number of cubes)

96 cm^2	192 cm^2	384 cm^2

Total volume (height × width × length × number of cubes)

64 cm^3	64 cm^3	64 cm^3

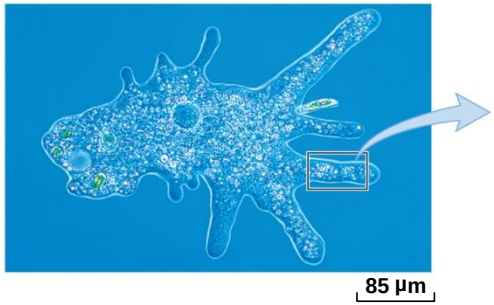
Surface area: Volume per cube (surface area ÷ volume)

1.5:1	3:1	6:1

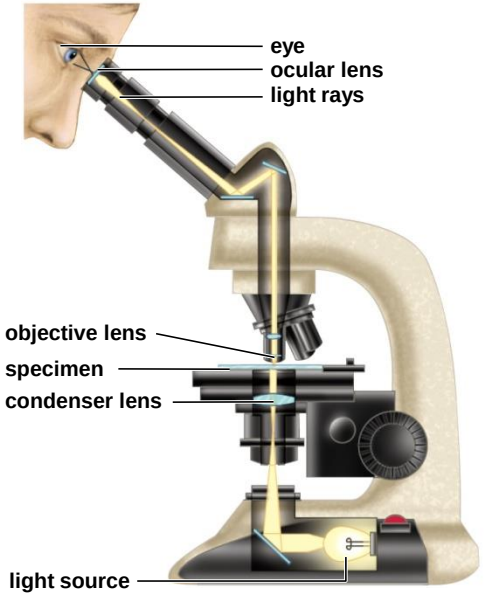
Microscopy Today: Compound Light Microscope

- Light passed through specimen
- Focused by glass lenses
- Image formed on human retina
- Max magnification about 1000X
- Resolves objects separated by 0.2 μm, 500X better than human eye

Compound Light Microscope



amoeba, light micrograph

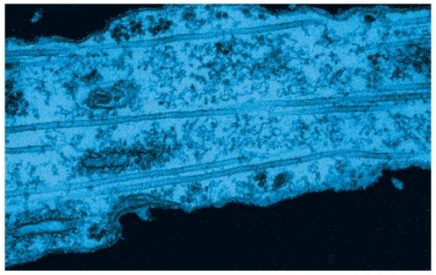


a. Compound light microscope

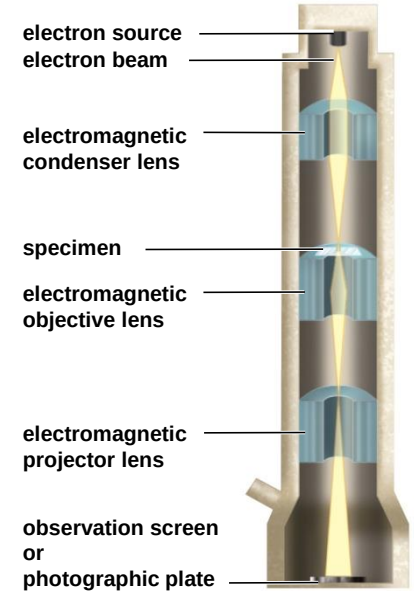
Microscopy Today: Transmission Electron Microscope

- Abbreviated T.E.M.
- Electrons passed through specimen
- Focused by magnetic lenses
- Image formed on fluorescent screen
  - Similar to TV screen
  - Image is then photographed
- Max magnification 1000,000sX
- Resolves objects separated by 0.00002 μm, 100,000X better than human eye

Transmission Electron Microscope



pseudopod segment, transmission electron micrograph

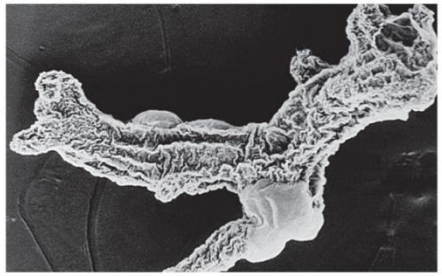


b. Transmission electron microscope

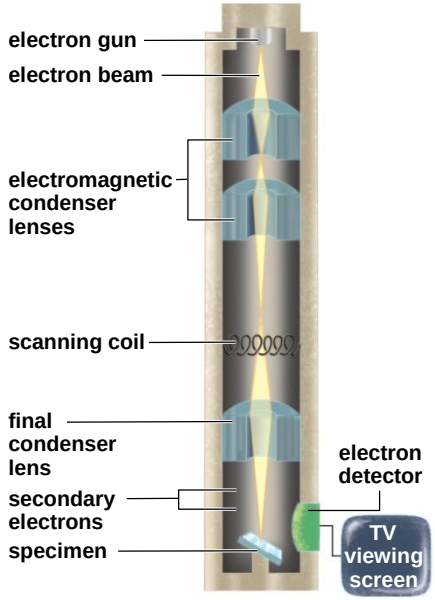
Microscopy Today: Scanning Electron Microscope

- Abbreviated S.E.M.
- Specimen sprayed with thin coat of metal
  - Electron beam scanned across surface of specimen
  - Metal emits secondary electrons
- Emitted electrons focused by magnetic lenses
- Image formed on fluorescent screen
  - Similar to TV screen
  - Image is then photographed

Scanning Electron Microscope



amoeba, scanning electron micrograph



c. Scanning electron microscope

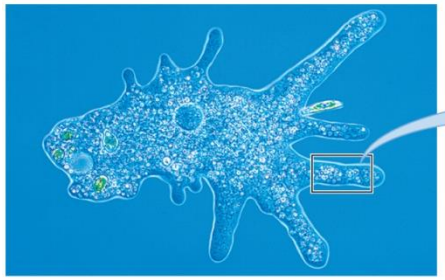
Microscopy Today: Immunofluorescence Light Microscope

- Antibodies developed against a specific protein
  - Fluorescent dye molecule attached to antibody molecules
  - Specimen exposed to fluorescent antibodies
- Ultra-violet light (black light) passed through specimen
  - Fluorescent dye glows in color where antigen is located
  - Emitted light is focused by glass lenses onto human retina
- Allows mapping distribution of a specific protein in cell

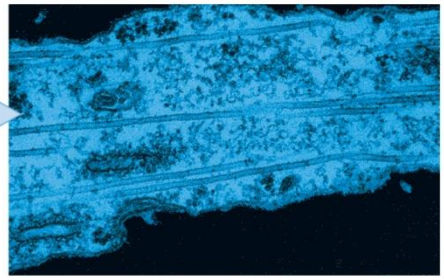
Microscopy Today: Confocal Microscopy

- Narrow laser beam scanned across transparent specimen
- Beam is focused at a very thin plane
- Allows microscopist to optically section a specimen
  - Sections made at different levels
  - Allows assembly of 3d image on computer screen that can be rotated

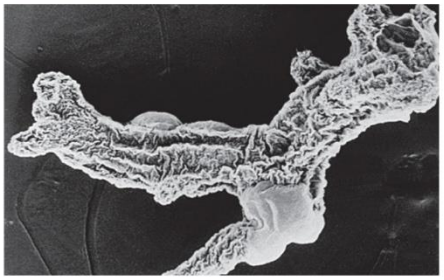
Microscopy and *Amoeba proteus*



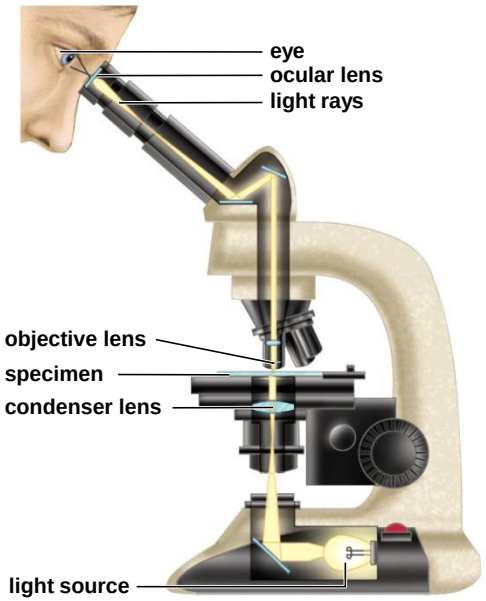
amoeba, light micrograph



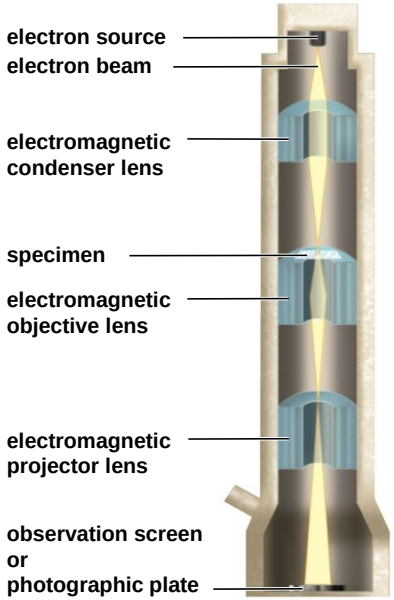
pseudopod segment, transmission electron micrograph



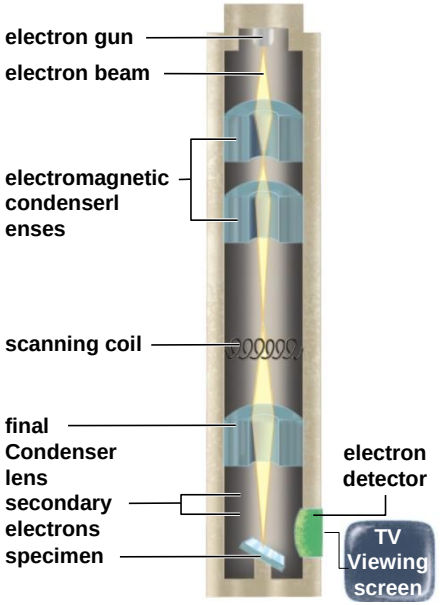
amoeba, scanning electron micrograph



a. Compound light microscope



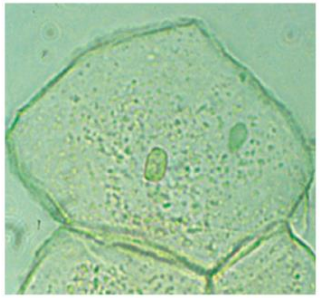
b. Transmission electron microscope



c. Scanning electron microscope

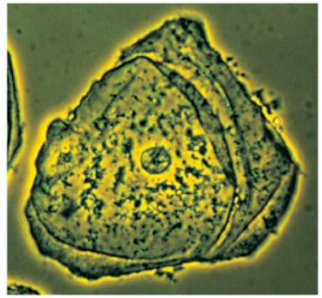
Microscopy and Cheek Cells

Bright-field. Light passing through the specimen is brought directly into focus. Usually, the low level of contrast within the specimen interferes with viewing all but its largest components.

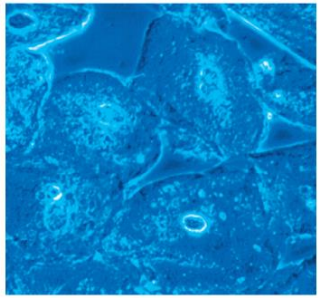


Bright-field (stained). Dyes are used to stain the specimen. Certain components take up the dye more than other components, and therefore contrast is enhanced.

Differential interference contrast. Optical methods are used to enhance density differences within the specimen so that certain regions appear brighter than others. This technique is used to view living cells, chromosomes, and organelle masses.



Phase contrast. Density differences in the specimen cause light rays to come out of "phase." The microscope enhances these phase differences so that some regions of the specimen appear brighter or darker than others. The technique is widely used to observe living cells and organelles.



Dark-field. Light is passed through the specimen at an oblique angle so that the objective lens receives only light diffracted and scattered by the object. This technique is used to view organelles, which appear quite bright against a dark field.

