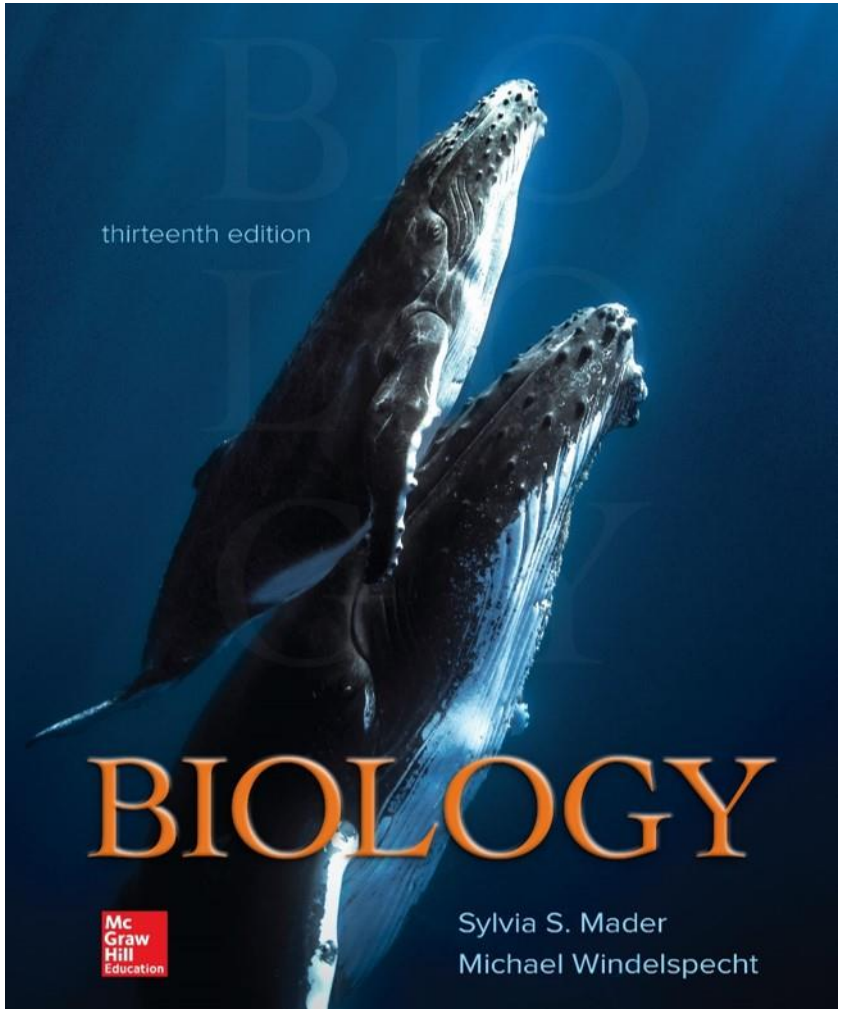


Biology

Sylvia S. Mader
Michael Windelspecht

Chapter 4
Cell Structure and Function
Lecture Online

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Outline

Think, Pair, Share

4.1 Cellular Level of Organization

Detailed study of the cell in the 1830s

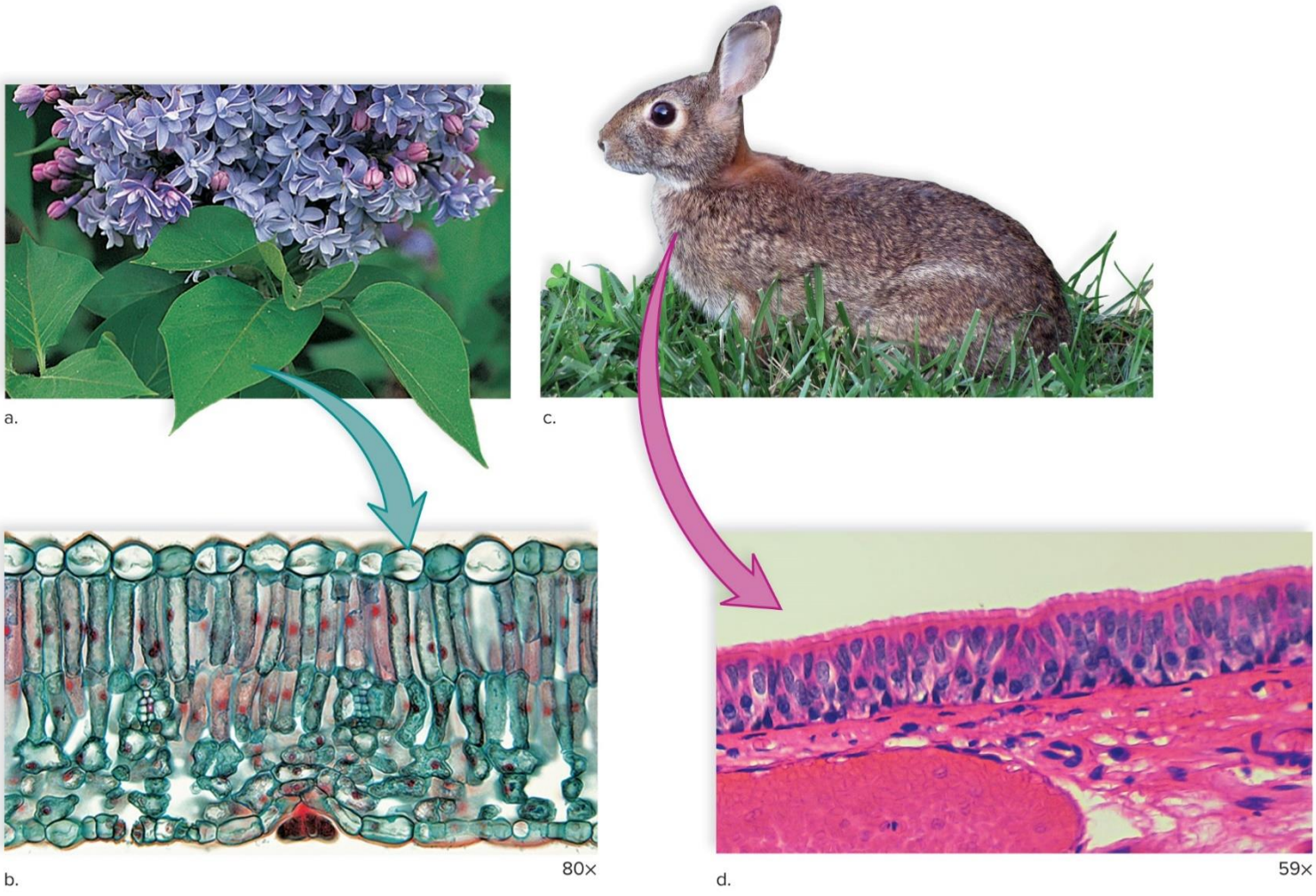
A unifying concept in biology

Originated from the work of biologists Schleiden and Schwann in 1838 to 1839

Cell Theory:

- All organisms are composed of cells.
  - German botanist Matthias Schleiden (1804 to 1881)
  - German zoologist Theodor Schwann (1810 to 1882)
- Cells come only from preexisting cells because cells are self-reproducing.
  - German physician Rudolph Virchow (1821 to 1902)
- Cells are the basic units of structure and function in organisms

Organisms and Cells



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Jump to Organisms and Cells Long Description

Cell Size

Cells range in size from one millimeter (mm) down to one micrometer (μm) in diameter.

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, which also decreases the efficiency of transporting materials in and out of the cell
- Small cells – larger surface-area-to-volume ratio is advantageous for exchanging molecules

Surface-Area-to-Volume Relationships

	One 4-centimeter cube	Eight 2-centimeter cubes	Sixty-four 1-centimeter cubes
Total surface area (height × width × number of sides × number of cubes)	96 centimeter^2	192 centimeter^2	384 centimeter^2
Total volume (height × width × length × number of cubes)	64 centimeter^3	64 centimeter^3	64 centimeter^3
Surface area/Volume of each cube (surface area ÷ volume)	1.5:1	3:1	6:1

Jump to Surface-Area-to-Volume Relationships Long Description

Think, Pair, Share

Why do cells have to be as small as they are?

Microscopy Today: Compound Light Microscope

Light is passed through the specimen.

Then it is focused by a series of glass lenses.

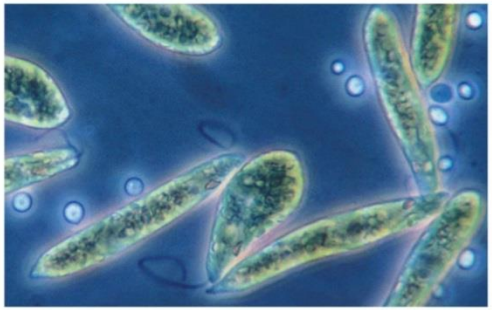
It forms an image on the human retina.

The maximum magnification is about 1000×.

The compound light microscope resolves objects separated by 0.2 millimeter, 500× better than the human eye.

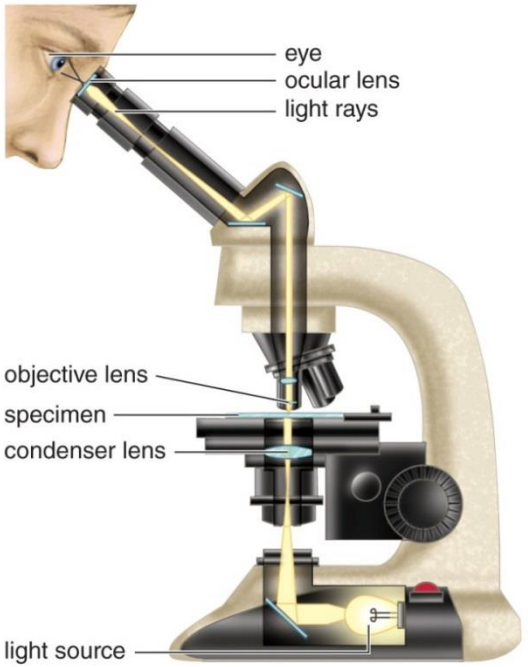
- Assuming the resolving power of the human eye is 1.0

Compound Light Microscope



200×

Euglena, light micrograph



a. Compound light microscope

4.2 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**
  - Cause diseases but are also environmentally important as decomposers
  - Can be useful in manufacturing products and drugs
- **Archaea**
  - Live in extreme habitats
- The two prokaryotic domains are structurally similar but biochemically different.

