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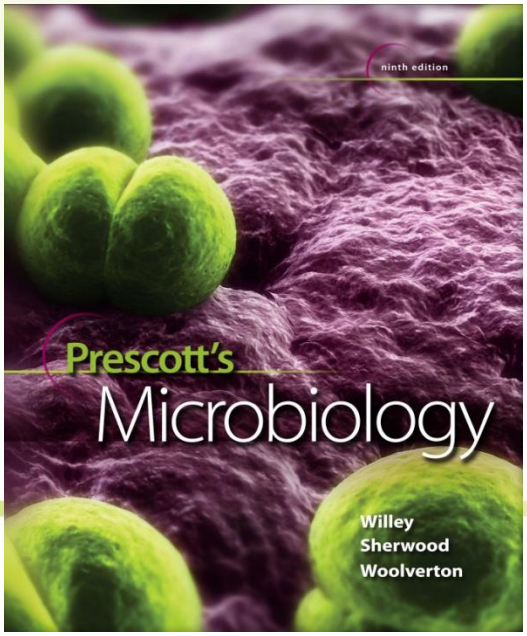


Eukaryotic Cell Structure

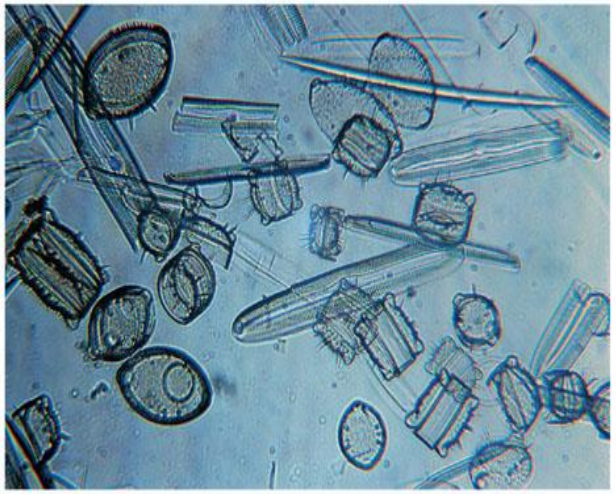
5.1 A typical eukaryotic cell

1. Compare and contrast eukaryotic, bacterial, and archaeal cells in terms of their use of membranes, size, morphological diversity, and organelles.

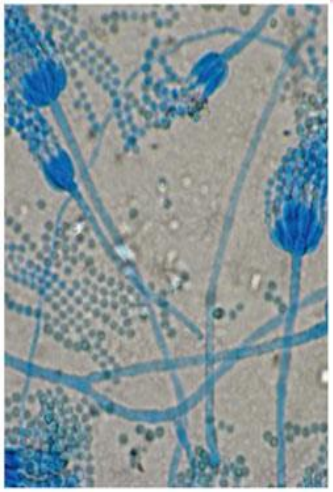
Eukaryotic Microorganisms

- Prominent members of ecosystems
- Useful as model systems and industry
- Some are major human pathogens
- Two groups of eukaryotes commonly possess microbial members
  - protists
  - fungi

(a) *Paramecium* sp.



(b) Diatom frustules



(c) *Penicillium* sp.