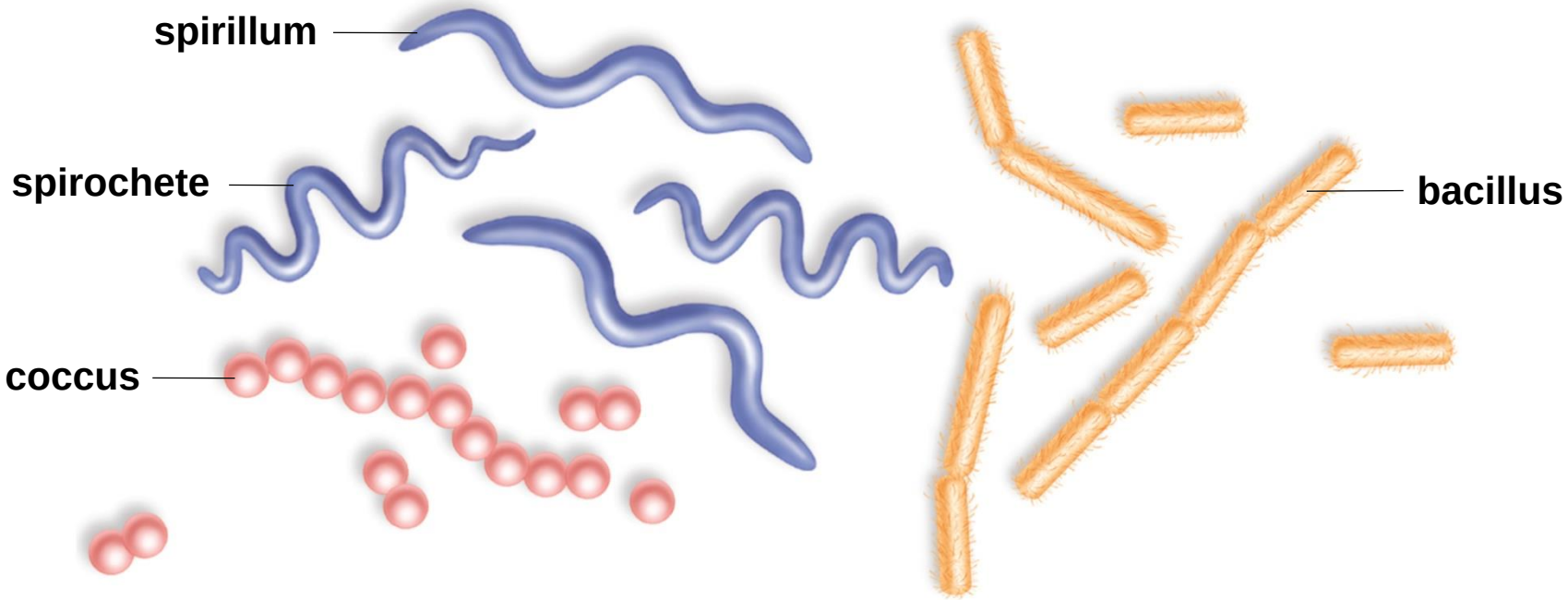
Prokaryotic Cells

- Lack a membrane-bound nucleus
- Structurally smaller and simpler than eukaryotic cells (which have a nucleus).
- Prokaryotic cells are placed in two taxonomic domains:
  - Bacteria
  - Archaea
    - Live in extreme habitats
  - Domains are structurally similar but biochemically different

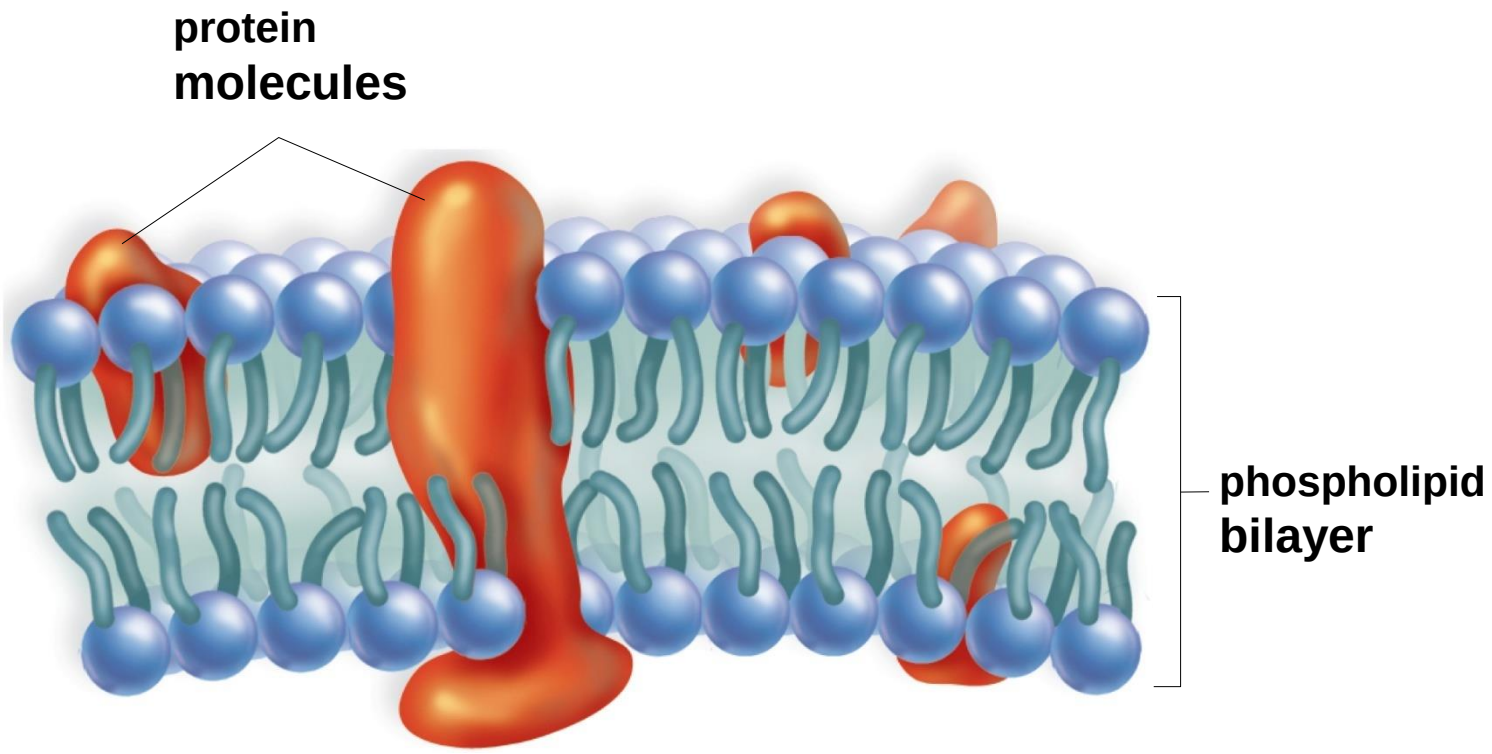
The Structure of Bacteria

- Extremely small - 1–1.5 μm wide and 2–6 μm long
- Occur in three basic shapes:
  - Spherical **coccus**,
  - Rod-shaped **bacillus**,
  - Spiral **spirillum** (if rigid) or **spirochete** (if flexible).
- Cell Envelope includes:
  - Plasma membrane - lipid bilayer with imbedded and peripheral protein
    - Form internal pouches (mesosomes)
  - Cell wall - maintains the shape of the cell and is strengthened by **peptidoglycan**
  - Glycocalyx - layer of polysaccharides on the outside of the cell wall
    - Well organized and resistant to removal (capsule)

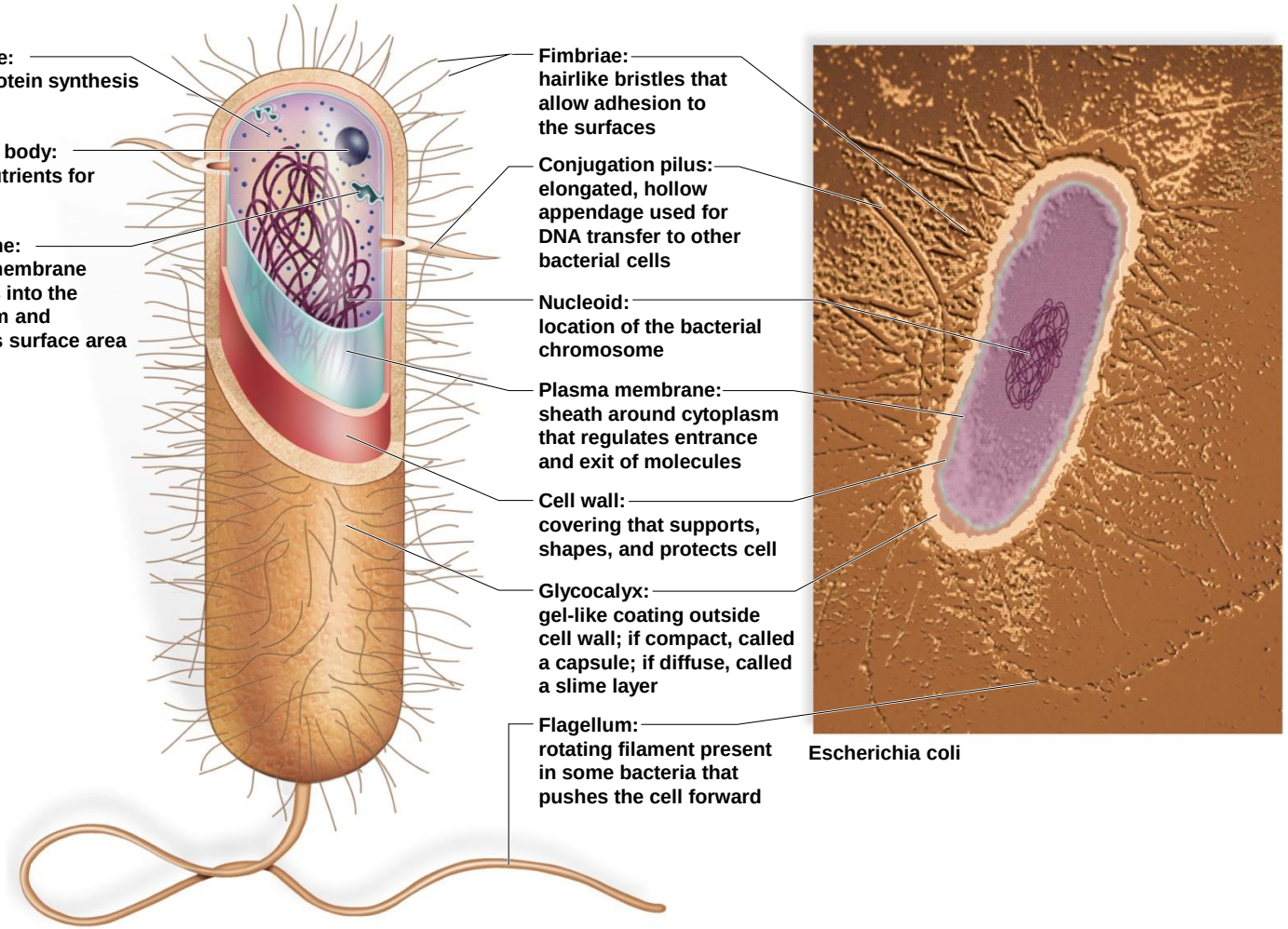
The Structure of Bacteria



The Structure of Bacteria



The Structure of Bacteria



Escherichia coli

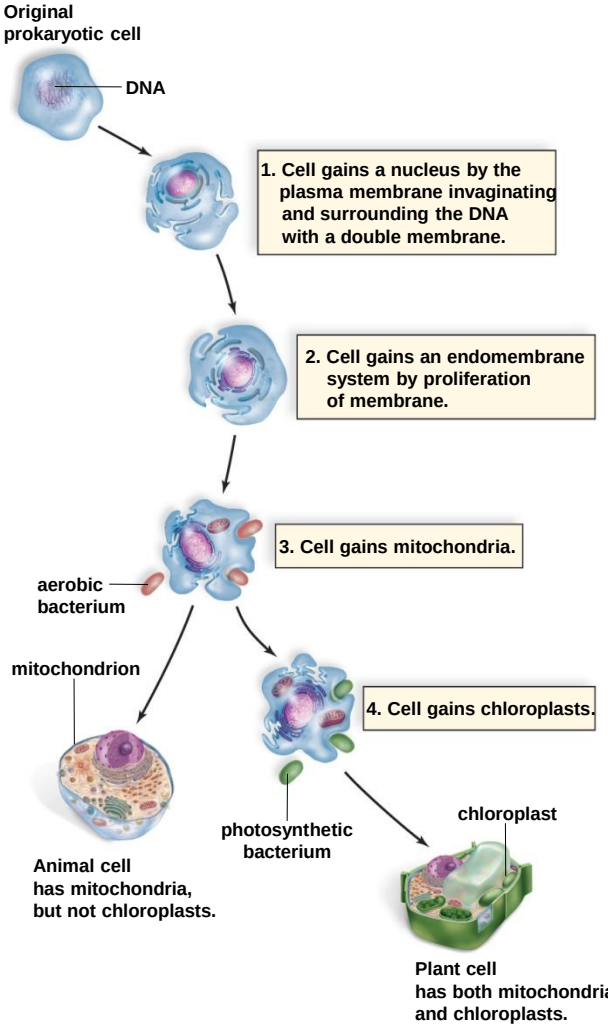
The Structure of Bacteria Cytoplasm & Appendages

- Cytoplasm
  - Semifluid solution
    - Bounded by plasma membrane
    - Contains water, inorganic and organic molecules, and enzymes.
  - **Nucleoid** is a region that contains the single, circular DNA molecule.
  - **Plasmids** are small accessory (extrachromosomal) rings of DNA
- Appendages
  - Flagella – Provide motility
  - Fimbriae – small, bristle-like fibers that sprout from the cell surface
  - Sex pili – rigid tubular structures used to pass DNA from cell to cell

Eukaryotic Cells

- Domain Eukarya includes:
  - Protists
  - Fungi
  - Plants
  - Animals
- Cells contain:
  - Membrane-bound nucleus that houses DNA
  - Specialized organelles
  - Plasma membrane
  - Much larger than prokaryotic cells
  - Some cells (e.g., plant cells) have a **cell wall**