The Structure of Prokaryotes (1)

Extremely small: 1 to 1.5 micrometer wide and 2 to 6 micrometer long

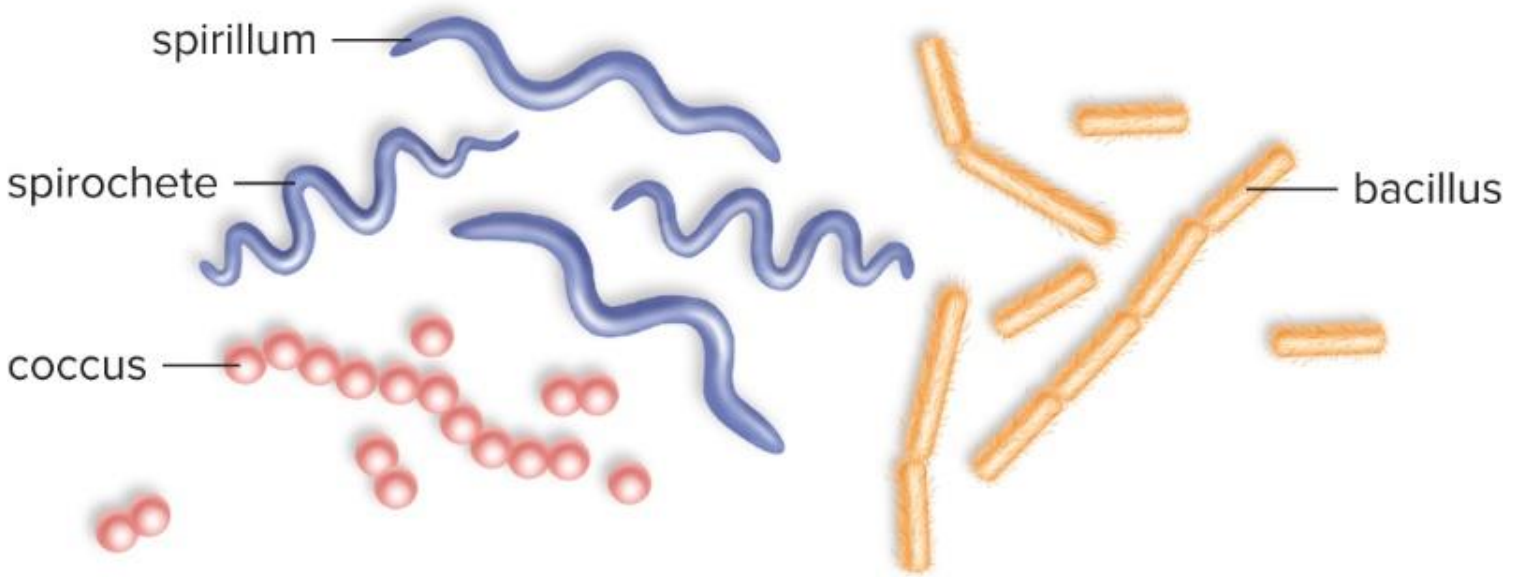
Occur in three basic shapes:

- Spherical **coccus**
- Rod-shaped **bacillus**
- Spiral **spirillum** (if rigid) or **spirochete** (if flexible)

Cell Envelope includes**:**

- **Plasma membrane** – lipid bilayer with embedded and peripheral proteins
  - Can form internal pouches (**mesosomes**), which increase surface area
- **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 Prokaryotes (2)

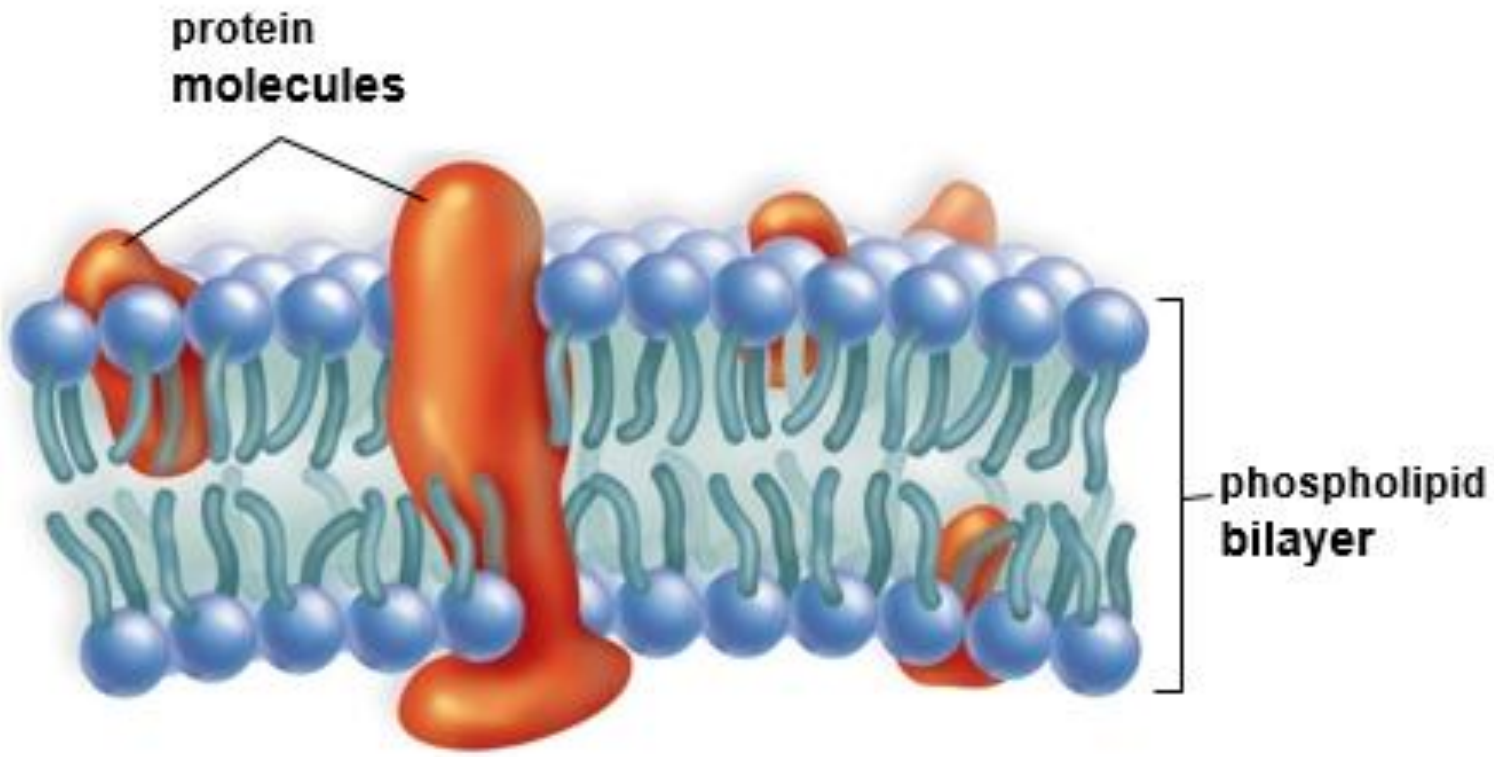


Think, Pair, Share

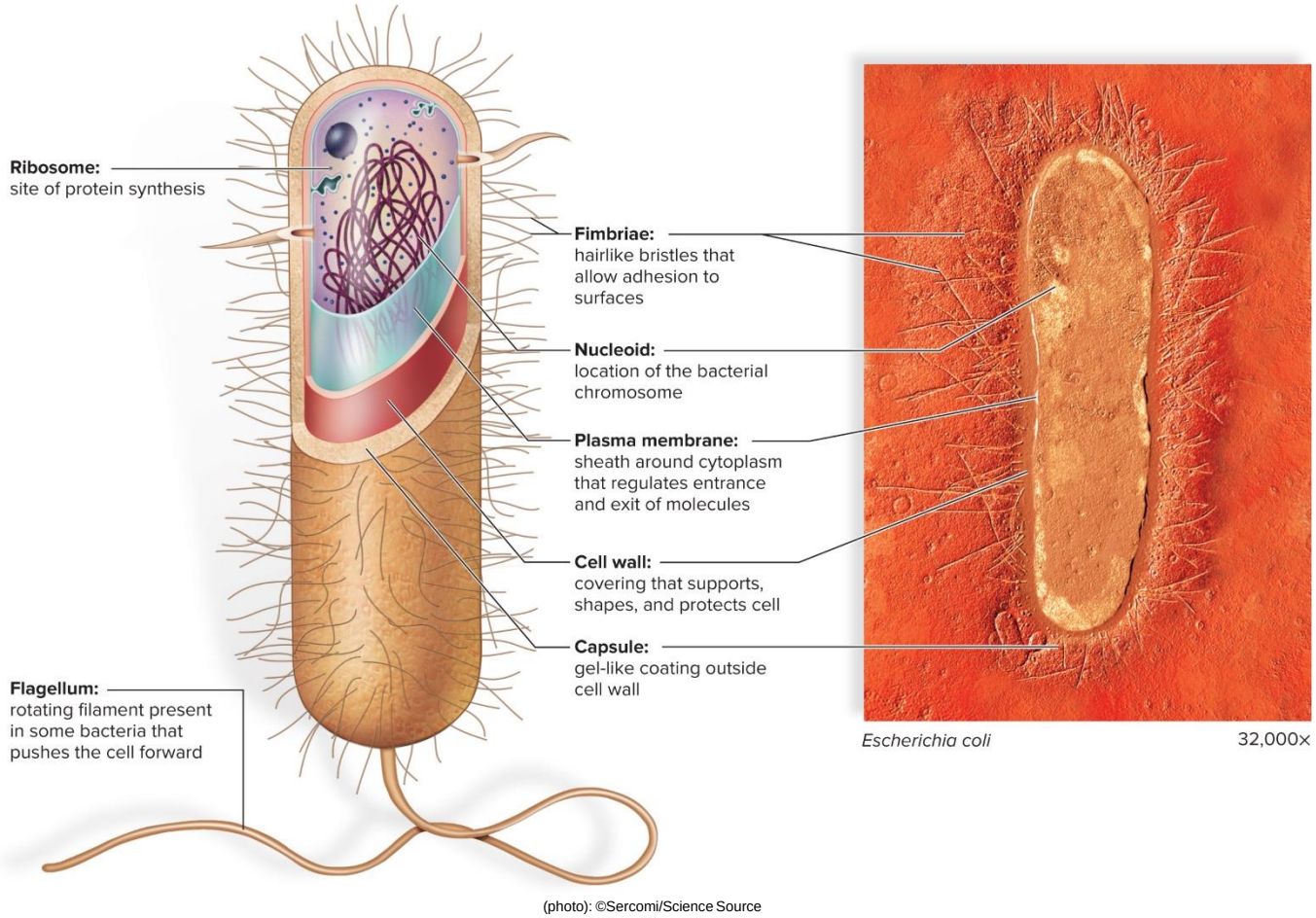
What is the maximum magnification of light microscopes?

What domains belong to the prokaryotic group?

The Structure of Prokaryotes—The Plasma Membrane



The Structure of Prokaryotes—A Prokaryotic Cell



(photo): ©Sercomi/Science Source

Jump to The Structure of Prokaryotes—A Prokaryotic Cell Long Description

Prokaryotic Cytoplasm and External Structures

Cytoplasm

- Semifluid solution
  - Encased 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.
- **Ribosomes** are tiny structures in the cytoplasm that synthesize proteins.

External Structures

- **Flagella** – provide motility
- **Fimbriae** – small, bristle-like fibers that sprout from the cell surface
- **Conjugation pili** – rigid tubular structures used to pass DNA from cell to cell (singular pilus)

Think, Pair, Share

What kinds of structures do prokaryotic cells possess? What do they do?