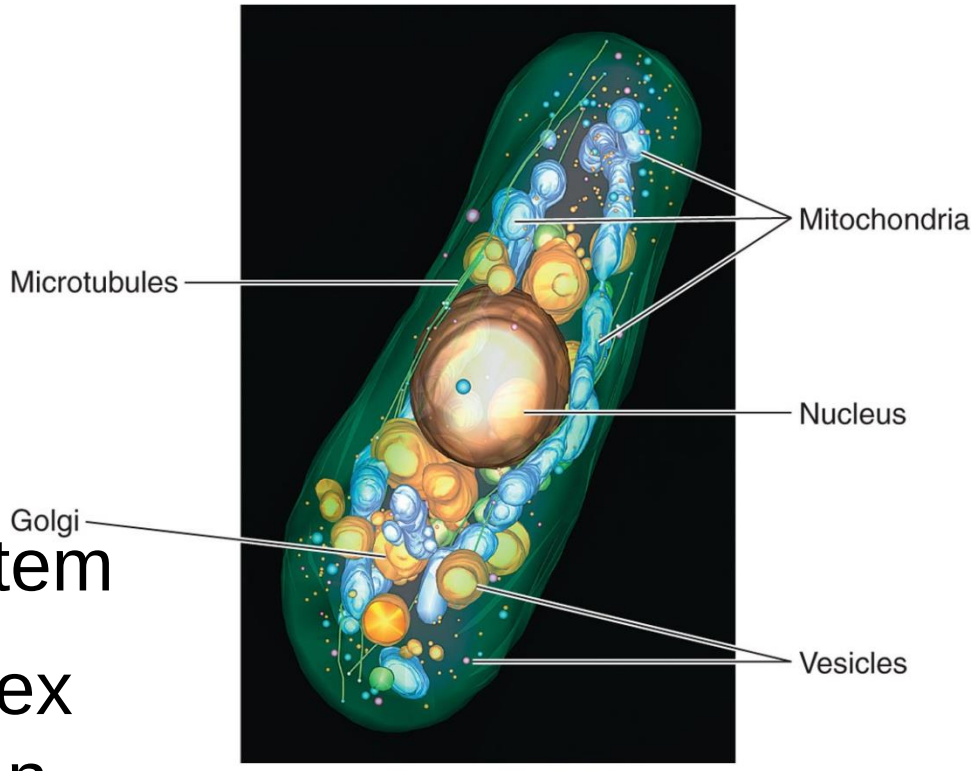
(d) *Stentor* sp.

(e) *Gonium* sp.

(f) *Polysiphonia* sp.

Common Features of Eukaryotic Cells

- Membrane-delimited nuclei
- Membrane-bound organelles that perform specific functions
- Intracytoplasmic membrane complex serves as transport system
- More structurally complex and generally larger than bacterial or archaeal cells



European Molecular Biology Laboratory (EMBL)