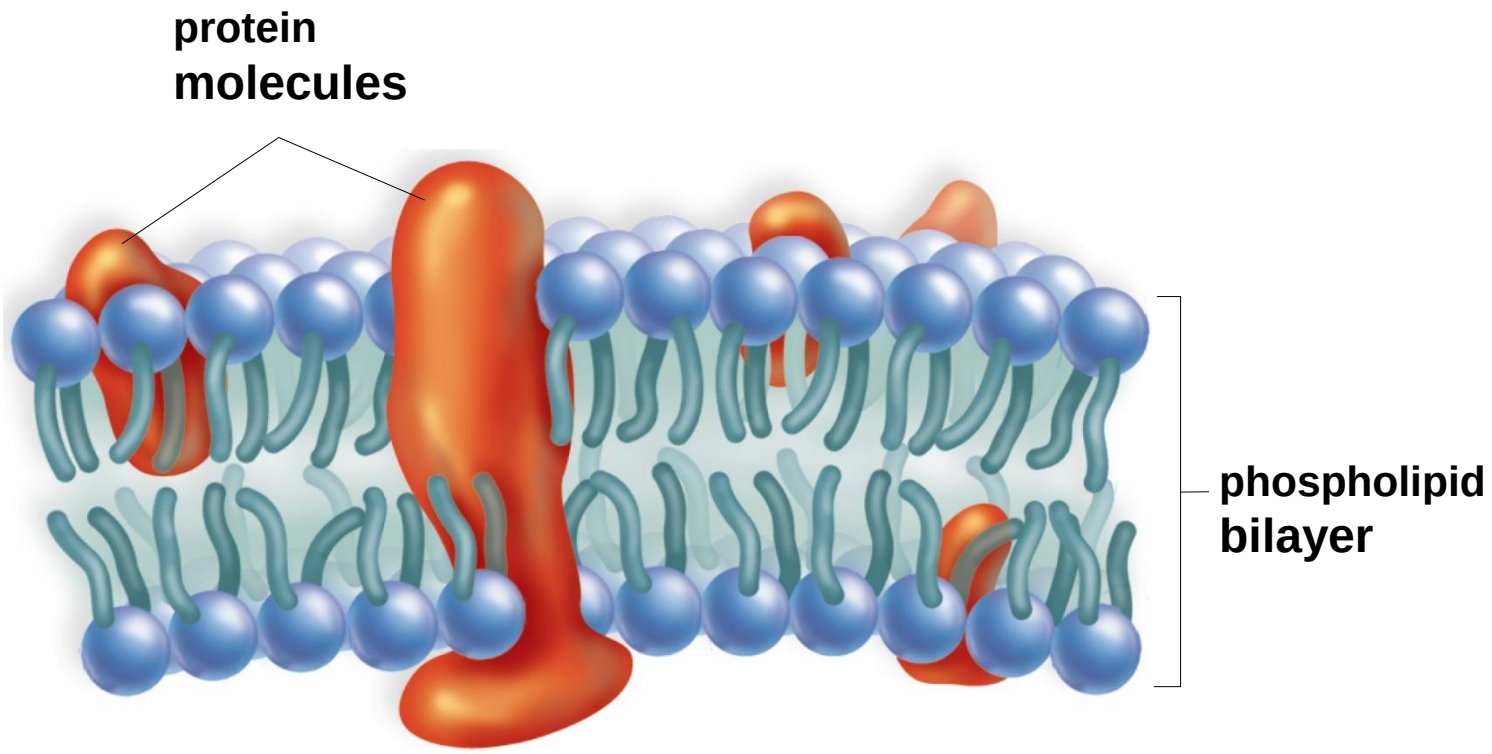
Hypothesized Origin of Eukaryotic Cells



Eukaryotic Cells: Organelles

- Eukaryotic cells are compartmentalized
  - They contain small structures called **organelles**
    - Perform specific functions
    - Isolates reactions from others
- Two classes of organelles:
  - Endomembrane system:
    - Organelles that communicate with one another
      - Via membrane channels
      - Via small vesicles
  - Energy related organelles
    - Mitochondria & chloroplasts
    - Basically independent & self-sufficient

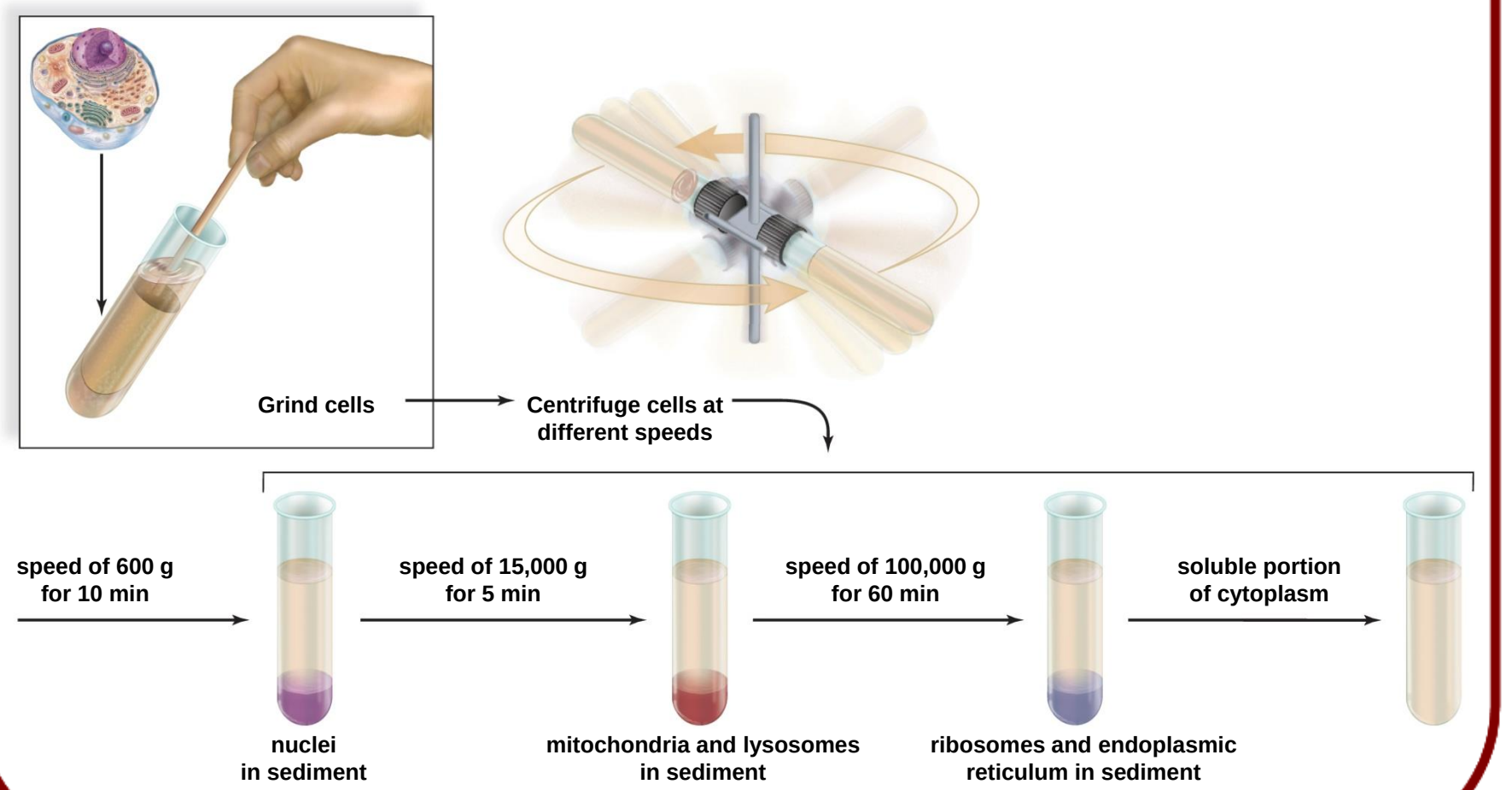
Plasma Membrane



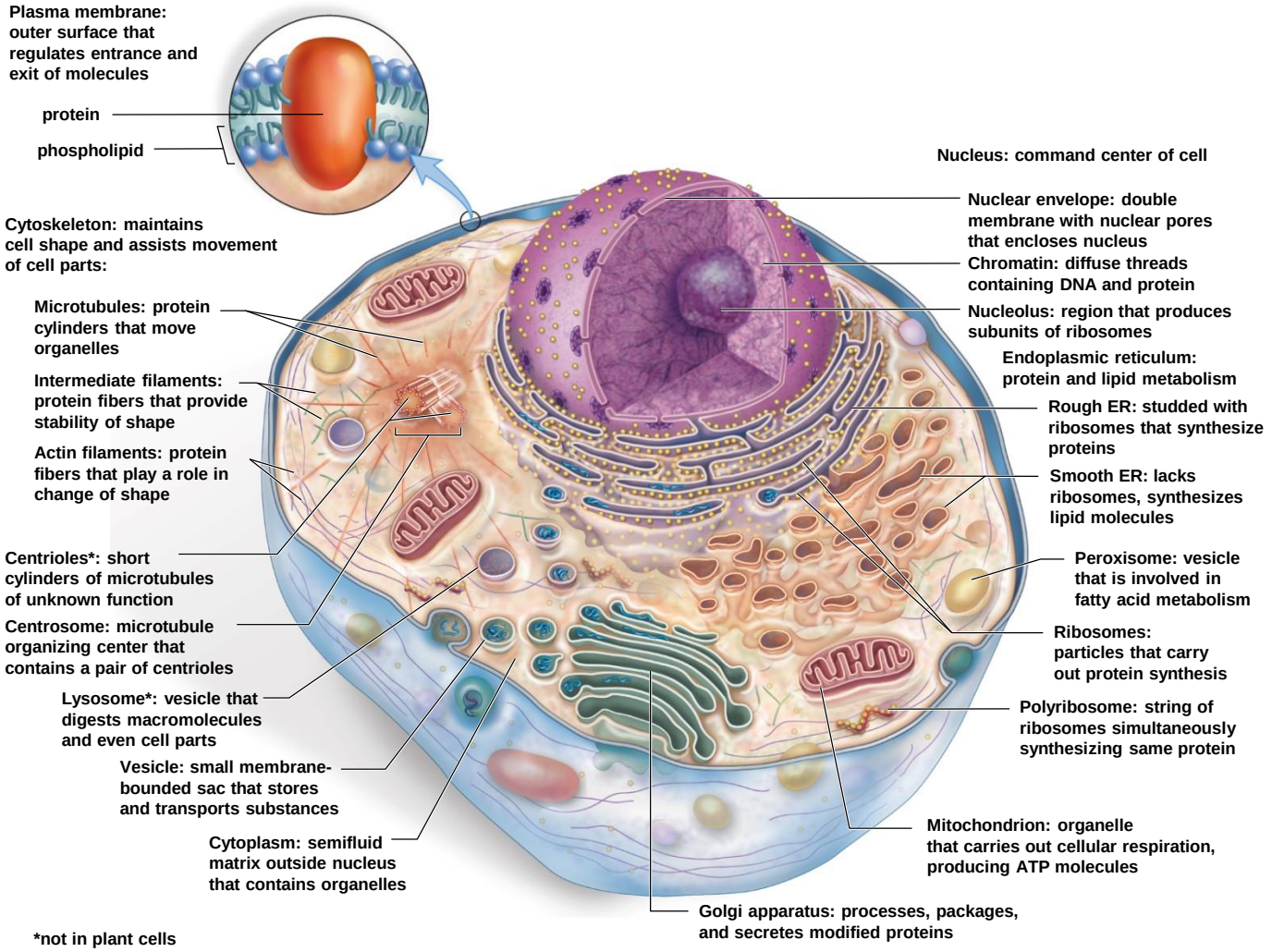
Cell Fractionation and Differential Centrifugation

- Cell fractionation is the breaking apart of cellular components
- Differential centrifugation:
  - Allows separation of cell parts
  - Separated out by size & density
- Works like spin cycle of washer
- The faster the machine spins, the smaller the parts that are settled out