4.3 Introduction to Eukaryotic Cells

Eukaryotic cells contain:

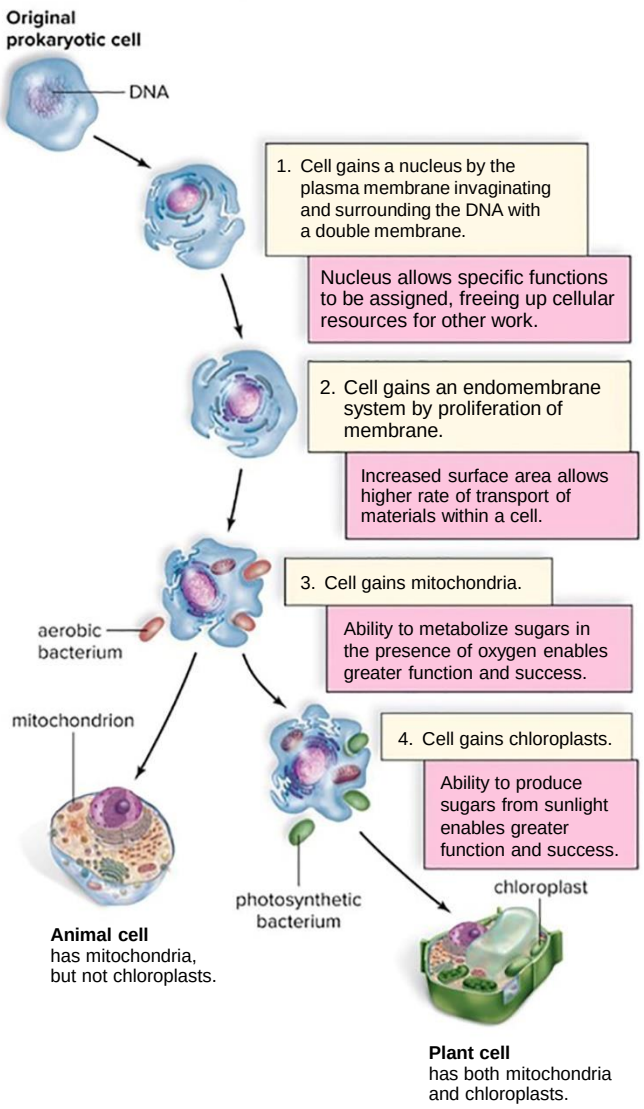
- Membrane-bound nucleus that houses DNA
- Specialized organelles
- Plasma membrane which
  - separates cell contents from environment
  - regulates passage of materials in and out
  - is composed of a phospholipid bilayer with embedded proteins
- The first two distinguish eukaryotic from prokaryotic cells

Eukaryotic cells are also much larger than prokaryotic cells.

Eukaryotic cells are compartmentalized.

- They contain small structures called **organelles** which
  - perform specific functions.
  - isolate reactions from other reactions.

Origin of Organelles



Jump to Origin of Organelles Long Description

Origin of the Eukaryotic Cell

The fossil record suggest that the first cells were prokaryotes.

Biochemical data shows eukaryotes are more closely related to archaea than bacteria.

The nucleus is believed to have evolved by invagination of the plasma membrane.

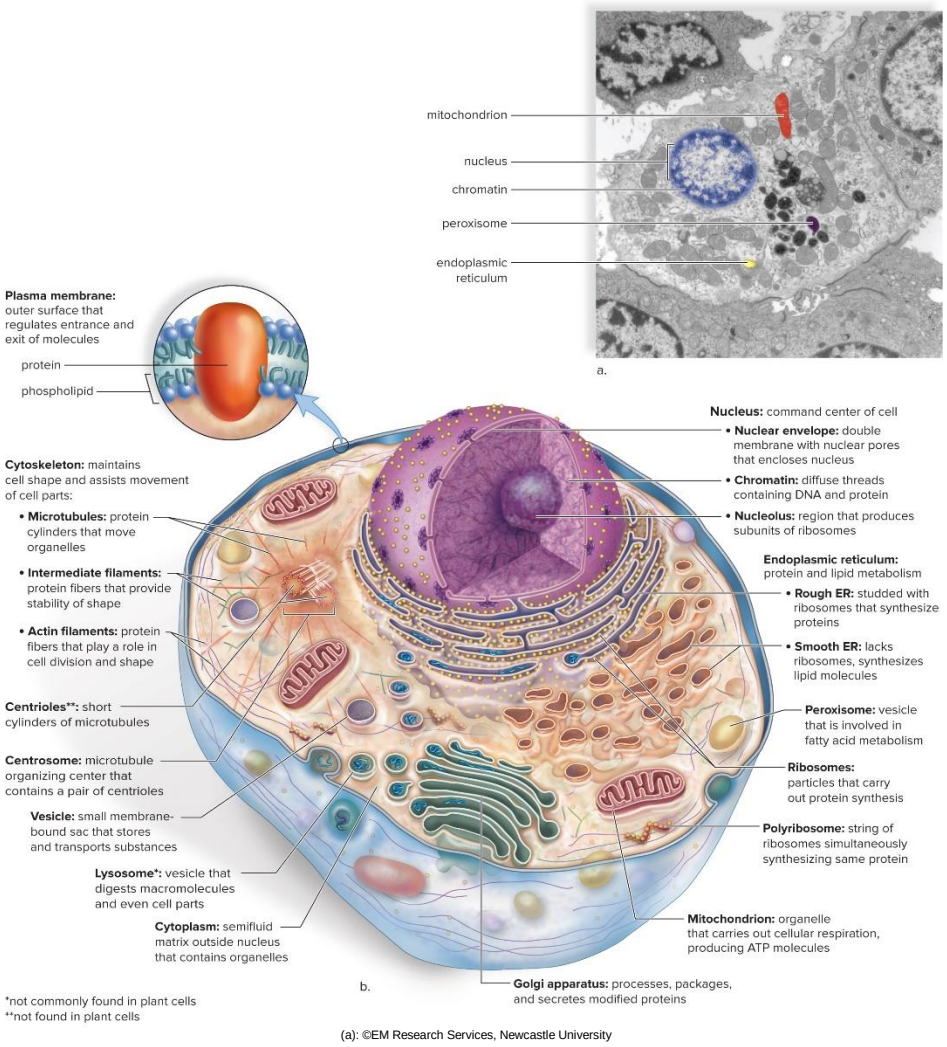
- The invagination process also explains origins of endoplasmic reticulum and Golgi.
- Energy organelles, mitochondria and chloroplasts, may have originated when eukaryotic cell engulfed smaller prokaryotic cells.
  - Eukaryotic cells would have benefitted the from ability to utilize oxygen or synthesize organic food.
  - Endosymbiotic theory is the name of the hypothesis.

Introduction to Eukaryotic Cells

There are two classes of organelles.

- **Endomembrane system**
  - Organelles that communicate with one another
    - Via membrane channels
    - Via small vesicles
- Energy-related organelles
  - **Mitochondria** and **chloroplasts**
  - Independent and self-sufficient

Animal Cell Anatomy



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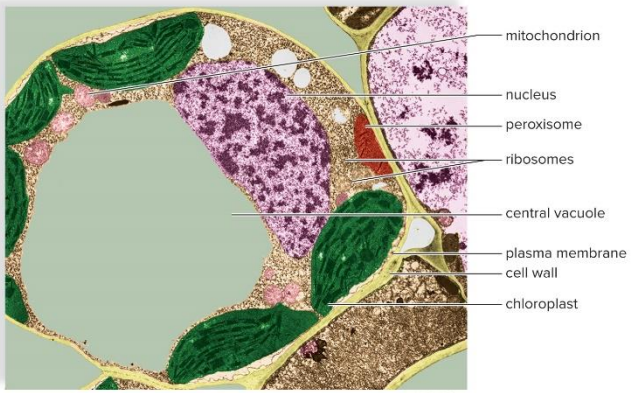
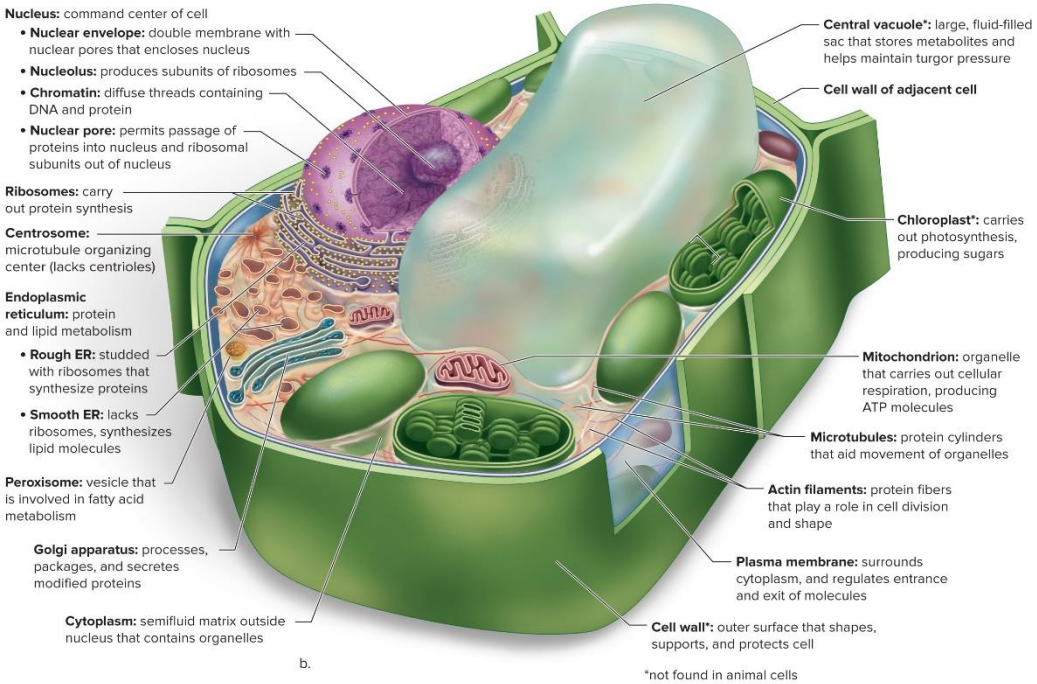
Jump to Animal Cell Anatomy Long Description

Plant Cell Anatomy



a. 12,300×



b.

(a): ©Biophoto Associates/Science Source

Jump to Plant Cell Anatomy Long Description

Think, Pair, Share

Where are the organelles of eukaryotic cells thought to have come from?

Structure of a Eukaryotic Cell (1)

Plant and animal cell diagrams are generalized for study purposes.

Specialized cells may have more or fewer copies of organelles, depending on their functions.

- Example: Liver cells, which detoxify drugs, have more smooth endoplasmic reticulum than other cells.
- Example: Nerve cells, which carry electrical impulses, have more plasma membrane.

The cell is a system of interconnected organelles that work together.

- Example: The nucleus is a compartment that houses genetic material.
  - It communicates with ribosomes in the cytoplasm.

Structure of a Eukaryotic Cell (2)

Production of specific molecules takes place in or on organelles by enzymes in membranes.

Products are transported around cell by vesicles.

- Vesicles are sacs made of membrane material.

Vesicles move around using the cytoskeletal network.

- Protein fibers are like railroad tracks.

Plant cells, fungi, and many protists have cell walls.