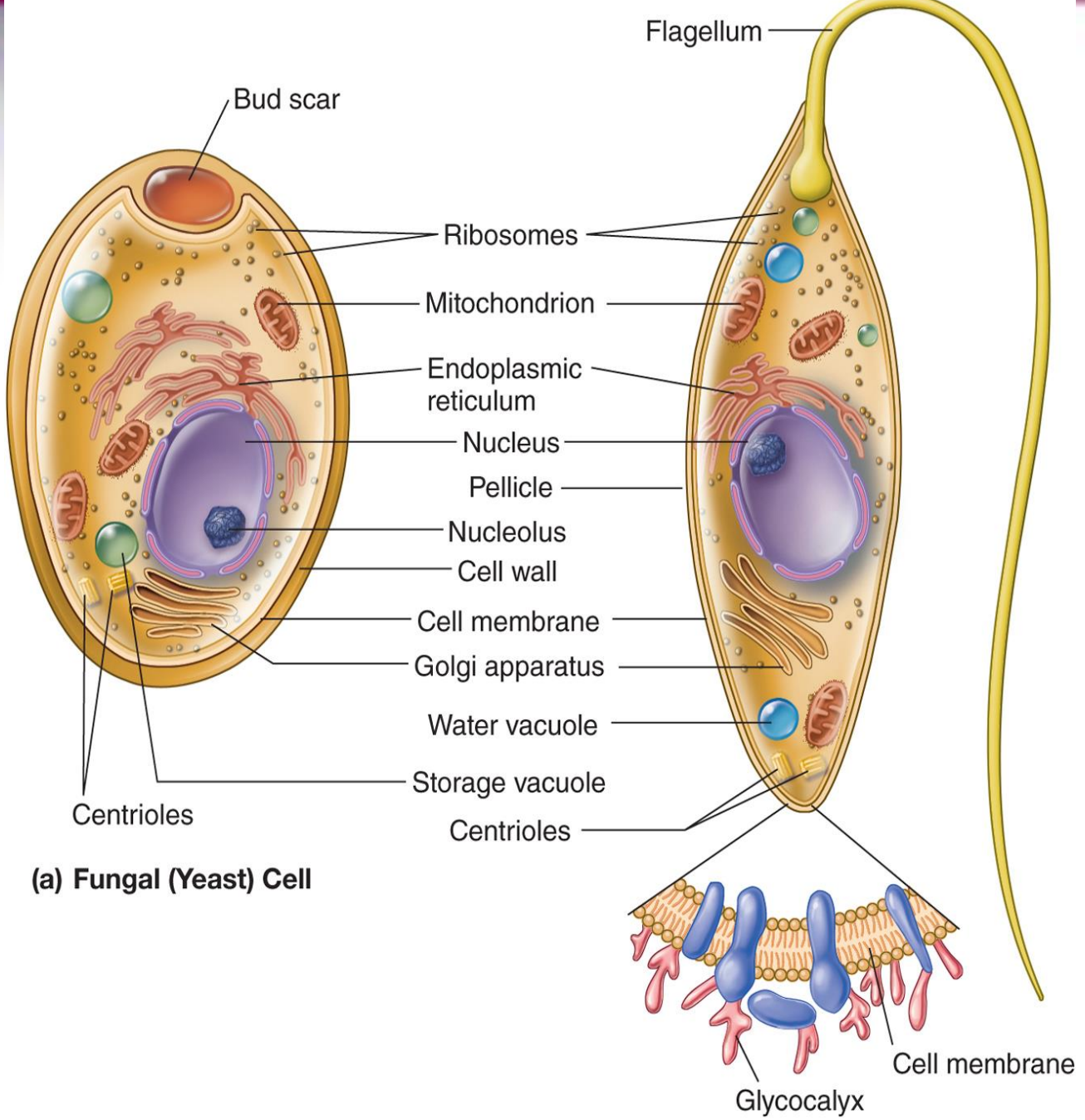

Flagellum
Bud scar
Ribosomes
Mitochondrion
Endoplasmic reticulum
Nucleus
Pellicle
Nucleolus
Cell wall
Cell membrane
Golgi apparatus
Water vacuole
Storage vacuole
Centrioles
Centrioles
(a) Fungal (Yeast) Cell
Cell membrane
Glycocalyx
(b) Protozoan Cell

Table 5.1 Functions of Eukaryotic Organelles

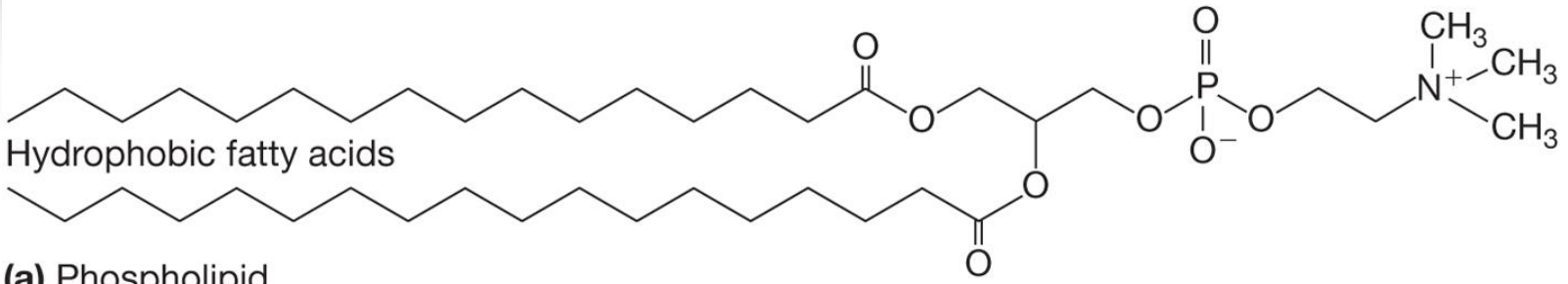
Plasma membrane	Mechanical cell boundary; selectively permeable barrier with transport systems; mediates cell-cell interactions and adhesion to surfaces; secretion; signal transduction
Cytoplasm	Composed of cytosol (liquid portion) and organelles; location of many metabolic processes
Cytoskeleton	Composed of actin filaments, intermediate filaments, and microtubules; provides cell structure and movements
Endoplasmic reticulum	Transport of materials; lipid synthesis
Ribosomes	Protein synthesis
Golgi apparatus	Packaging and secretion of materials for various purposes; lysosome formation
Lysosomes	Intracellular digestion
Mitochondria	Energy production through use of the tricarboxylic acid cycle, electron transport, oxidative phosphorylation, and other pathways
Chloroplasts	Photosynthesis—trapping light energy and forming carbohydrate from CO_2 and water
Nucleus	Repository for genetic information
Nucleolus	Ribosomal RNA synthesis; ribosome construction
Cell wall and pellicle	Strengthen and give shape to the cell
Cilia and flagella	Cell movement
Vacuole	Temporary storage and transport; digestion (food vacuoles); water balance (contractile vacuole)