Cell Fractionation and Differential Centrifugation

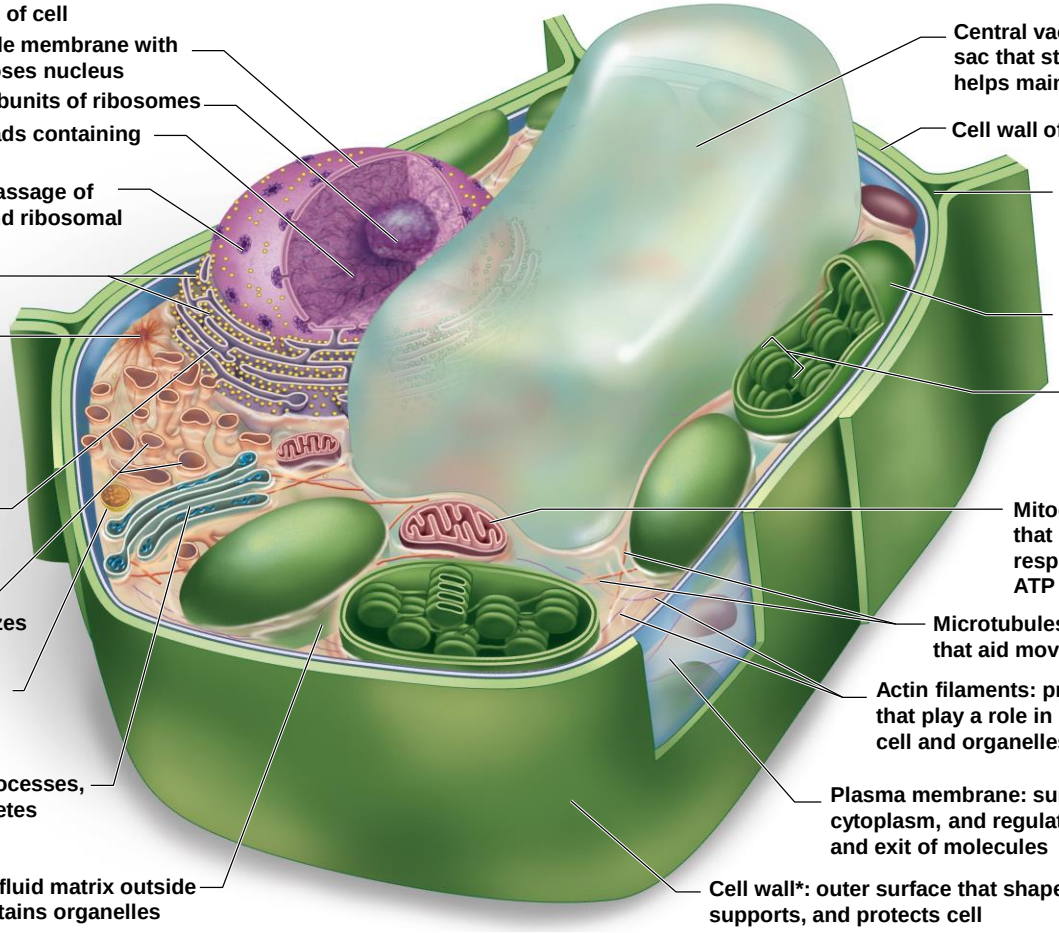


Animal Cell Anatomy



*not in plant cells

Plant Cell Anatomy



Nucleus: command center of cell

Nuclear envelope: double membrane with nuclear pores that encloses nucleus

Nucleolus: produces subunits of ribosomes

Chromatin: diffuse threads containing DNA and protein

Nuclear pore: permits passage of proteins into nucleus and ribosomal subunits out of nucleus

Ribosomes: carry out protein synthesis

Centrosome: microtubule organizing center (lacks centrioles)

Endoplasmic reticulum: protein and lipid metabolism

Rough ER: studded with ribosomes that synthesize proteins

Smooth ER: lacks ribosomes, synthesizes lipid molecules

Peroxisome: vesicle that is involved in fatty acid metabolism

Golgi apparatus: processes, packages, and secretes modified proteins

Cytoplasm: semifluid matrix outside nucleus that contains organelles

Central vacuole*: large, fluid-filled sac that stores metabolites and helps maintain turgor pressure

Cell wall of adjacent cell

Middle lamella: cements together the primary cell walls of adjacent plant cells

Chloroplast*: carries out photosynthesis, producing sugars

Granum*: a stack of chlorophyll-containing thylakoids in a chloroplast

Mitochondrion: organelle that carries out cellular respiration, producing ATP molecules

Microtubules: protein cylinders that aid movement of organelles

Actin filaments: protein fibers that play a role in movement of cell and organelles

Plasma membrane: surrounds cytoplasm, and regulates entrance and exit of molecules

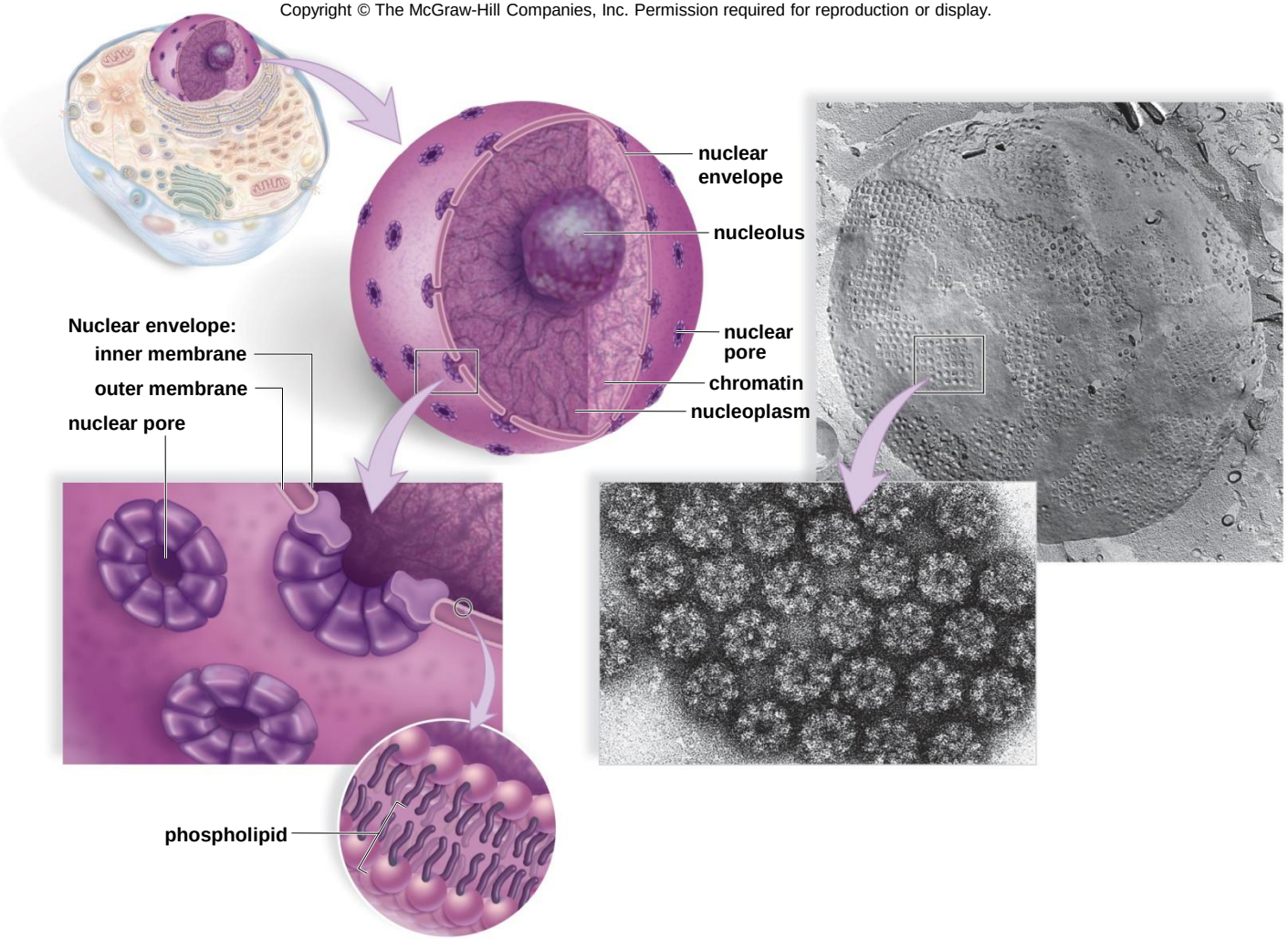
Cell wall*: outer surface that shapes, supports, and protects cell

*not in animal cells

Nucleus

- Command center of cell, usually near center
- Separated from cytoplasm by nuclear envelope
  - Consists of double layer of membrane
  - Nuclear pores permit exchange between nucleoplasm & cytoplasm
- Contains chromatin in semifluid nucleoplasm
  - Chromatin contains DNA of genes, and proteins
  - Condenses to form chromosomes
    - Chromosomes are formed during cell division
- Dark nucleolus composed of rRNA
  - Produces subunits of ribosomes

Anatomy of the Nucleus

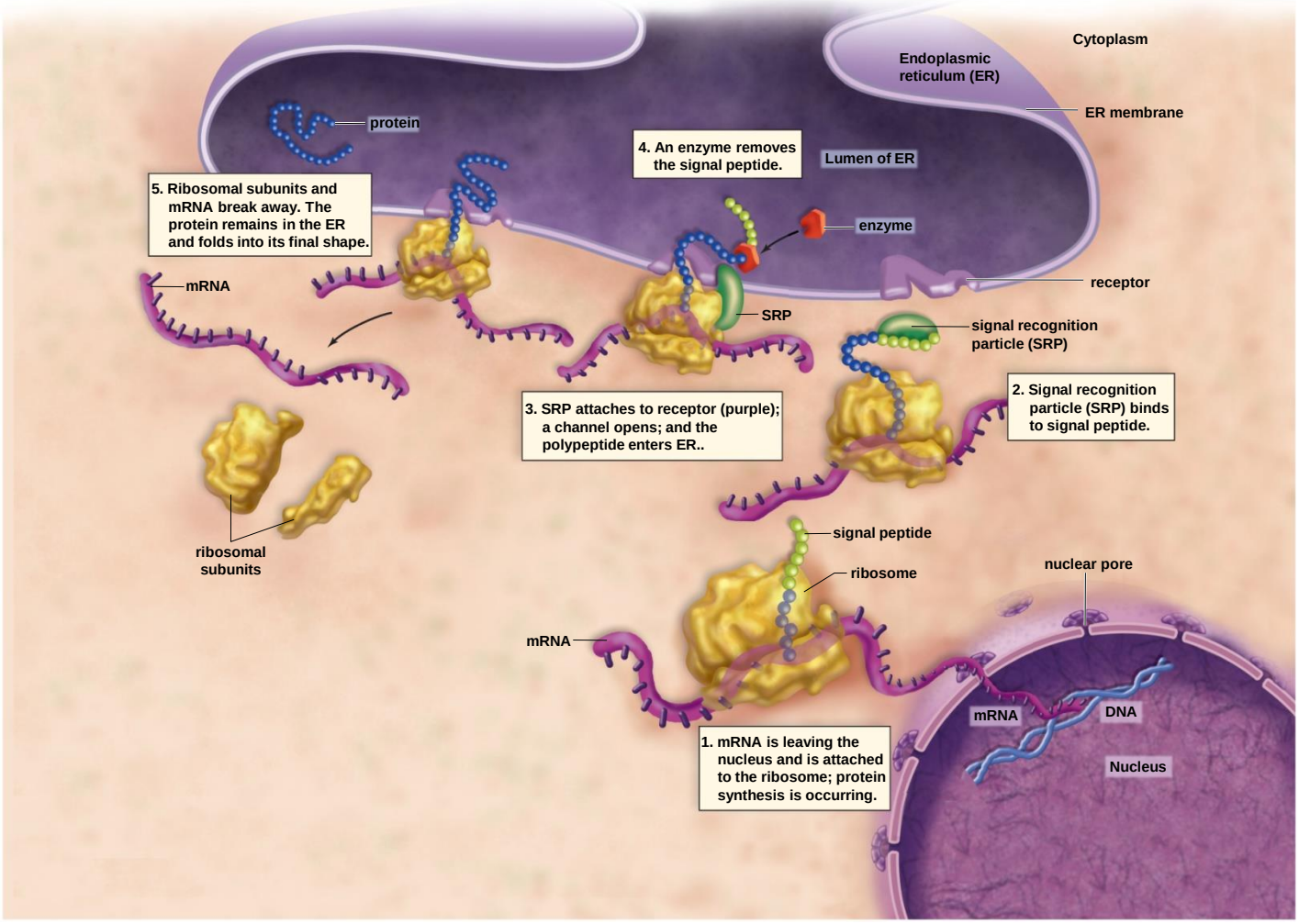


(Bottom): Courtesy Ron Milligan/Scripps Research Institute; (Top right): Courtesy E.G. Pollock

Ribosomes

- Are the site of protein synthesis in the cell
- Composed of rRNA
  - Consists of a large subunit and a small subunit
  - Subunits made in nucleolus
- May be located:
  - On the endoplasmic reticulum (thereby making it “rough”), or
  - Free in the cytoplasm, either singly or in groups, called polyribosomes