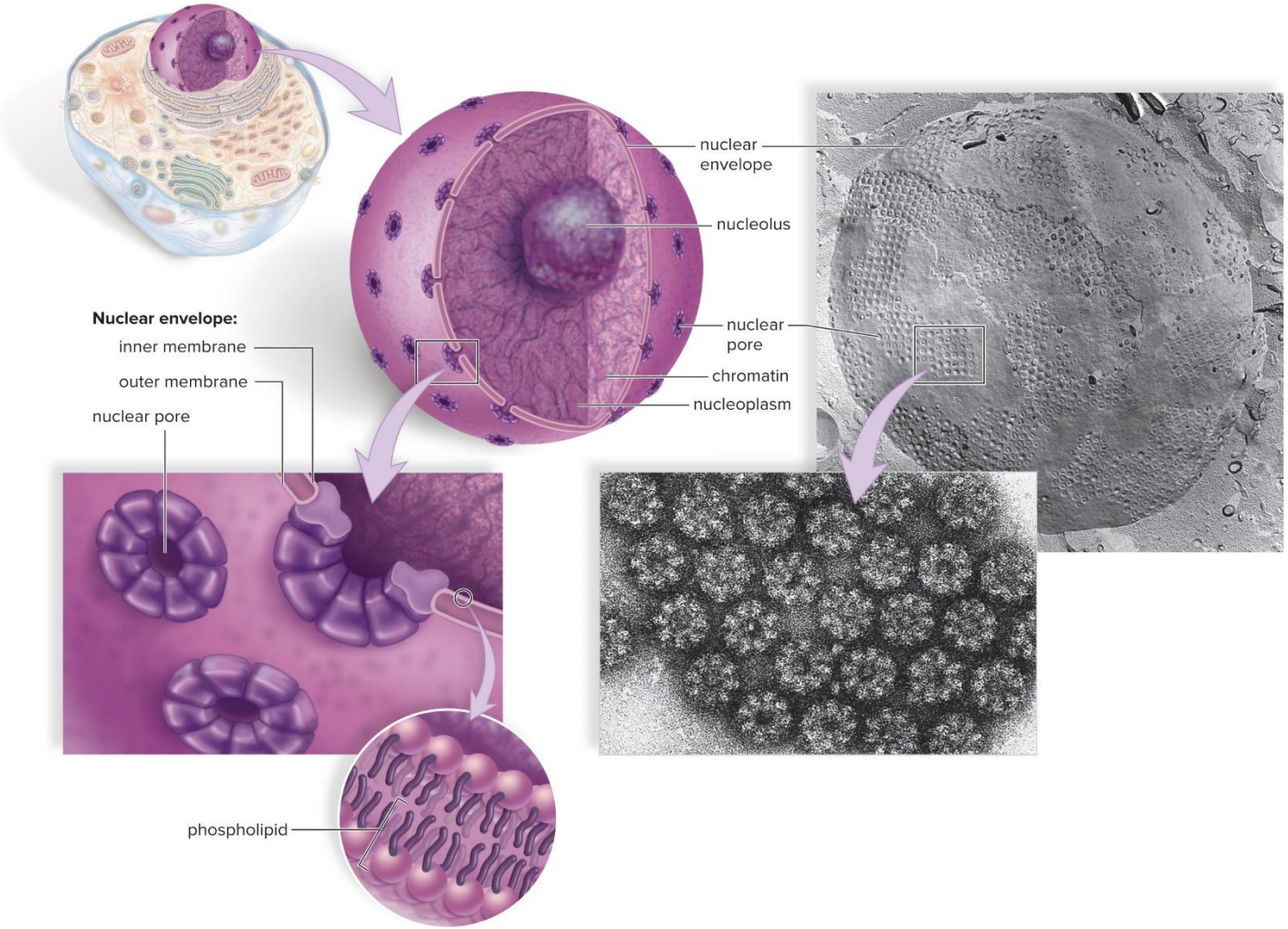
- Plant cell walls contain cellulose, a structural polysaccharide.

4.4 The Nucleus and Ribosomes

The 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 and cytoplasm
- Contains **chromatin** in semifluid **nucleoplasm**
  - Chromatin contains nucleic acids and proteins.
    - Condenses to form **chromosomes**
      - Chromosomes are formed during cell division.
      - Chromosomes are carriers of genetic information.
- Dark nucleolus composed of rRNA
  - Produces subunits of ribosomes

Anatomy of the Nucleus



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Jump to Anatomy of the Nucleus Long Description 4-29

Ribosomes

Composed of rRNA

- Consist of a large subunit and a small subunit
  - Subunits are 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**.

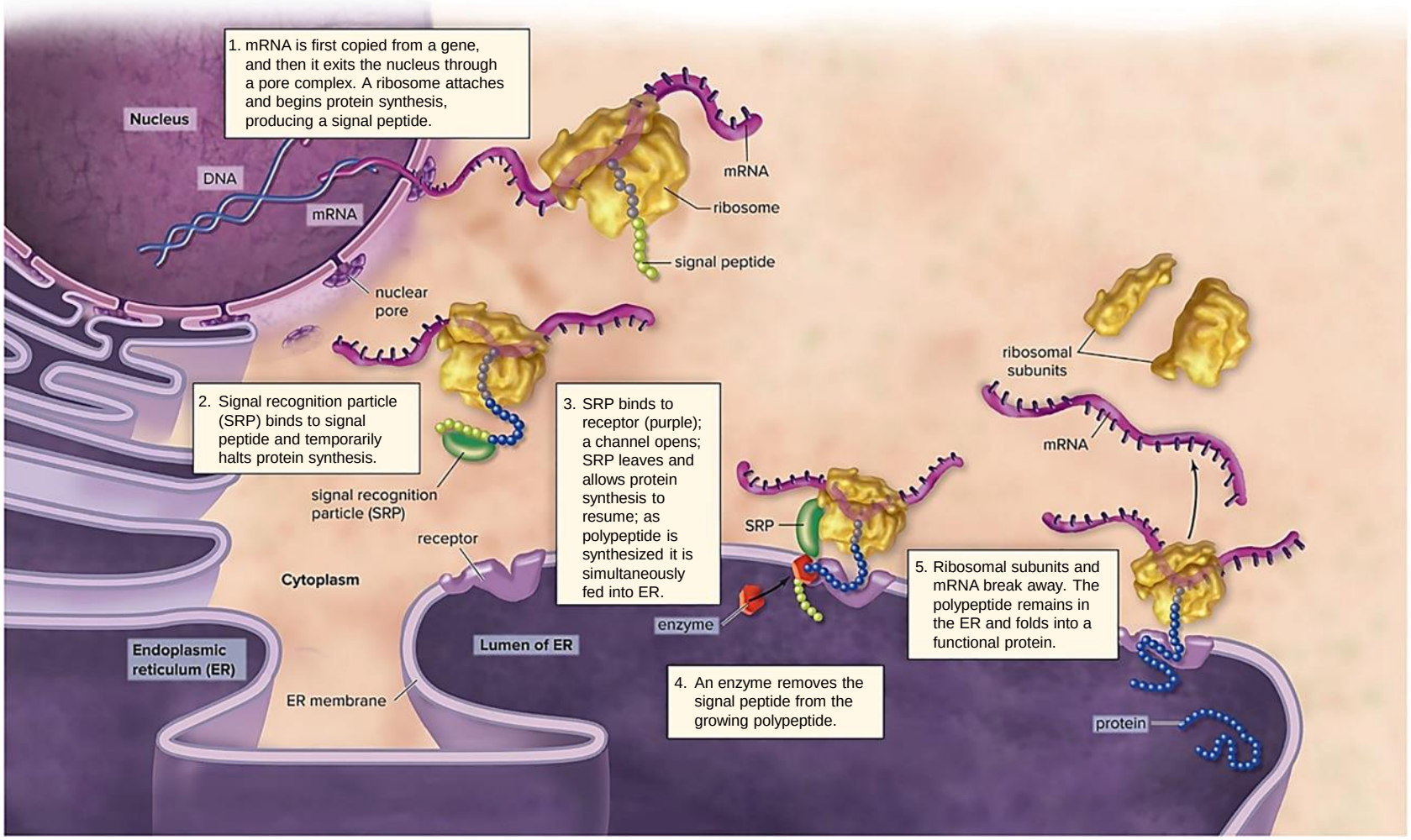
Site of protein synthesis in the cell

In the process of transcription and translation:

- information for the gene is copied into mRNA, which is exported into the cytoplasm.
- ribosomes receive the mRNA with a coded message from DNA with the correct sequence of amino acids to make a protein.
- proteins synthesized by cytoplasmic ribosomes stay in cytoplasm; those by attached ribosomes end up in ER.

The central dogma of molecular biology is the DNA-mRNA-protein sequence of events

Function of Ribosomes



Jump to Function of Ribosomes Long Description

4.5 The 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

Endoplasmic Reticulum (1)

A system of membrane channels and saccules (flattened vesicles) continuous with the outer membrane of the nuclear envelope

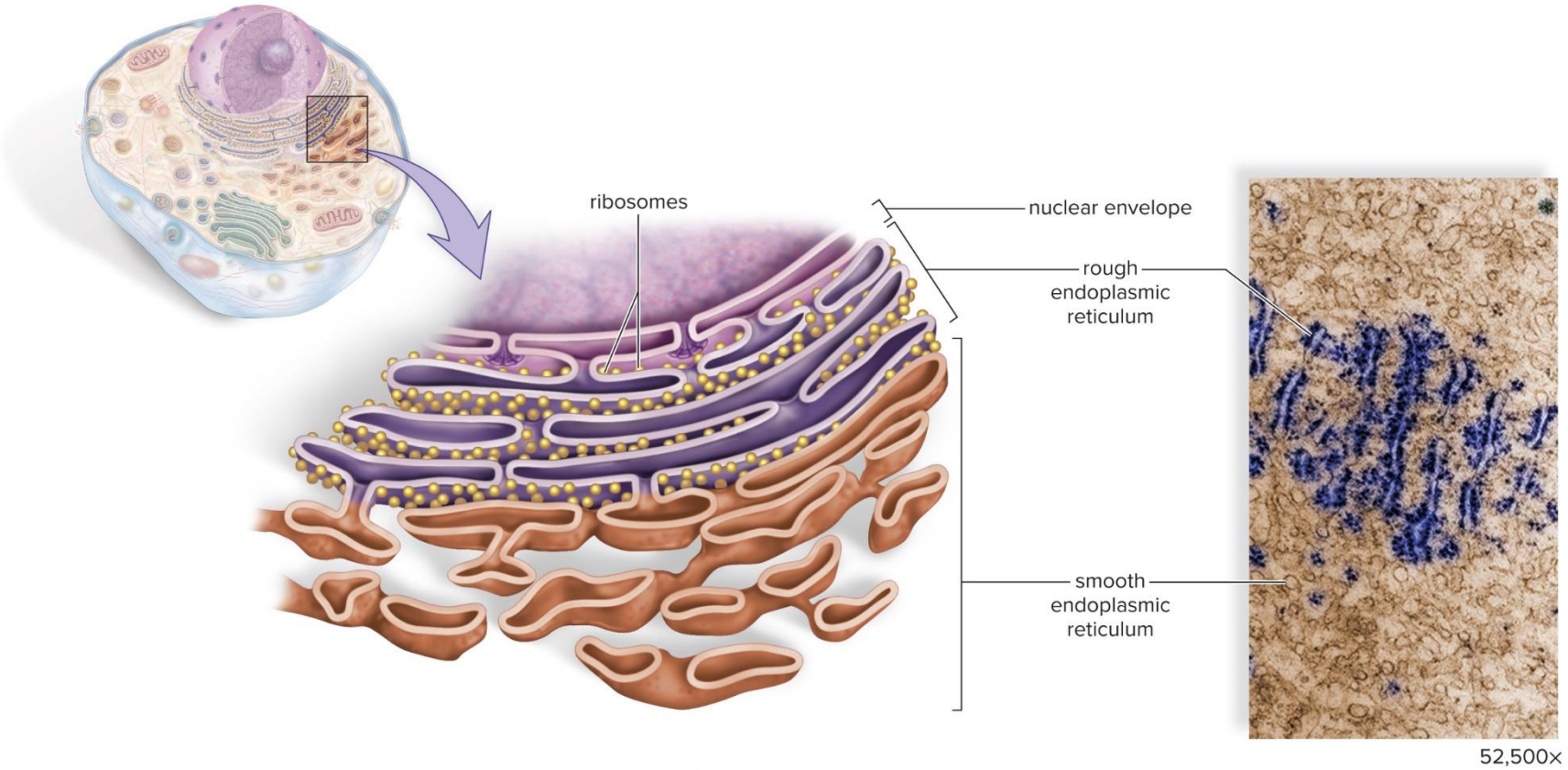
Rough ER

- Studded with ribosomes on cytoplasmic side
- Protein anabolism
  - Synthesizes proteins
  - Modifies and processes proteins
- Forms **transport vesicles**
  - Substances can move to Golgi apparatus.