5.2 Eukaryotic cell envelopes

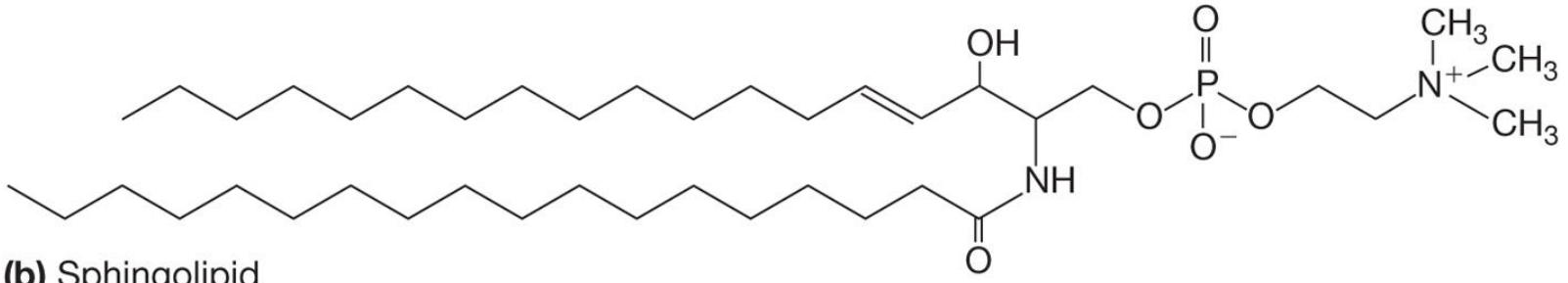
1. Identify the types of eukaryotic microbes that have cell walls and distinguish them from plant cell walls.
2. Compare and contrast the cell envelopes of members of *Bacteria*, *Archaea*, and *Eukarya* in terms of their component layers, molecular make-up, and function.

Eukaryotic Cell Envelopes

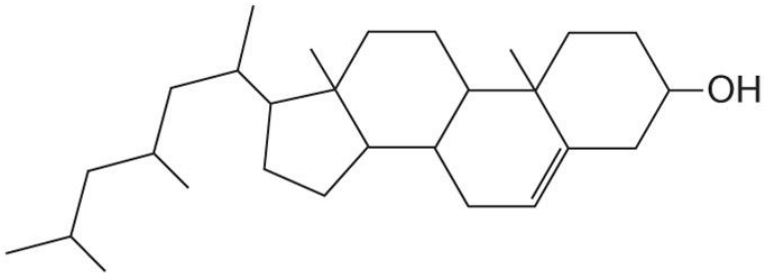
- Consists of the plasma membrane and all coverings external to it
- Plasma membrane is a lipid bilayer
  - major membrane lipids include phosphoglycerides, sphingolipids, and cholesterol, all of which contribute to strength of membrane
  - microdomains participate in variety of cellular processes