Nucleus, Ribosomes, & ER



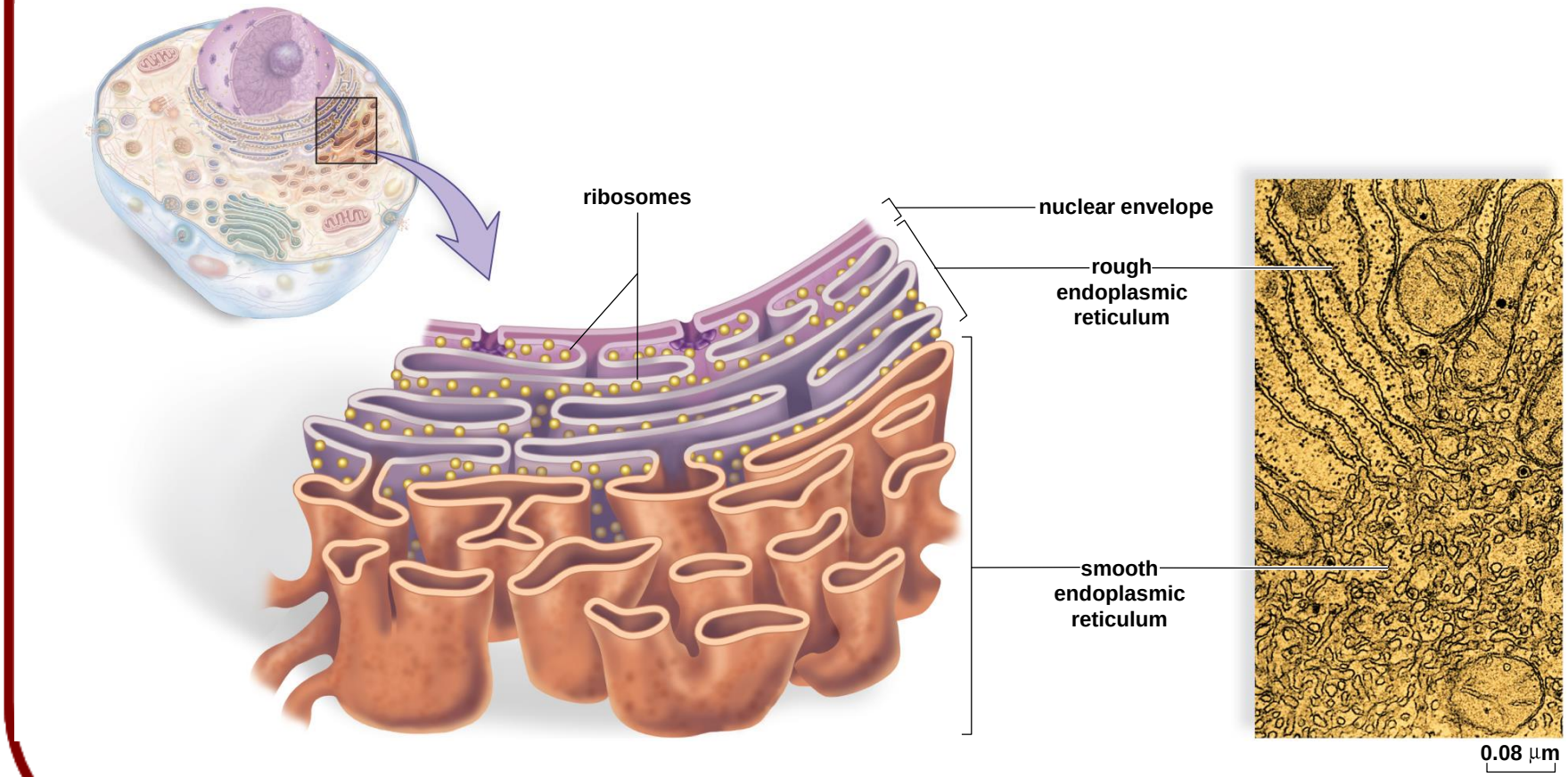
Endomembrane System

- Series of intracellular membranes that compartmentalize the cell
- Restrict enzymatic reactions to specific compartments within cell
- Consists of:
  - Nuclear envelope
  - Membranes of endoplasmic reticulum
  - Golgi apparatus
  - Vesicles
    - Several types
    - Transport materials between organelles of system

Endomembrane System: The Endoplasmic Reticulum

- A system of membrane channels and saccules (flattened vesicles) continuous with the outer membrane of the nuclear envelope
- Rough ER
  - Studded with ribosomes on cytoplasmic side
  - Protein anabolism
    - Synthesizes proteins
    - Modifies and processes proteins
      - Adds sugar to protein
      - Results in glycoproteins
- Smooth ER
  - No ribosomes
  - Synthesis of lipids
  - Site of various synthetic processes, detoxification, and storage
  - Forms **transport vesicles**

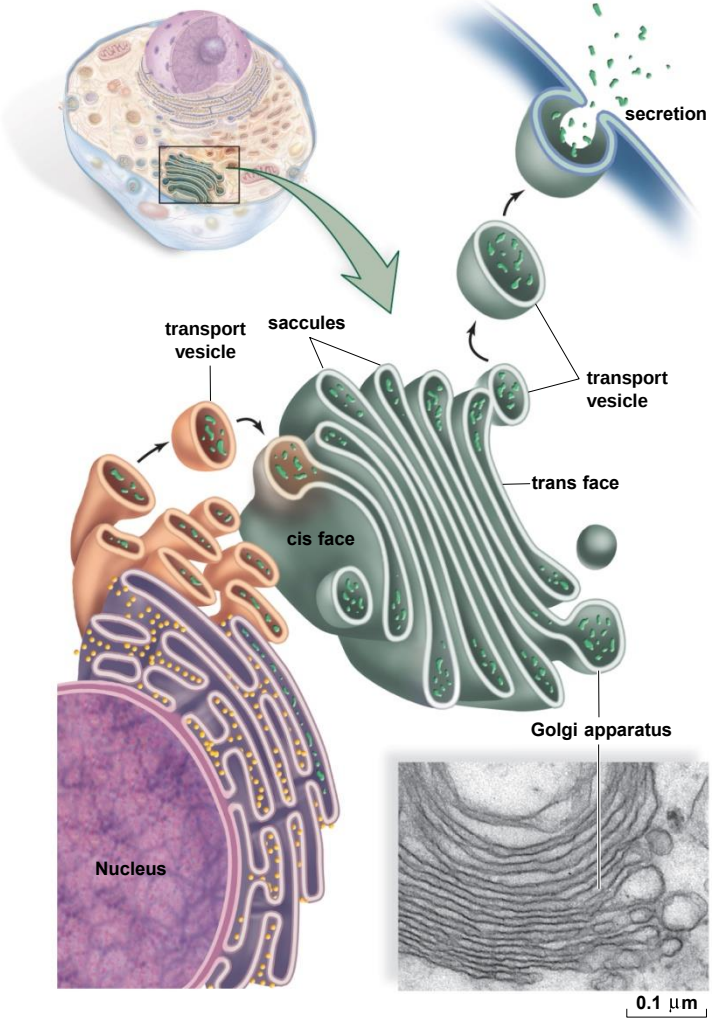
Endoplasmic Reticulum



Endomembrane System: The Golgi Apparatus

- Golgi Apparatus
  - Consists of 3-20 flattened, curved saccules
  - Resembles stack of hollow pancakes
  - Modifies proteins and lipids
    - Receives vesicles from ER on cis (or inner face)
    - Packages them in vesicles
    - Prepares for “shipment” in v Packages them in vesicles from trans (or outer face)
      - Within cell
      - Export from cell (secretion, exocytosis)

Golgi Apparatus

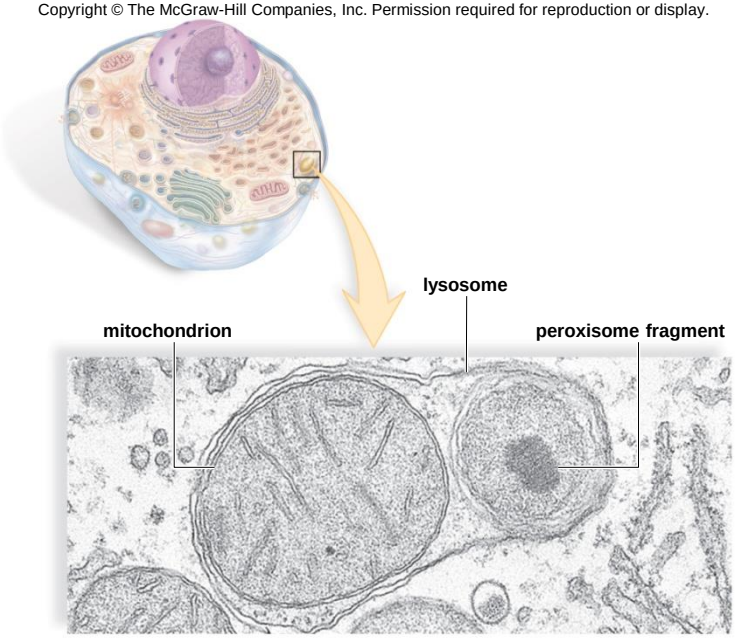


Courtesy Charles Flickinger, from *Journal of Cell Biology* 49: 221-226, 1971, Fig. 1 page 224

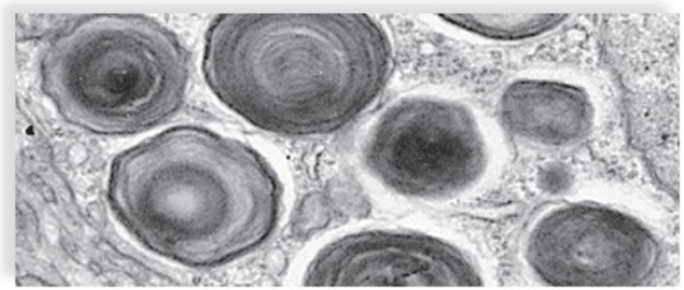
Endomembrane System: Lysosomes

- Membrane-bound vesicles (not in plants)
  - Produced by the Golgi apparatus
  - Contain powerful digestive enzymes and are highly acidic
    - Digestion of large molecules
    - Recycling of cellular resources
    - Apoptosis (programmed cell death, like tadpole losing tail)
- Some genetic diseases
  - Caused by defect in lysosomal enzyme
  - Lysosomal storage diseases (Tay-Sachs)

Lysosomes



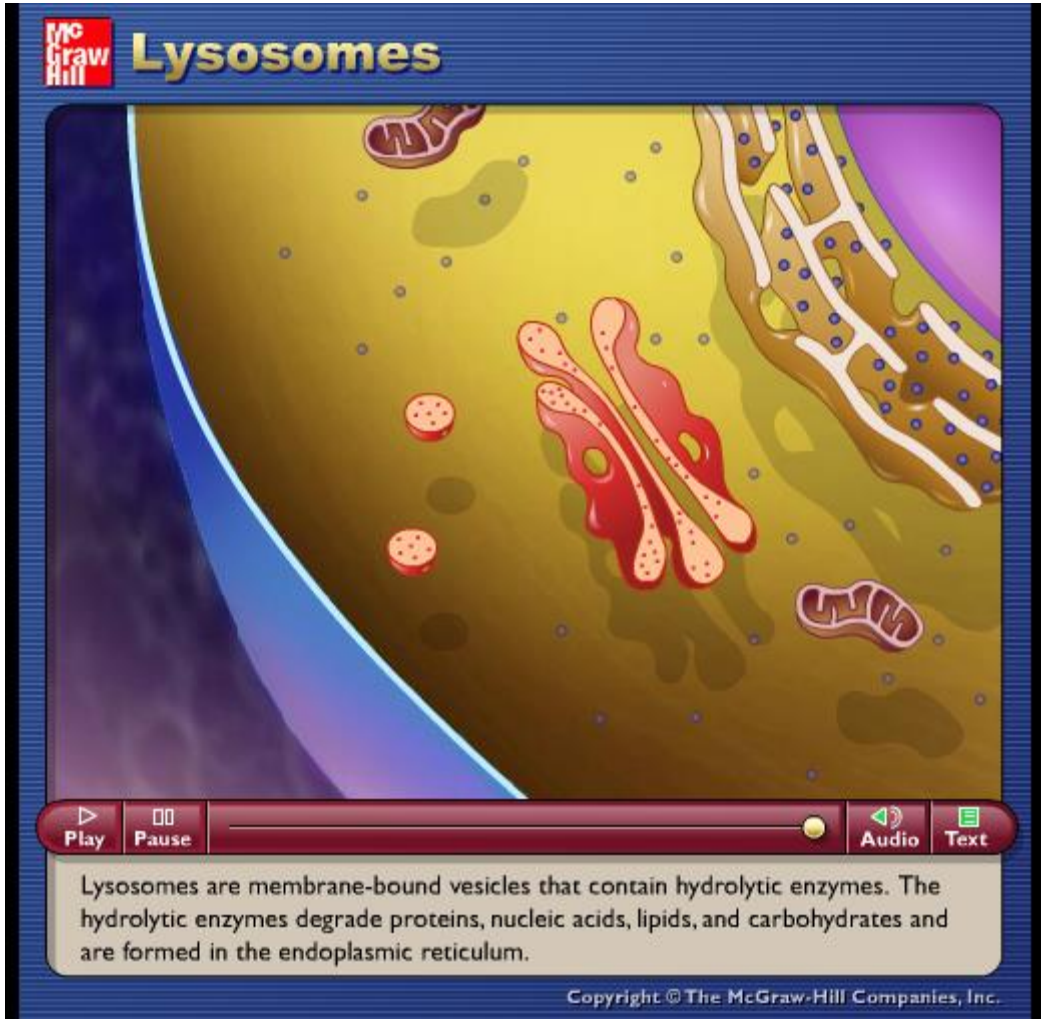
a. Mitochondrion and a peroxisome in a lysosome



b. Storage bodies in a cell with defective lysosomes

a: Courtesy Daniel S. Friend; b: Courtesy Robert D. Terry/Univ. of San Diego School of Medicine