Smooth ER

- No ribosomes
- Synthesis of lipids
  - In testes, testosterone is produced by smooth ER.
- Site of various synthetic processes, detoxification, and storage
  - The liver, with abundant smooth ER, detoxifies drugs.
- Forms **transport vesicles**
  - Substances can move to Golgi apparatus.

Endoplasmic Reticulum (2)



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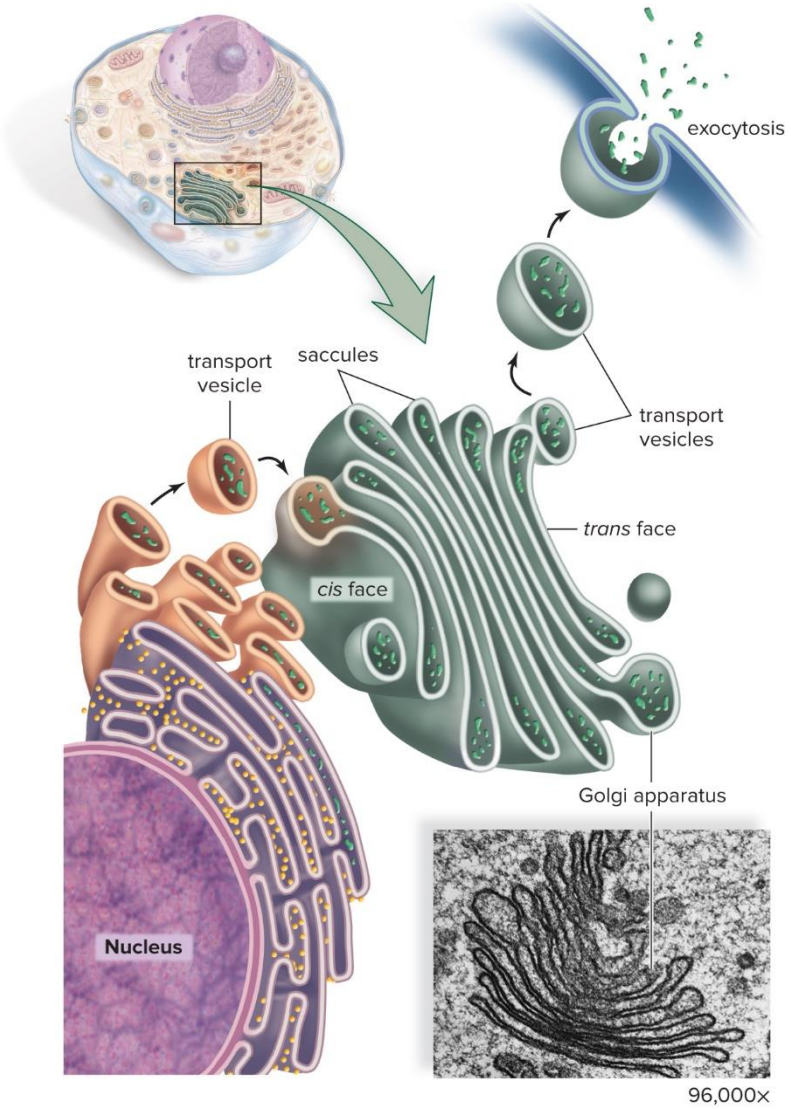
Jump to Endoplasmic Reticulum (2) Long Description

The Golgi Apparatus

Golgi Apparatus

- Consists of flattened, curved saccules
- Resembles stack of hollow pancakes
- Modifies proteins and lipids with “signal” sequences
  - Receives vesicles from ER on cis (or inner) face
  - After modification, prepares for “shipment” and packages proteins and lipids in vesicles that leave Golgi from trans (or outer) face
    - Some transported to locations within cell
    - Some exported from cell (secretion, exocytosis)
    - Others returned to ER or merged with plasma membrane

Golgi Apparatus



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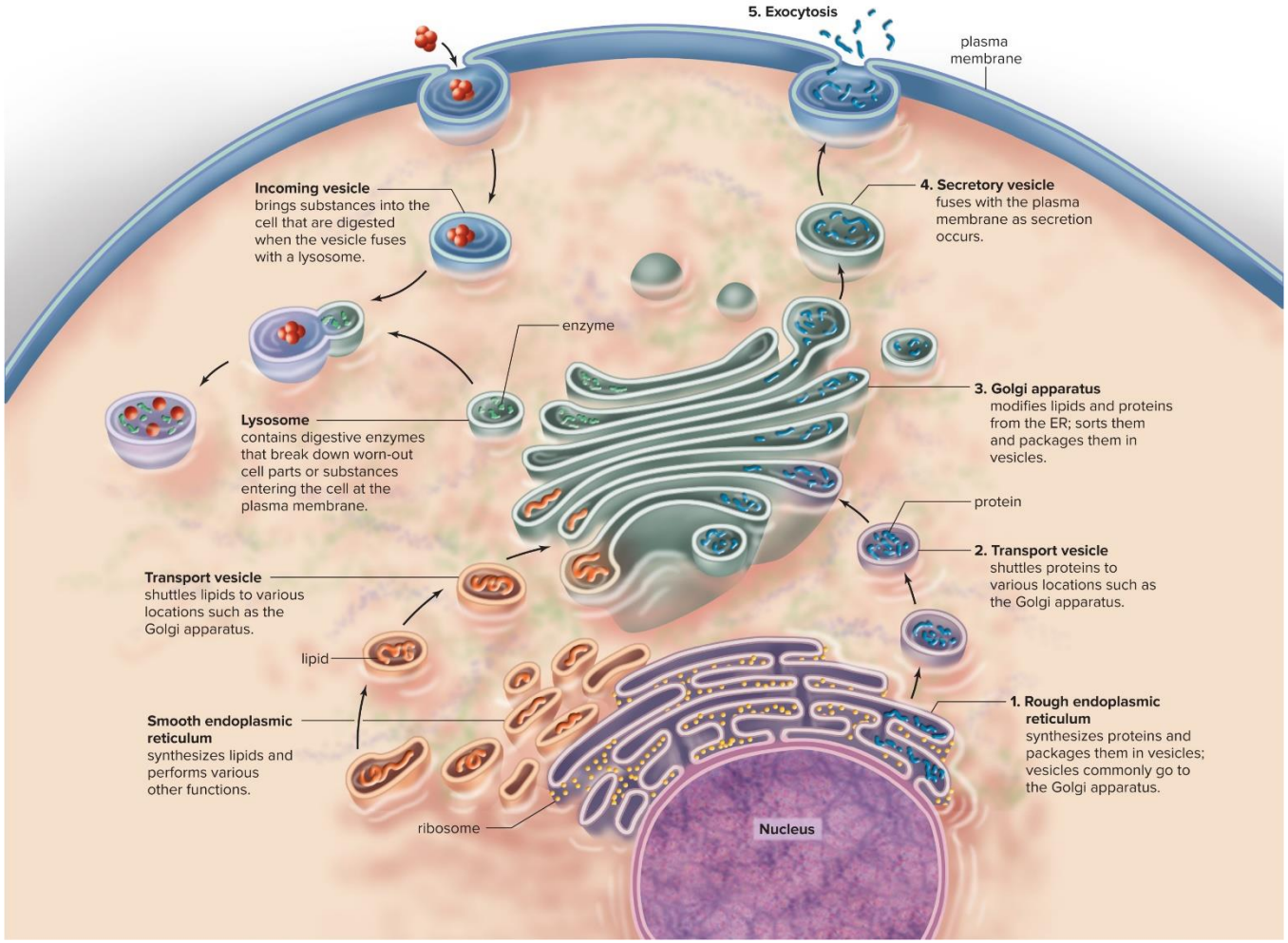
Jump to Golgi Apparatus Long Description

Think, Pair, Share

What are some components of the endomembrane system?

What are their functions?

Endomembrane System



Jump to Endomembrane System Long Description

Lysosomes (1)

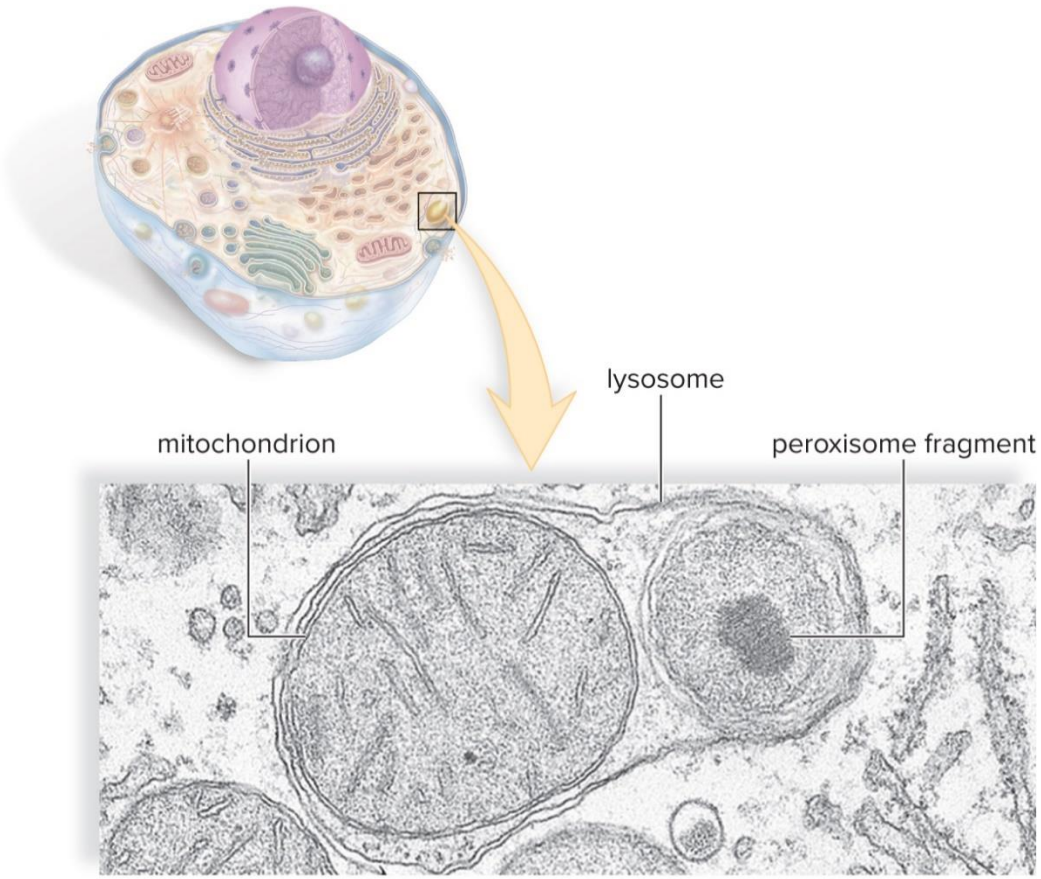
Membrane-bound vesicles (not found in plants)

- Produced by the Golgi apparatus
- Contain powerful digestive enzymes and are highly acidic
  - Digest large molecules into simpler subunits
  - Recycle cellular resources
  - In white blood cells they engulf pathogens