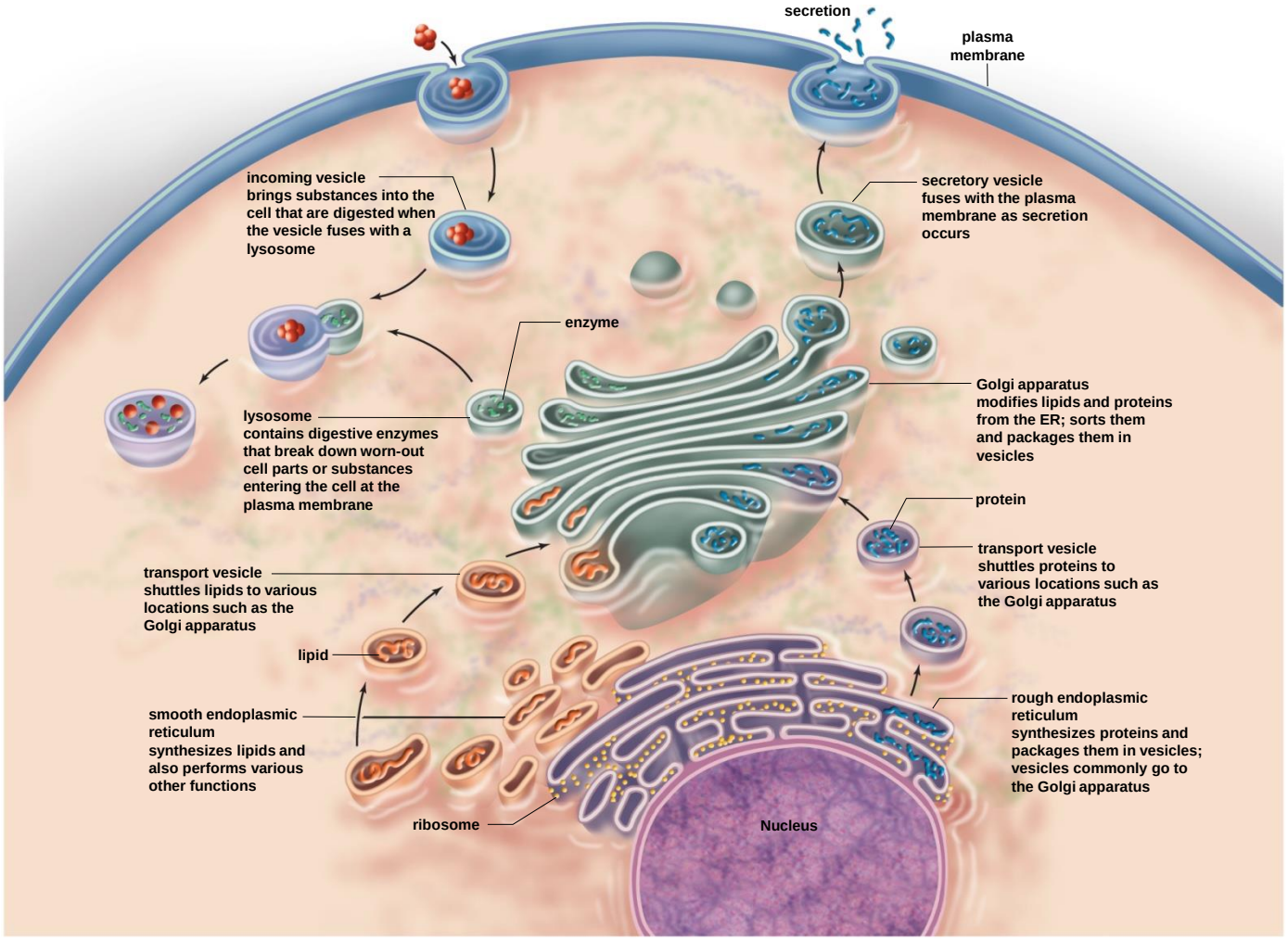
Animation


Lysosomes
Play
Pause
Audio
Text
Lysosomes are membrane-bound vesicles that contain hydrolytic enzymes. The hydrolytic enzymes degrade proteins, nucleic acids, lipids, and carbohydrates and are formed in the endoplasmic reticulum.
Copyright © The McGraw-Hill Companies, Inc.

Endomembrane System: Summary

- Proteins produced in rough ER and lipids from smooth ER are carried in vesicles to the Golgi apparatus.
- The Golgi apparatus modifies these products and then sorts and packages them into vesicles that go to various cell destinations.
- Secretory vesicles carry products to the membrane where exocytosis produces secretions.
- Lysosomes fuse with incoming vesicles and digest macromolecules.

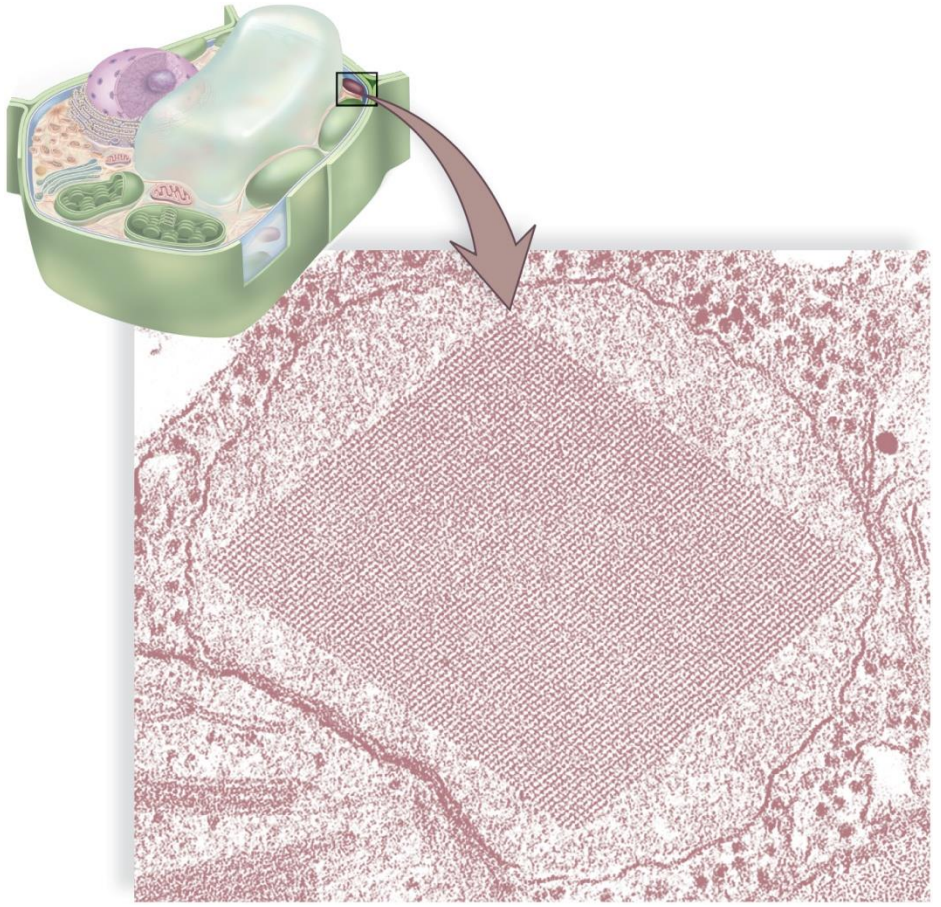
Endomembrane System: A Visual Summary



Peroxisomes

- Similar to lysosomes
  - Membrane-bounded vesicles
  - Enclose enzymes
- However
  - Enzymes synthesized by free ribosomes in cytoplasm (instead of ER)
  - Active in lipid metabolism
  - Catalyze reactions that produce hydrogen peroxide H_2O_2
    - Toxic
    - Broken down to water & O_2 by catalase

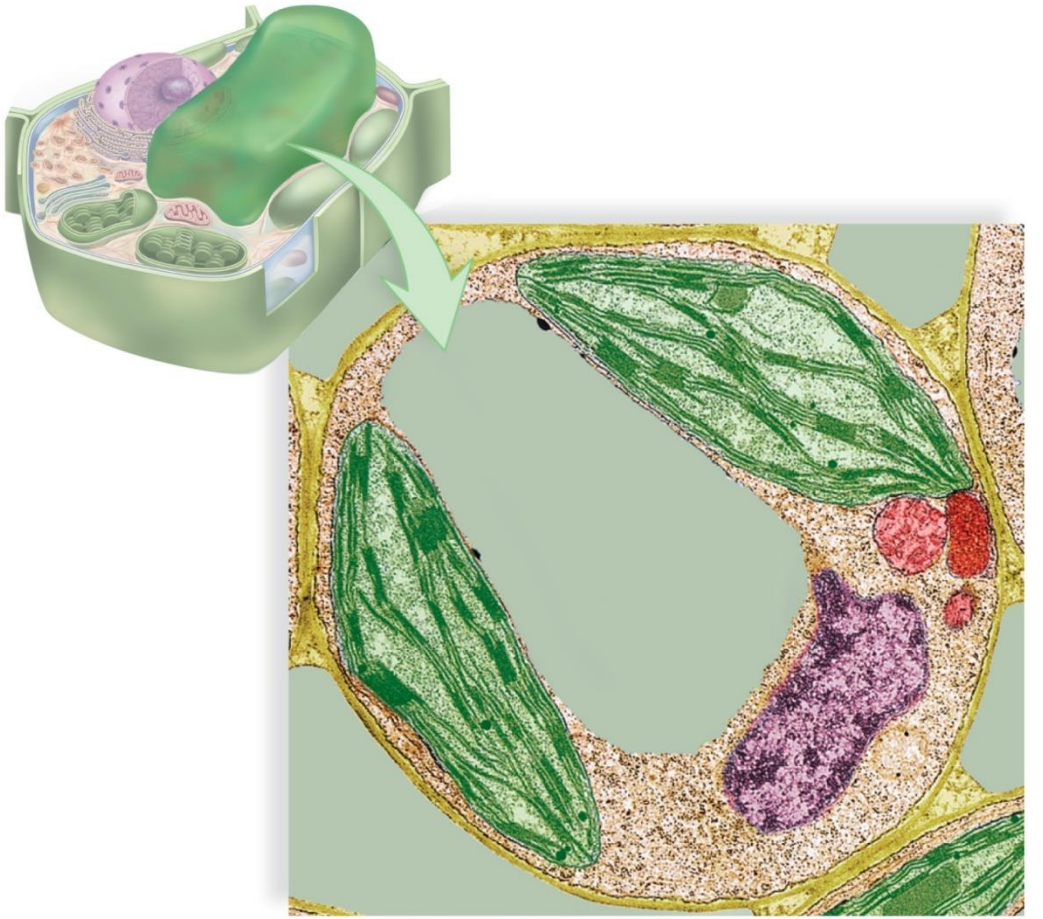
Peroxisomes



Vacuoles

- Membranous sacs that are larger than vesicles
  - Store materials that occur in excess
  - Others very specialized (contractile vacuole)
- Plants cells typically have a central vacuole
  - Up to 90% volume of some cells
  - Functions in:
    - Storage of water, nutrients, pigments, and waste products
    - Development of turgor pressure
    - Some functions performed by lysosomes in other eukaryotes

Vacuoles



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Energy-Related Organelles: Chloroplast Structure

- Bounded by double membrane
- Inner membrane infolded
  - Forms disc-like thylakoids, which are stacked to form grana
  - Suspended in semi-fluid stroma
- Green due to chlorophyll
  - Green photosynthetic pigment
  - Found ONLY in inner membranes of chloroplast

Energy-Related Organelles: Chloroplasts

- Membranous organelles (a type of **plastid**) that serve as the site of photosynthesis
- Captures light energy to drive cellular machinery
- Photosynthesis
  - Synthesizes carbohydrates from CO_2 & H_2O
  - Makes own food using CO_2 as only carbon source
  - Energy-poor compounds converted to energy-rich compounds