Lysosomal storage diseases

- Caused by defect in lysosomal enzyme
  - Gene therapy restores missing enzyme to cells

Lysosomes (2)



Mitochondrion and a peroxisome in a lysosome

(photo): ©Don W. Fawcett/Science Source

Jump to Lysosomes (2) Long Description

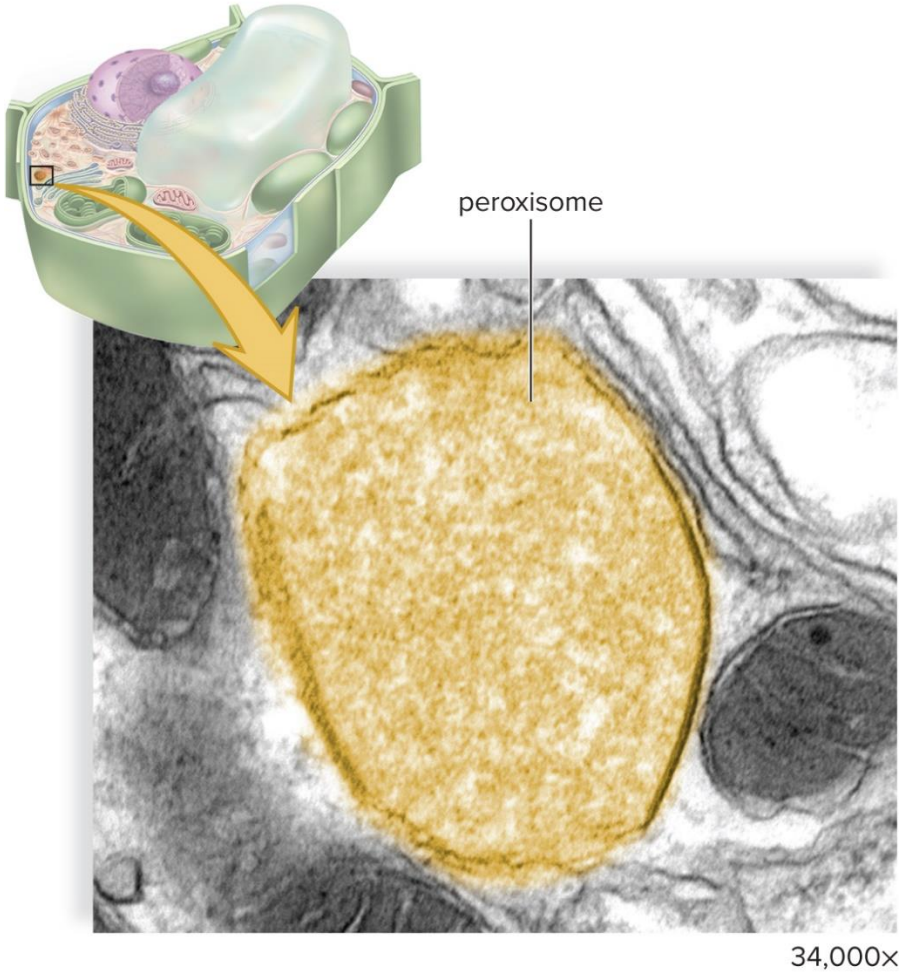
4.6 Microbodies and Vacuoles

Microbodies contain specialized enzymes to perform special metabolic functions.

Example: **Peroxisomes**

- Similar to lysosomes
  - Membrane-bounded vesicles
  - Enclose enzymes
  - Lack of peroxisomal membrane protein results in ALD, producing neurological damage
  - Active in lipid metabolism
  - Catalyze reactions that produce hydrogen peroxide (H_2O_2)
    - Toxic substance
      - Broken down to water and O_2 by catalase

Plant Cell Peroxisome



(photo): ©EM Research Services, Newcastle University

Vacuoles

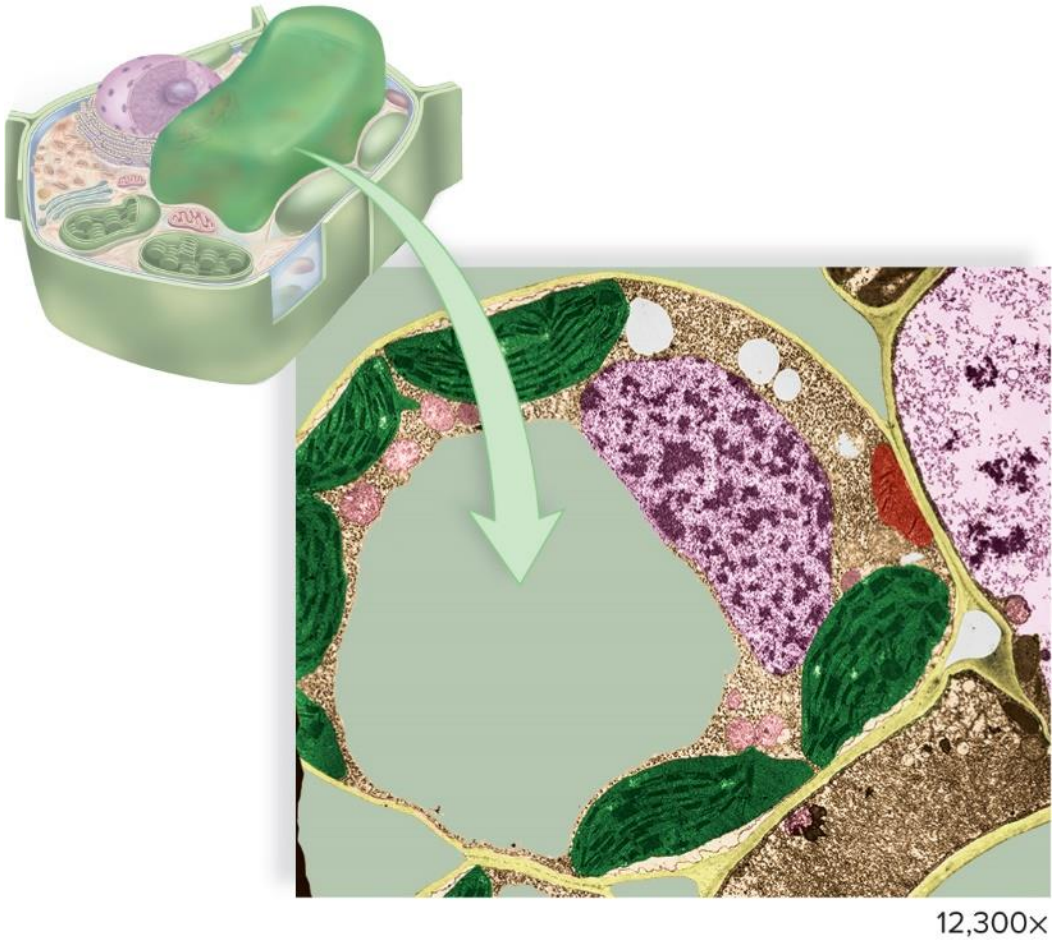
Membranous sacs that are larger than vesicles

- Store materials that occur in excess
- Others are very specialized (contractile vacuole)

Plants cells typically have a **central vacuole.**

- Up to 90% of the volume of some cells
- Functions in:
  - Storage of water, nutrients, pigments, and waste products
  - Development of turgor pressure
  - Toxic substances used for protection from herbivores
  - Some functions performed by lysosomes in other eukaryotes
    - Example: aged organelles are broken down by digestive enzymes

Plant Cell Central Vacuole (1)



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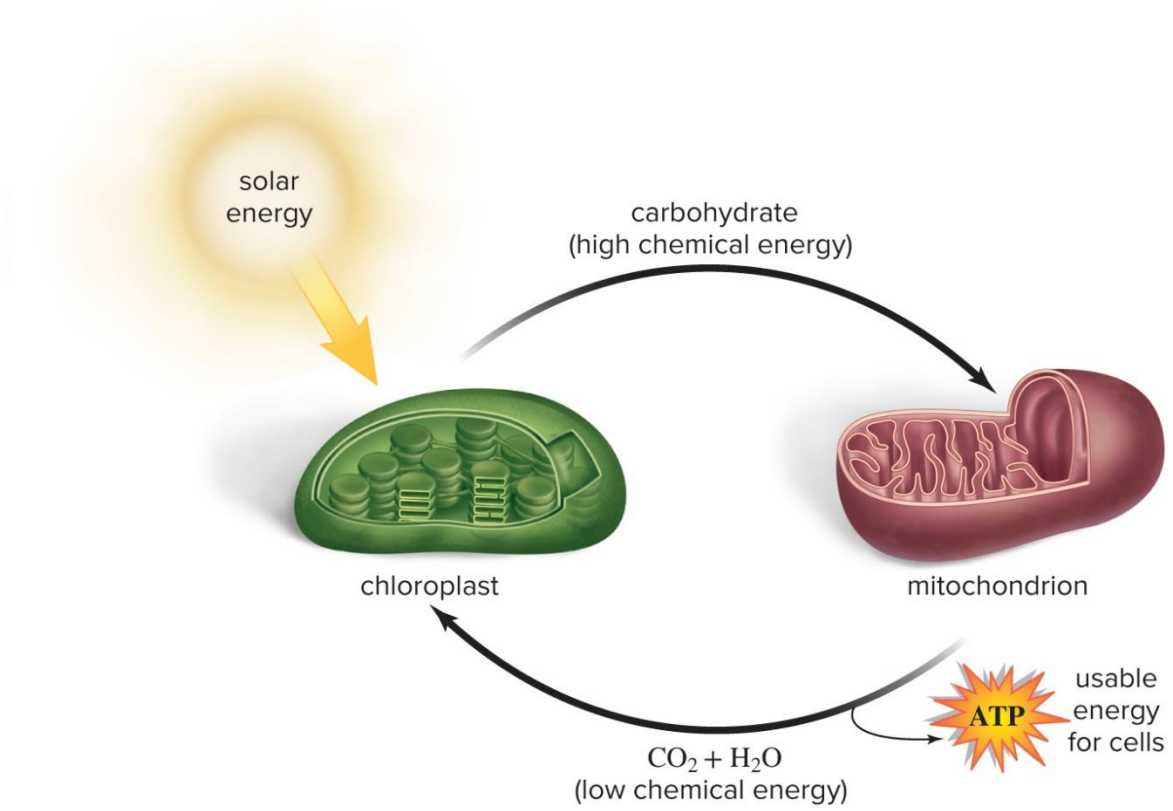
4.7 Energy-Producing Organelles

Chloroplasts

- Bounded by double membrane
- Inner membrane is folded
  - 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



Jump to Plant Cell Central Vacuole (2) Long Description

Chloroplasts

Membranous organelles (a type of **plastid**) serve as sites of photosynthesis.