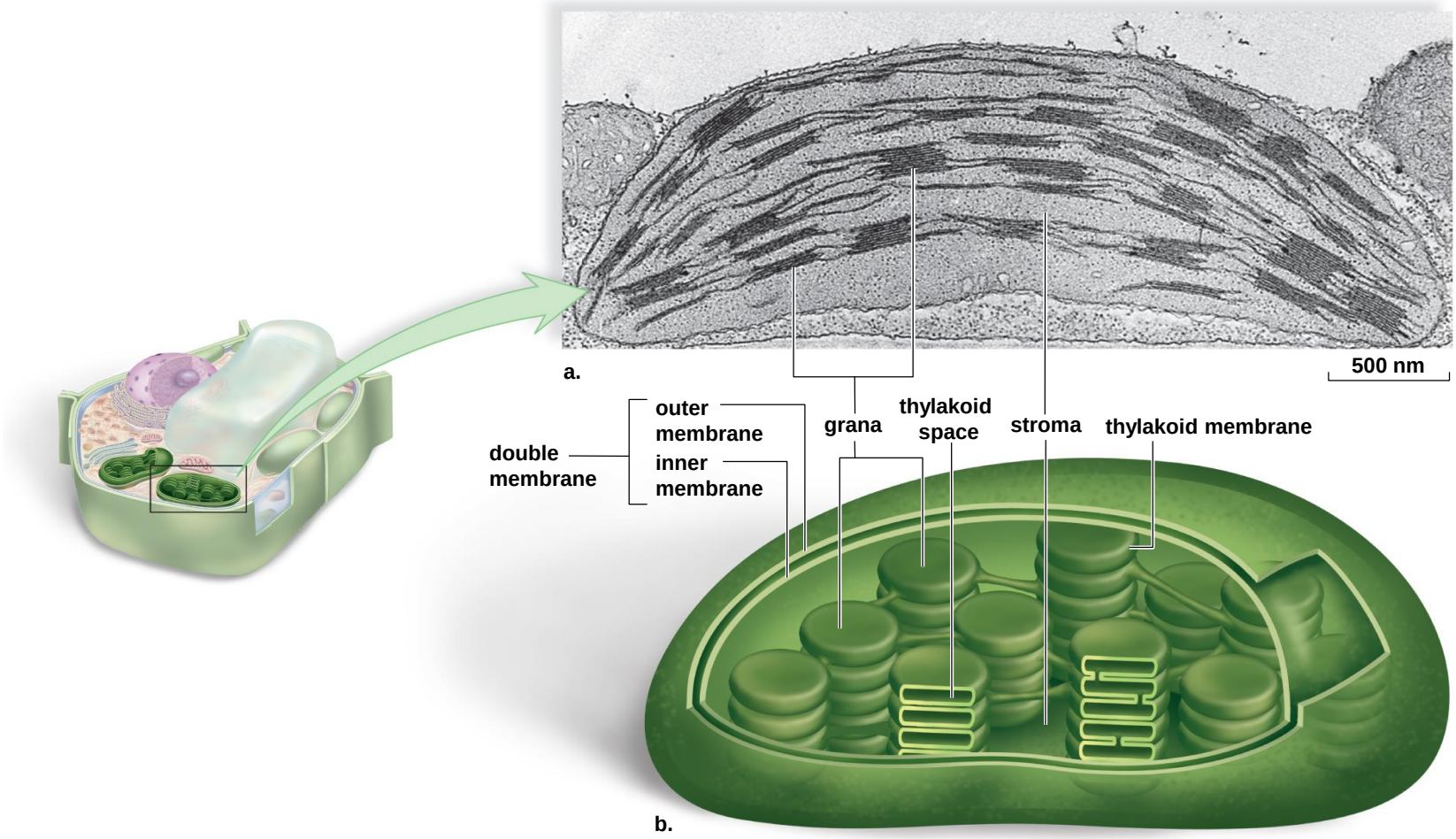
  solar energy + carbon dioxide + water $\rightarrow$ carbohydrate + oxygen

  - Only plants, algae, and certain bacteria are capable of conducting photosynthesis

Energy-Related Organelles: Chloroplasts

- Bound by a double membrane organized into flattened disc-like sacs called **thylakoids**
- Chlorophyll and other pigments capture solar energy
- Enzymes synthesize carbohydrates

Chloroplast Structure

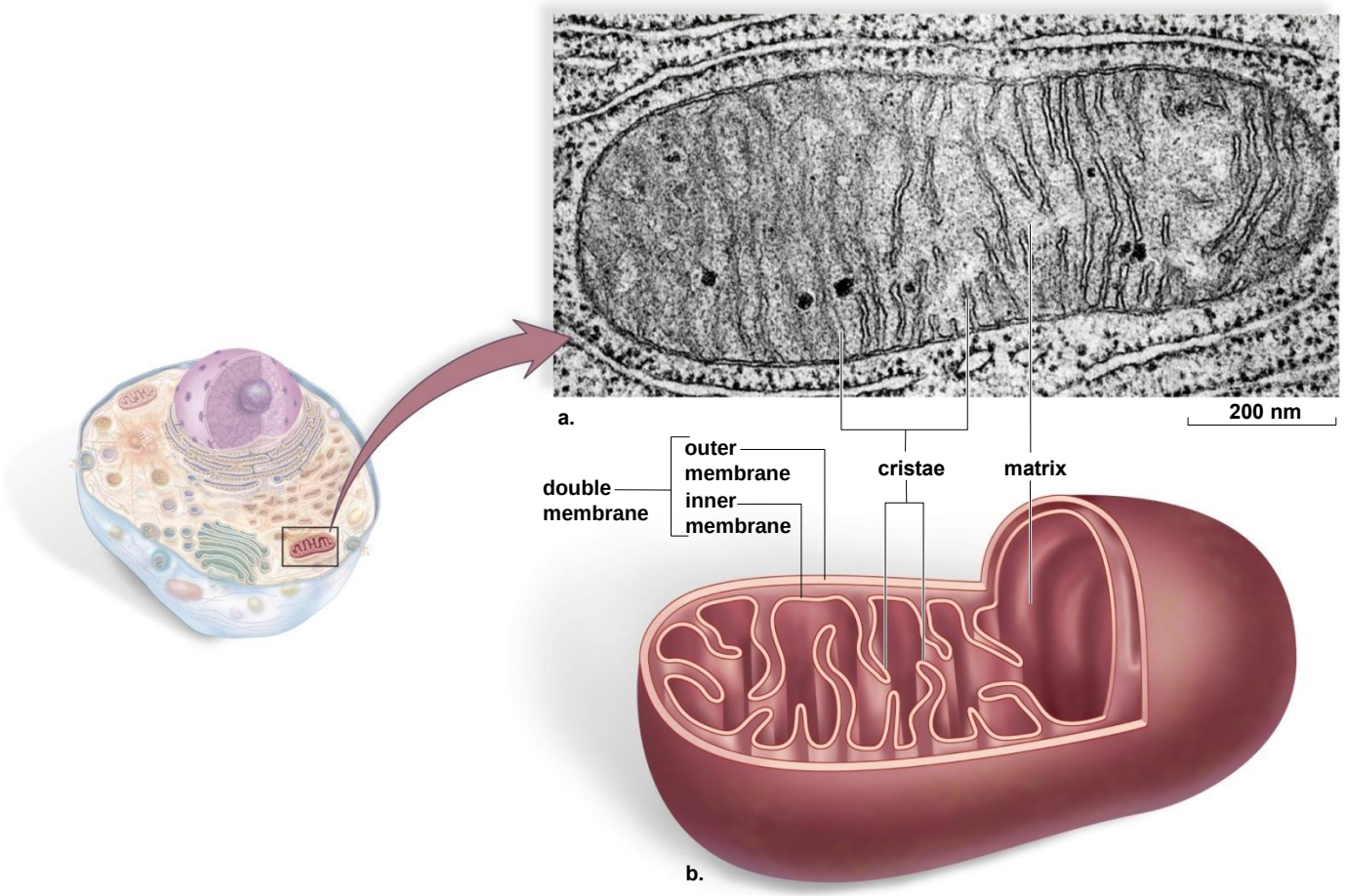


a: Courtesy Herbert W. Israel, Cornell University

Energy-Related Organelles: Mitochondria

- Smaller than chloroplast
- Contain ribosomes and their own DNA
- Surrounded by a double membrane
  - Inner membrane surrounds the **matrix** and is convoluted (folds) to form **cristae.**
  - Matrix – Inner semifluid containing respiratory enzymes
    - Break down carbohydrates
- Involved in cellular respiration
- Produce most of ATP utilized by the cell

Mitochondrial Structure



a: Courtesy Dr. Keith Porter

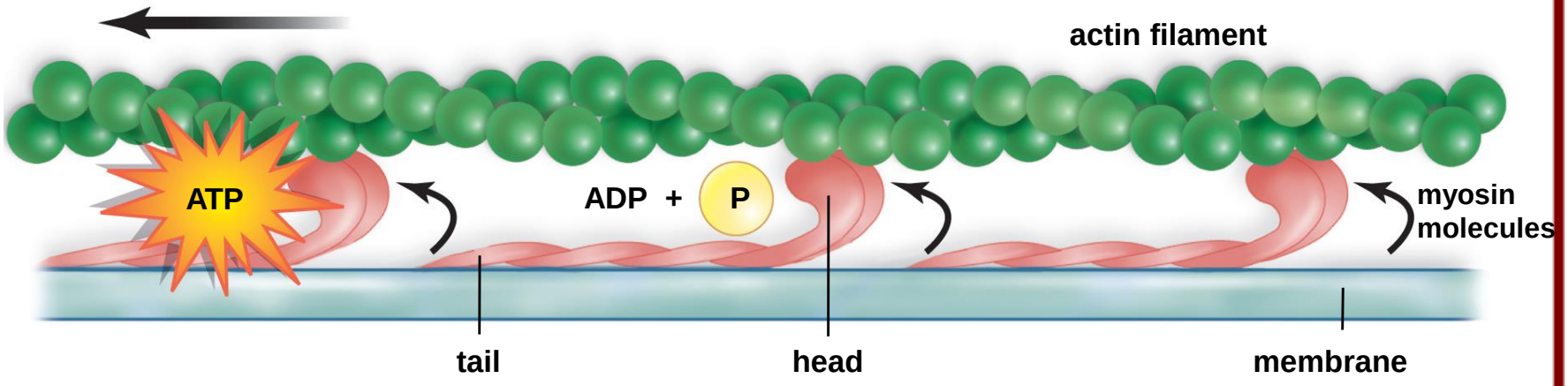
The Cytoskeleton

- Maintains cell shape
- Assists in movement of cell and organelles
- Three types of macromolecular fibers
  - Actin Filaments
  - Intermediate Filaments
  - Microtubules
- Assemble and disassemble as needed

The Cytoskeleton: Actin Filaments

- Extremely thin filaments like twisted pearl necklace
- Dense web just under plasma membrane maintains cell shape
- Support for microvilli in intestinal cells
- Intracellular traffic control
  - For moving stuff around within cell
  - Cytoplasmic streaming
- Function in pseudopods of amoeboid cells
- Pinch mother cell in two after animal mitosis
- Important component in muscle contraction (other is myosin)

The Cytoskeleton: Actin Filament Operation



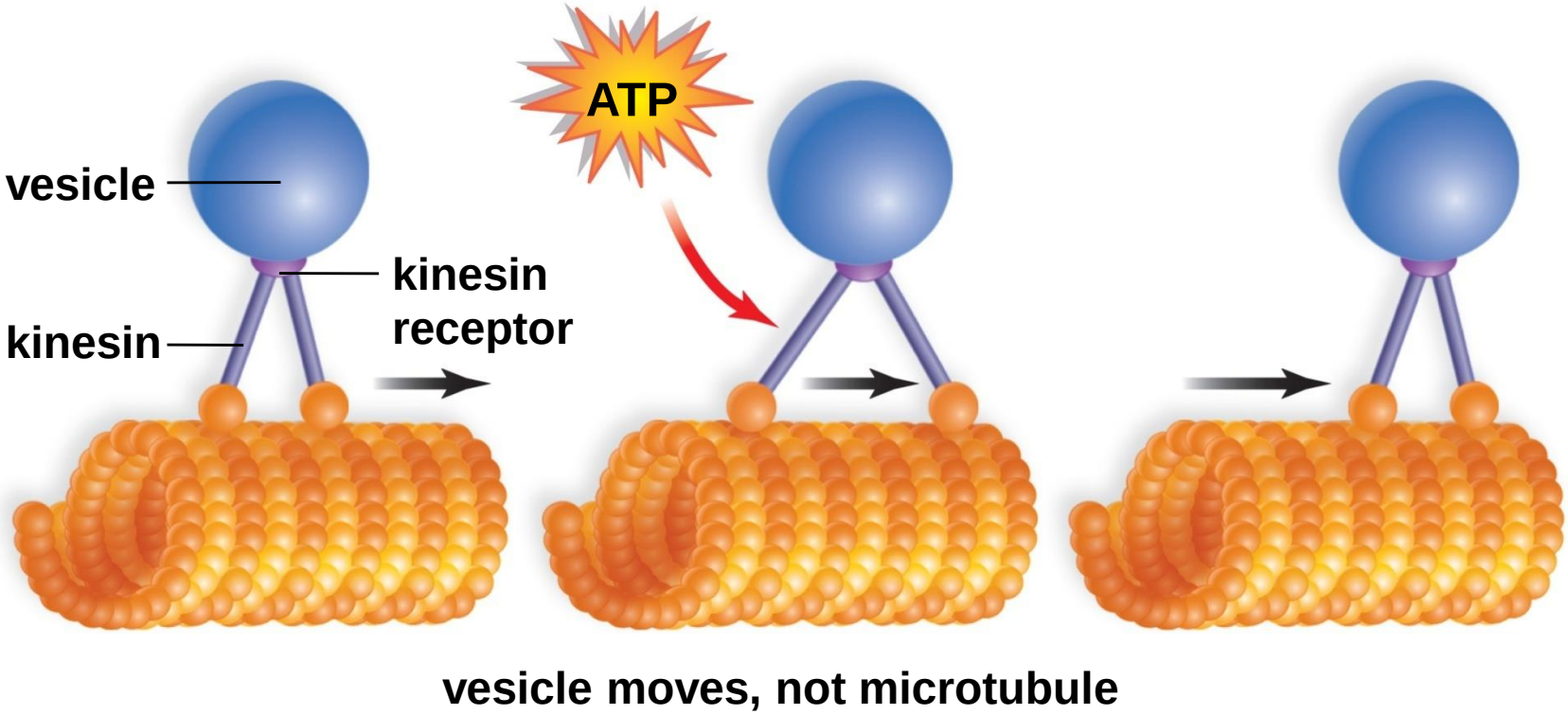
The Cytoskeleton: Intermediate Filaments

- Intermediate in size between actin filaments and microtubules
- Rope-like assembly of fibrous polypeptides
- Vary in nature
  - From tissue to tissue
  - From time to time
- Functions:
  - Support nuclear envelope
  - Cell-cell junctions, like those holding skin cells tightly together