Capture light energy to drive cellular machinery

Photosynthesis

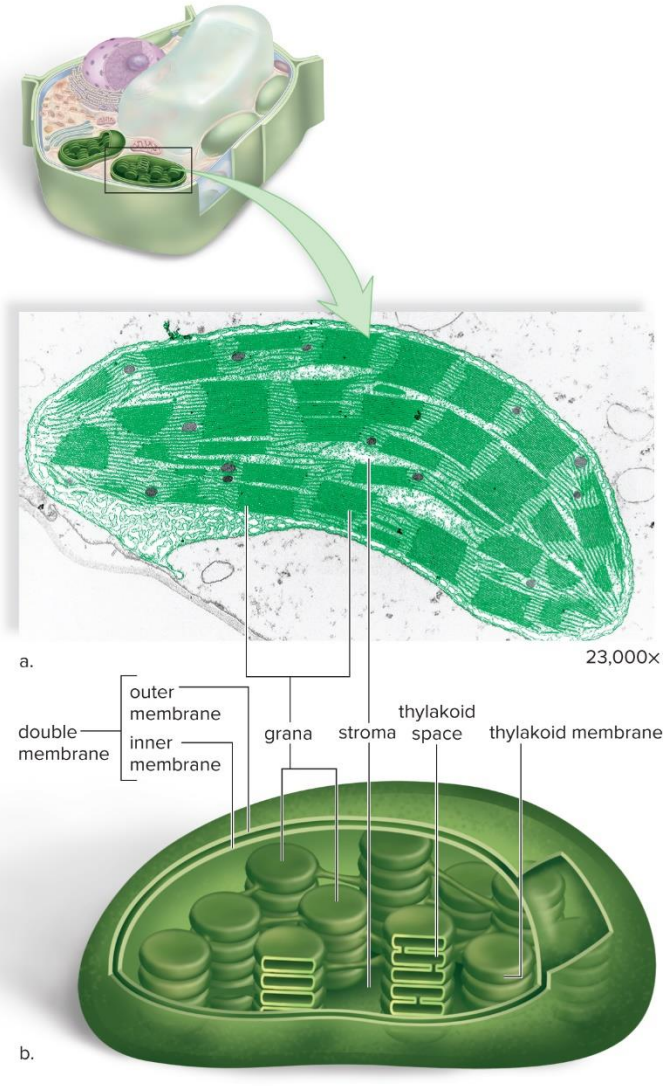
- Synthesizes carbohydrates from CO_2 and H_2O
- Makes food using CO_2 as its only carbon source
- Energy-poor compounds are converted to energy-rich compounds.

$$\text{solar energy} + \text{carbon dioxide} + \text{water} \rightarrow \text{carbohydrate} + \text{oxygen}$$

- Chlorophyll located in the thylakoid membrane; enzymes that synthesize carbohydrates located in the fluid stroma
- Only plants, algae, and certain bacteria are capable of conducting photosynthesis.

Endosymbiotic theory describes a eukaryotic cell engulfing photosynthetic bacterium.

Chloroplast Structure



(a): ©Science Source

Jump to Chloroplast Structure Long Description

Mitochondria

Contained by nearly all eukaryotic cells and all plant, algae, and animal cells

Smaller than chloroplast

Numbers vary with metabolic activities and energy requirements of cells

- Liver cells have as many as 1,000

Contain ribosomes and their own DNA

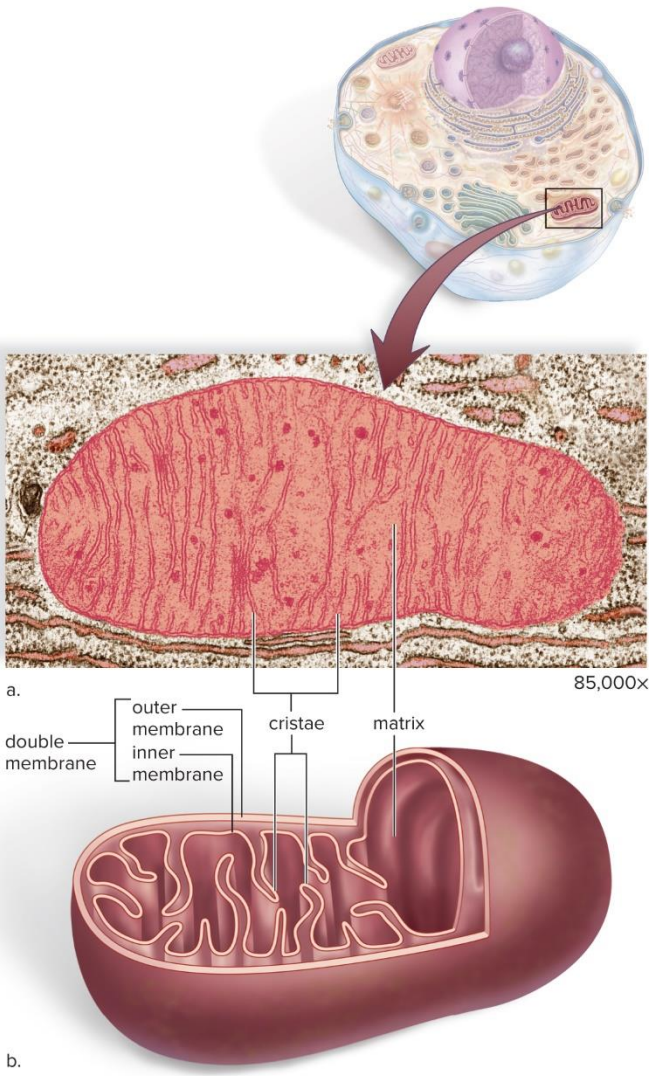
Surrounded by a double membrane

- Inner membrane surrounds the **matrix** and is convoluted (folded) to form **cristae**.
- Matrix – Inner semifluid substance containing respiratory enzymes
  - Break down carbohydrates

Involved in cellular respiration; oxygen used and carbon dioxide given off

Produce most of ATP utilized by the cell

Mitochondrion Structure



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Jump to Mitochondrion Structure Long Description

4.8 The Cytoskeleton

Maintains cell shape

Assists in movement of cell and organelles

Makes internal transport possible

Three types of macromolecular fibers

- **Actin filaments**
- **Intermediate filaments**
- **Microtubules**

Assemble and disassemble as needed

May be compared to the bones and muscles of an animal

- Is dynamic; responds to environmental changes

Think, Pair, Share

- What are the two energy producing organelles in eukaryotic cells?
- Do any waste products of one of these organelles serve as the starting materials for the other? If so, which ones?

Actin Filaments

Extremely thin filaments, like a 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

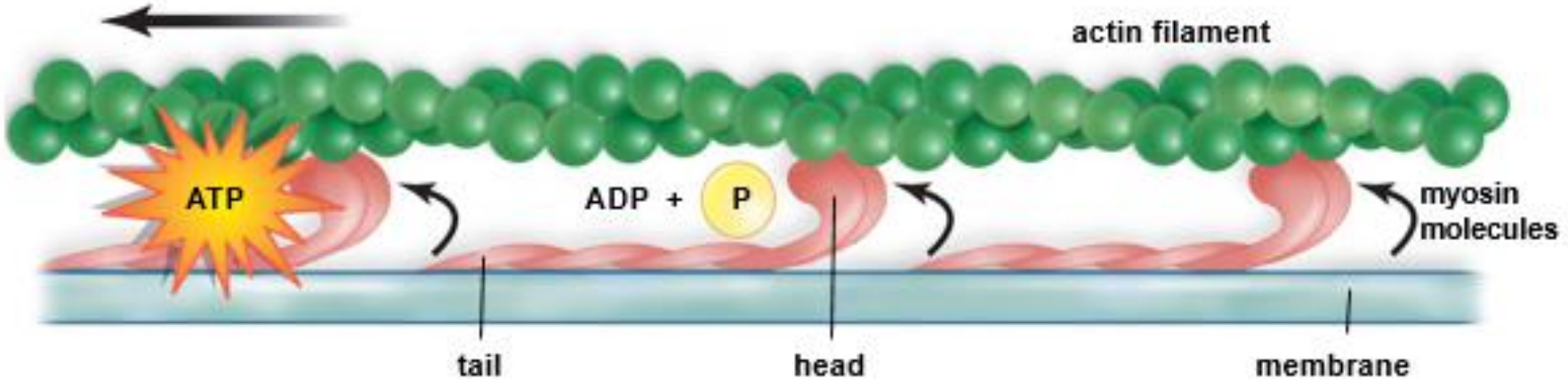
Function in pseudopods of amoeboid cells

Important component in muscle contraction (other is myosin, a “motor” molecule)

Important in animal cell division

- Two cells form from one cell

Actin Filament Operation



Intermediate Filaments

Intermediate in size between actin filaments and microtubules

Rope-like assembly of fibrous polypeptides

Vary in nature

- From tissue to tissue

Function:

- Support nuclear envelope
- Cell-cell junctions, like those holding skin cells tightly together
- The protein keratin provides mechanical strength to skin cells.

Microtubules

Hollow cylinders made of two globular proteins called α and β tubulin

Spontaneous pairings of α and β tubulin molecules form structures called dimers $(\mathrm{di} = 2)$.

Dimers then arrange themselves into tubular spirals of 13 dimers around.

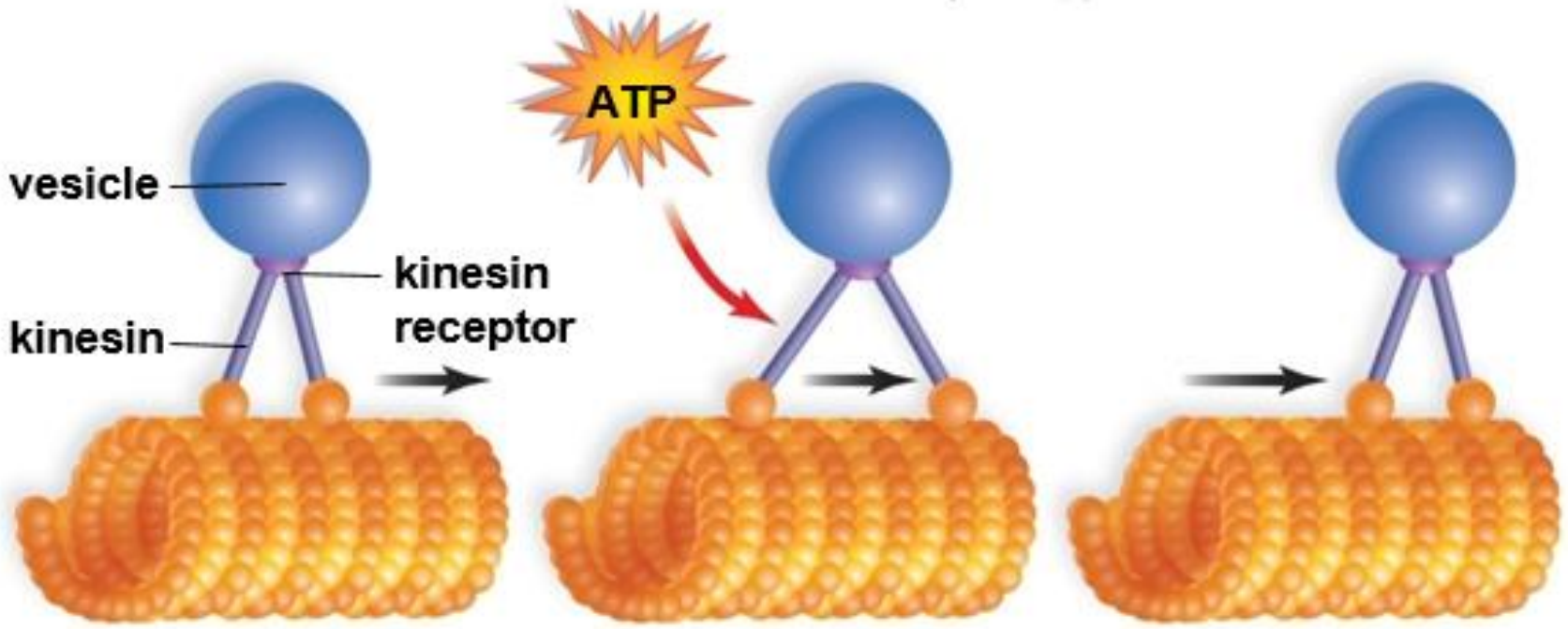
Assembly:

- Under control of Microtubule Organizing Center (MTOC)
- Most important MTOC is centrosome

Interacts with “motor” molecules, kinesin and dynein, to cause movement of organelles

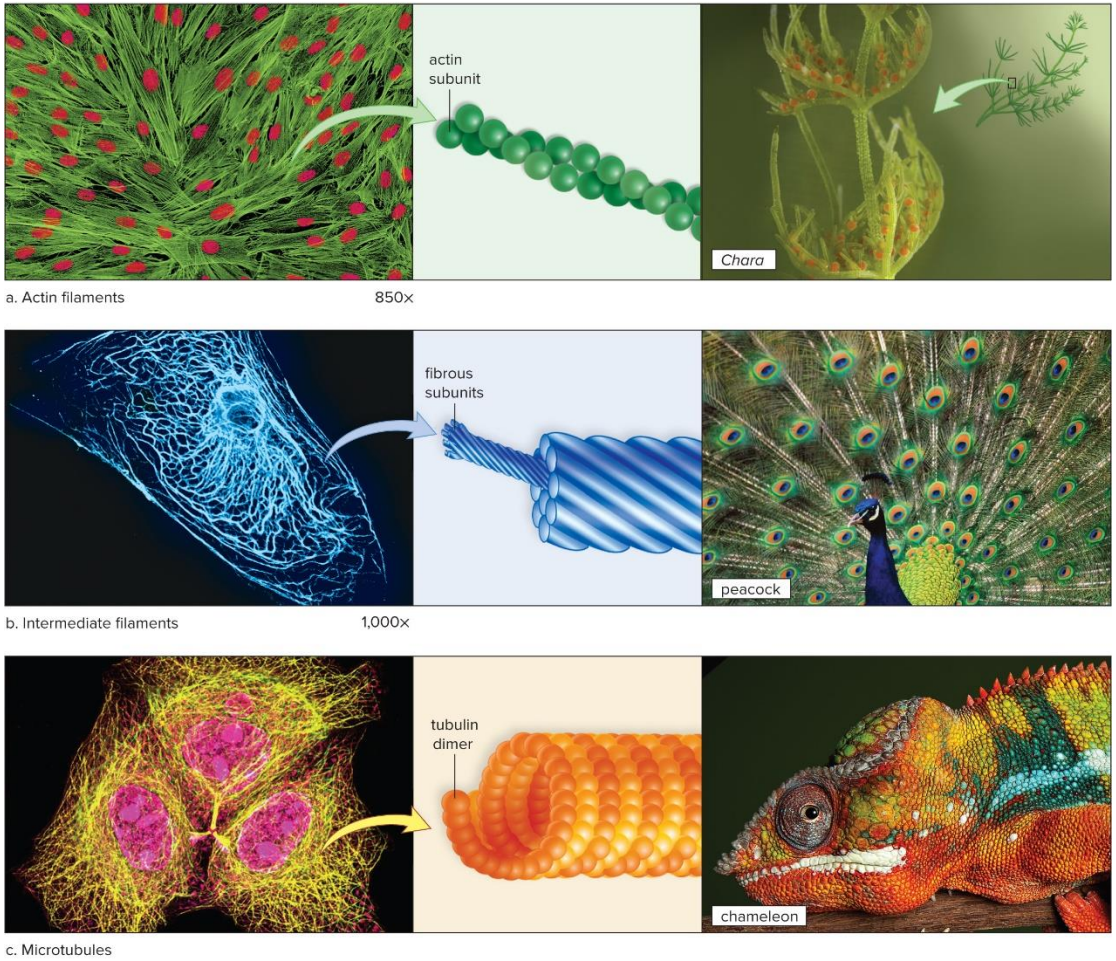
Mitotic “spindle” distributes chromosomes during cell division

Microtubule Operation



vesicle moves, not microtubule

The Cytoskeleton



(actin): ©Thomas Deerinck/Science Source; (Chara): ©Bob Gibbons/Alamy; (intermediate filaments): ©Cultura Science/Alvin Telser, PhD/ Getty Images; (peacock): ©Bryan Mullennix/age fotostock RF; (microtubules): ©Dr. Gopal Murti/Science Source; (chameleon): ©Cathy Keifer/123RF

Jump to The Cytoskeleton Long Description

Centrioles (1)

Short, hollow cylinders

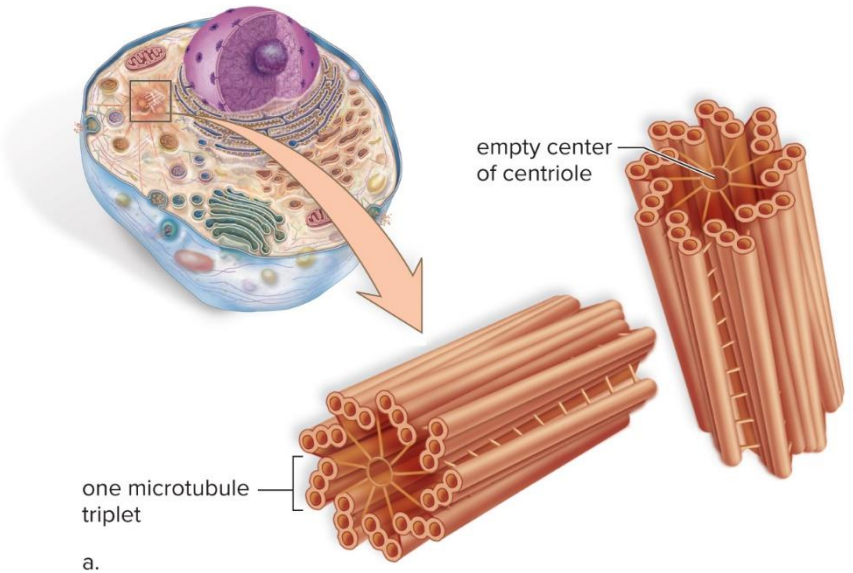
- Composed of 27 microtubules
- Microtubules arranged into 9 overlapping triplets

One pair per animal cell

- Located in **centrosome** of animal cells only
- 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**

Centrioles (2)



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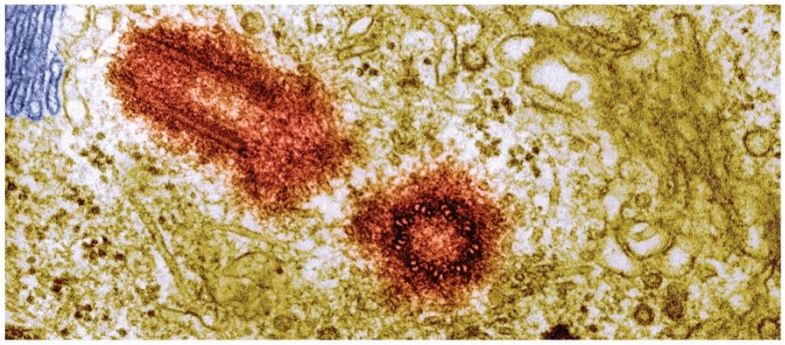


b. one centrosome containing a pair of centrioles

(b): ©Don W. Fawcett/Science Source

Jump to Centrioles (2) Long Description

Cilia and Flagella

Hair-like projections from cell surface that aid in cell movement

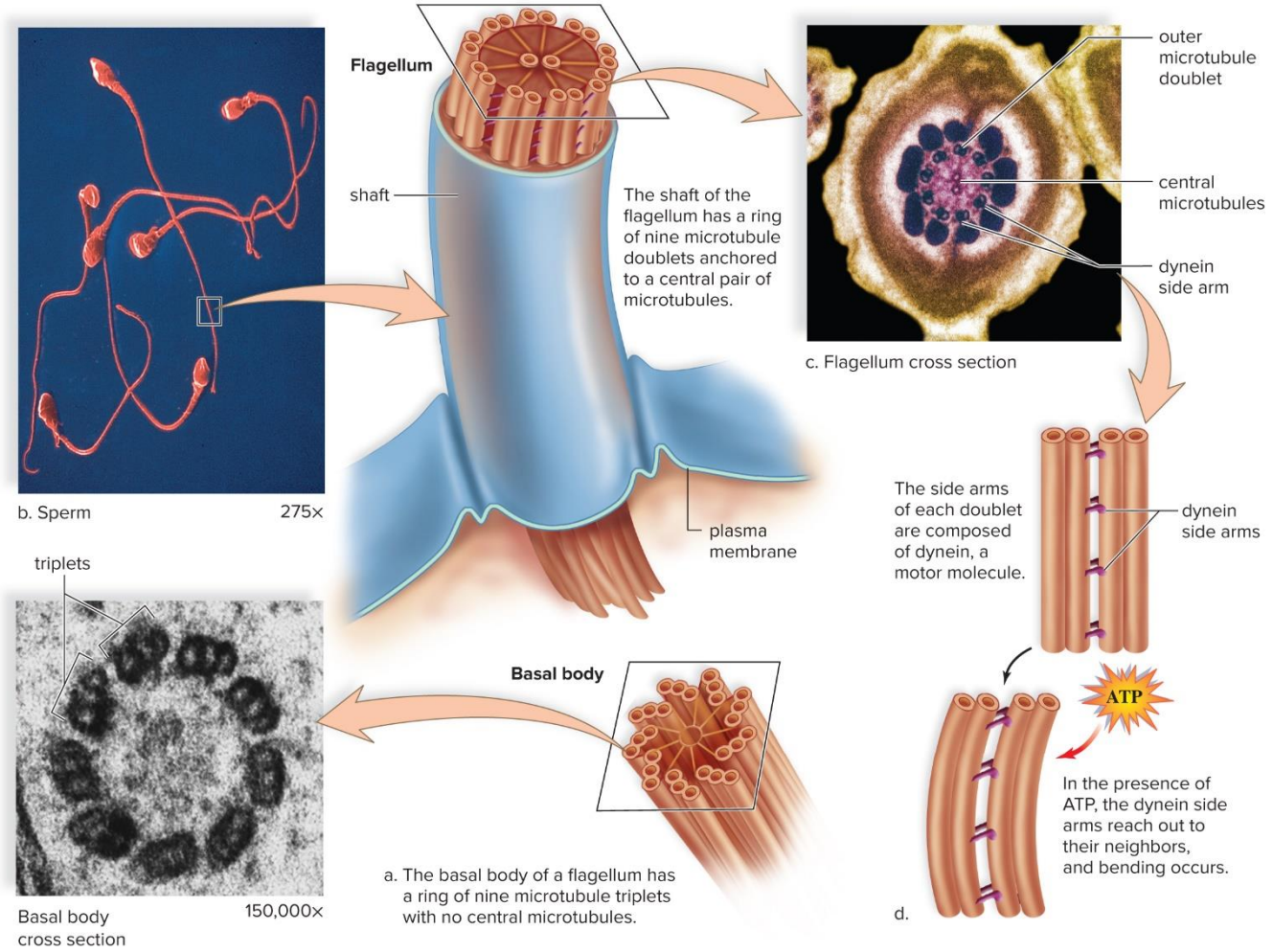
Very different from prokaryote flagella

- 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 is used by all cilia and flagella.

In eukaryotes, cilia are much shorter than flagella.

- Cilia move in coordinated waves like oars.
  - Example: Cells lining upper respiratory tract
- Flagella move like a propeller or cork screw.
  - Example: Sperm cells

Structure of a Flagellum



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Jump to Structure of a Flagellum Long Description