The Cytoskeleton: Microtubules

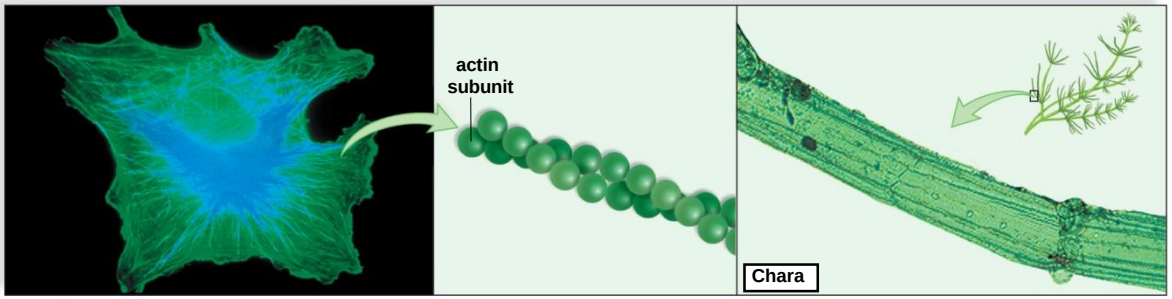
- Hollow cylinders made of two globular proteins called α and β tubulin
- Spontaneous pairing of α and β tubulin molecules form structures called dimers
- Dimers then arrange themselves into tubular spirals of 13 dimers around
- Assembly:
  - Under control of Microtubule Organizing Center (MTOC)
  - Most important MTOC is centrosome
- Interacts with proteins kinesin and dynein to cause movement of organelles

The Cytoskeleton: Microtubule Operation

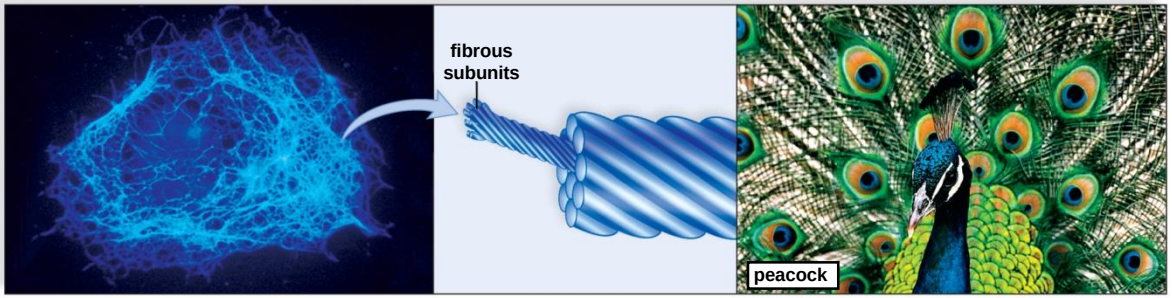


vesicle moves, not microtubule

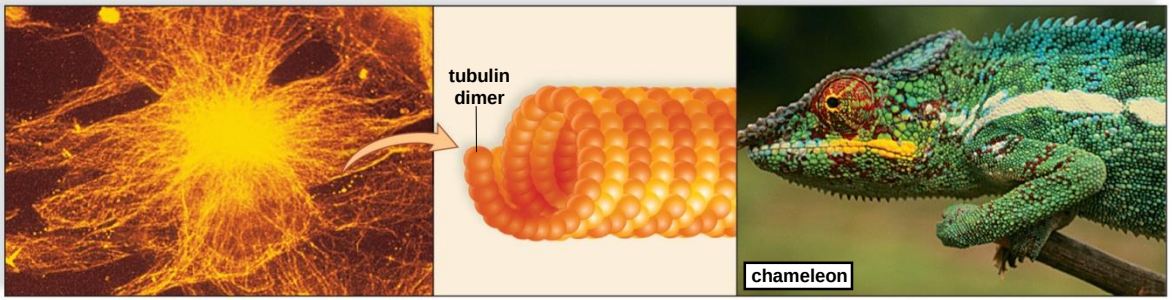
The Cytoskeleton



a. Actin filaments



b. Intermediate filaments



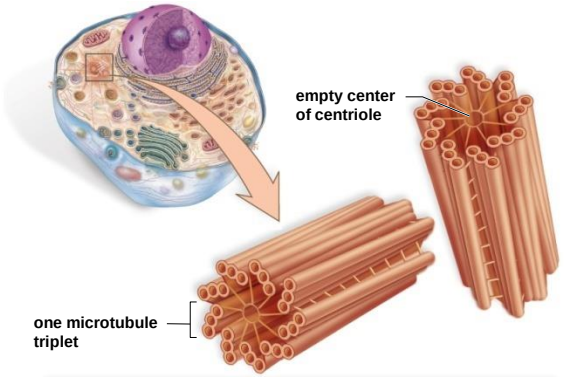
c. Microtubules

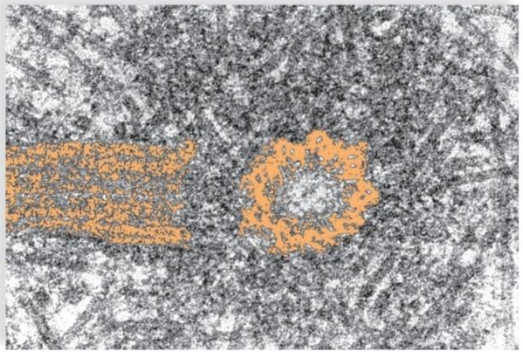
a(Actin): © M. Schliwa/Visuals Unlimited; b, c(Intermediate, Microtubules): © K.G. Murti/Visuals Unlimited; a(Chara): The McGraw-Hill Companies, Inc./photo by Dennis Strete and Darrell Vodopich; b(Peacock): © Vol. 86/Corbis; c(Chameleon): © Photodisc/Vol. 6/Getty Images

Microtubular Arrays: Centrioles

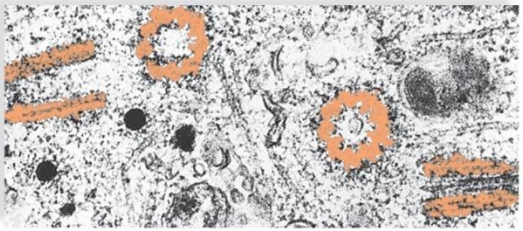
- Short, hollow cylinders
  - Composed of 27 microtubules
  - Microtubules arranged into 9 overlapping triplets
- One pair per animal cell
  - Located in centrosome of animal cells
  - Oriented at right angles to each other
  - Separate during mitosis to determine plane of division
- May give rise to basal bodies of cilia and flagella

Cytoskeleton: Centrioles





one centrosome: one pair of centrioles

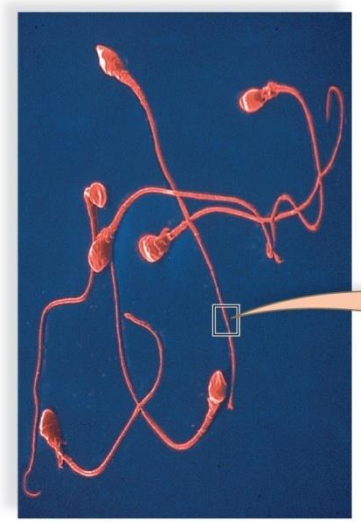


two centrosomes: two pairs of centrioles

Microtubular Arrays: Cilia and Flagella

- Hair-like projections from cell surface that aid in cell movement
- Very different from prokaryote flagella
  - Outer covering of plasma membrane
  - Inside this is a cylinder of 18 microtubules arranged in 9 pairs
  - In center are two single microtubules
  - This 9 + 2 pattern used by all cilia & flagella
- In eukaryotes, cilia are much shorter than flagella
  - Cilia move in coordinated waves like oars
  - Flagella move like a propeller or cork screw

Structure of a Flagellum



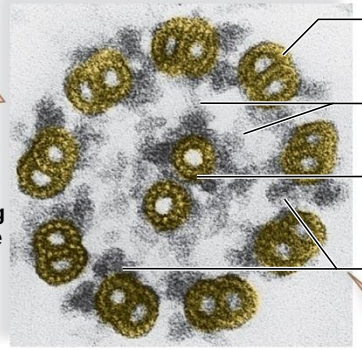
Sperm

Flagellum

shaft

The shaft of the flagellum has a ring of nine microtubule doublets anchored to a central pair of microtubules.

plasma membrane



outer microtubule doublet

radial spoke

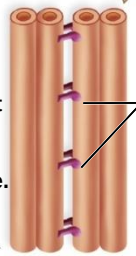
central microtubules

dynein side arm

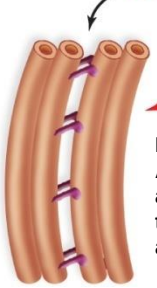
Flagellum cross section

25 nm

The side arms of each doublet are composed of dynein, a motor molecule.



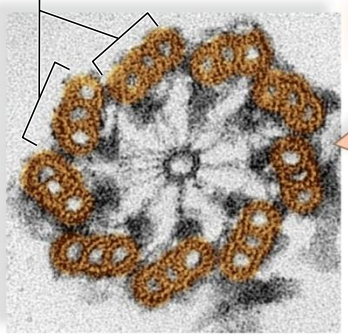
dynein side arms



ATP

In the presence of ATP, the dynein side arms reach out to their neighbors, and bending occurs.

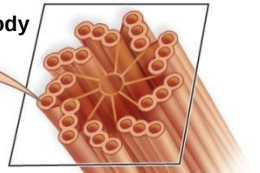
triplets



Basal body cross section

100 nm

Basal body



The basal body of a flagellum has a ring of nine microtubule triplets with no central microtubules.

Comparison of Prokaryotic and Eukaryotic Cells

TABLE 4.1

Comparison of Prokaryotic Cells and Eukaryotic Cells

	Prokaryotic Cells (1–20 μm in diameter)	*Eukaryotic Cells (10–100 μm in diameter)*	
		Animal	*Plant*
Cell wall	Usually (peptidoglycan)	No	Yes (cellulose)
Plasma membrane	Yes	Yes	Yes
Nucleus	No	Yes	Yes
Nucleolus	No	Yes	Yes
Ribosomes	Yes (smaller)	Yes	Yes
Endoplasmic reticulum	No	Yes	Yes
Golgi apparatus	No	Yes	Yes
Lysosomes	No	Yes	No
Mitochondria	No	Yes	Yes
Chloroplasts	No	No	Yes
Peroxisomes	No	Usually	Usually
Cytoskeleton	No	Yes	Yes
Centrioles	No	Yes	No
9 + 2 cilia or flagella	No	Often	No (in flowering plants) Yes (sperm of bryophytes, ferns, and cycads)

Review

- Cellular Level of Organization
  - Cell theory
  - Cell size
- Prokaryotic Cells
- Eukaryotic Cells
  - Organelles
- Nucleus and Ribosome
- Endomembrane System
- Other Vesicles and Vacuoles
- Energy related organelles
- Cytoskeleton
    - Centrioles, Cilia, and Flagella

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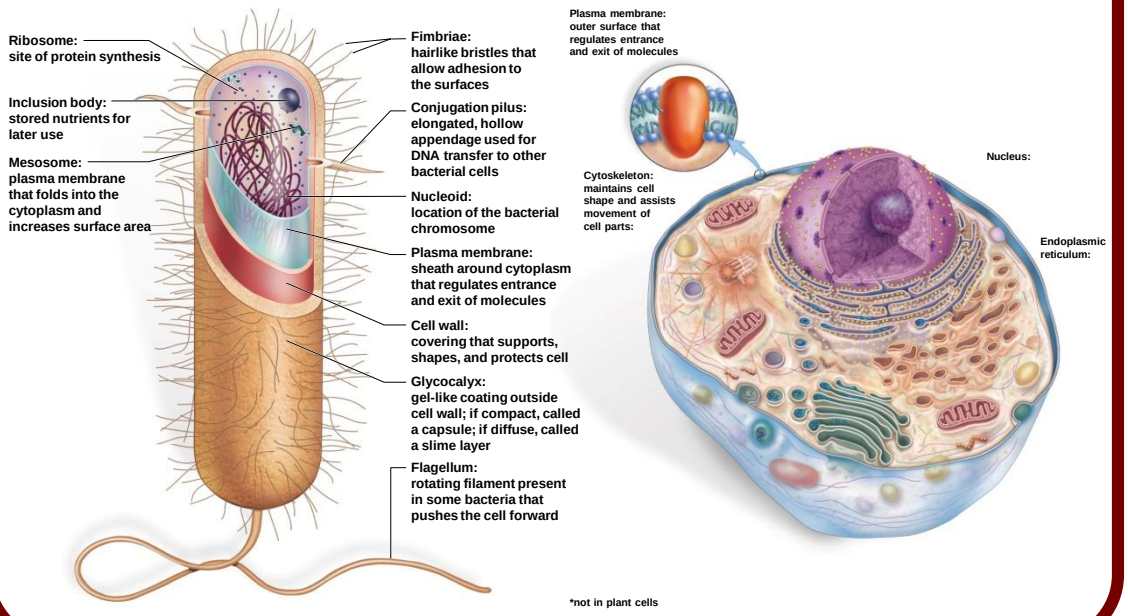
Cell Structure and Function



BIOLOGY

10th Edition

Sylvia S. Mader

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