(a) Phospholipid



(b) Sphingolipid



(c) Sterol

Eukaryotic Cell Envelopes - 2

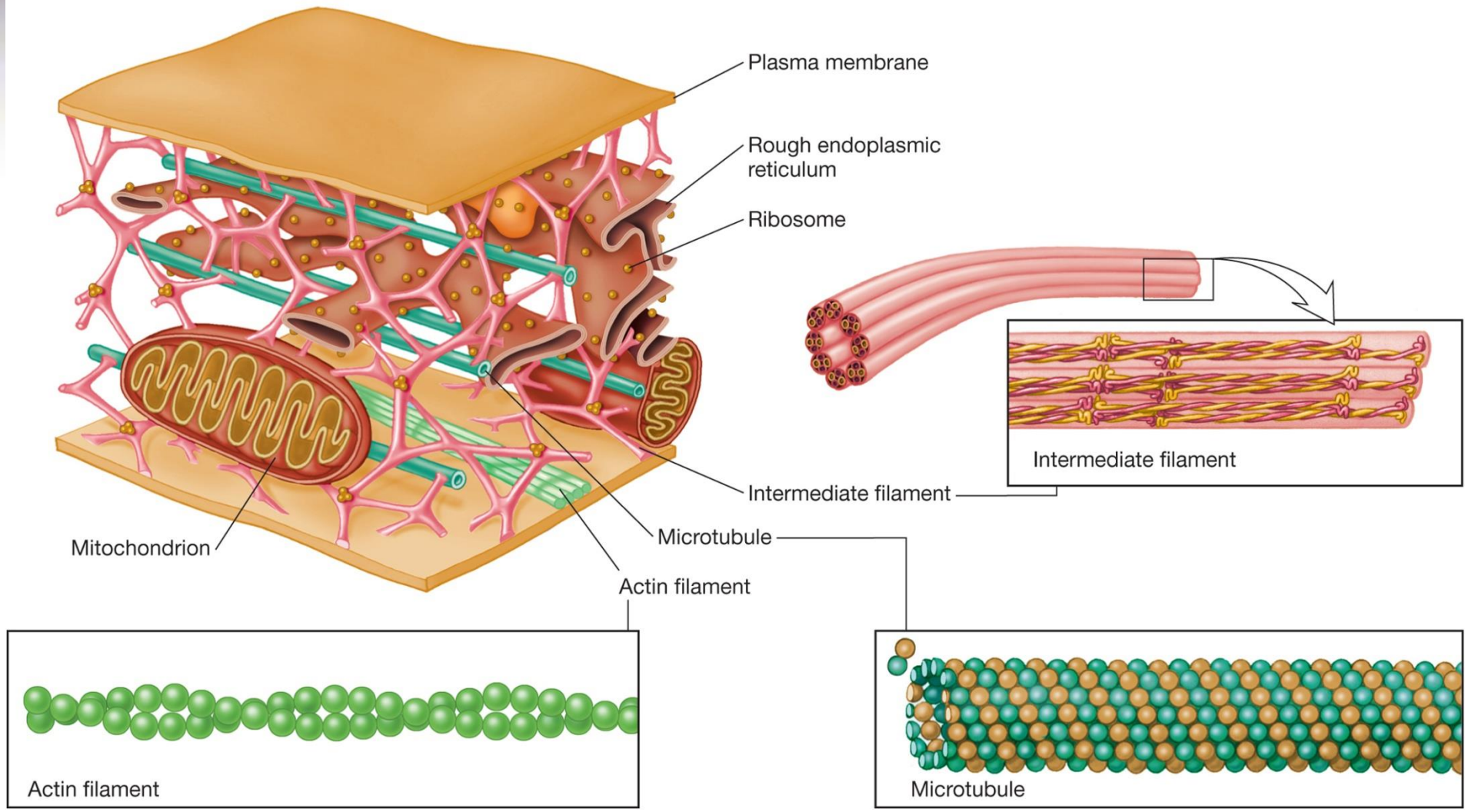
- Unlike the peptidoglycan in the cell wall of *Bacteria* and *Archaea*, many eukaryotes lack or have a chemically distinct cell wall
- Cell walls of photosynthetic algae have cellulose, pectin, and silica
- Cell walls of fungi consist of cellulose, chitin, or glucan

5.3 Cytoplasm of eukaryotes

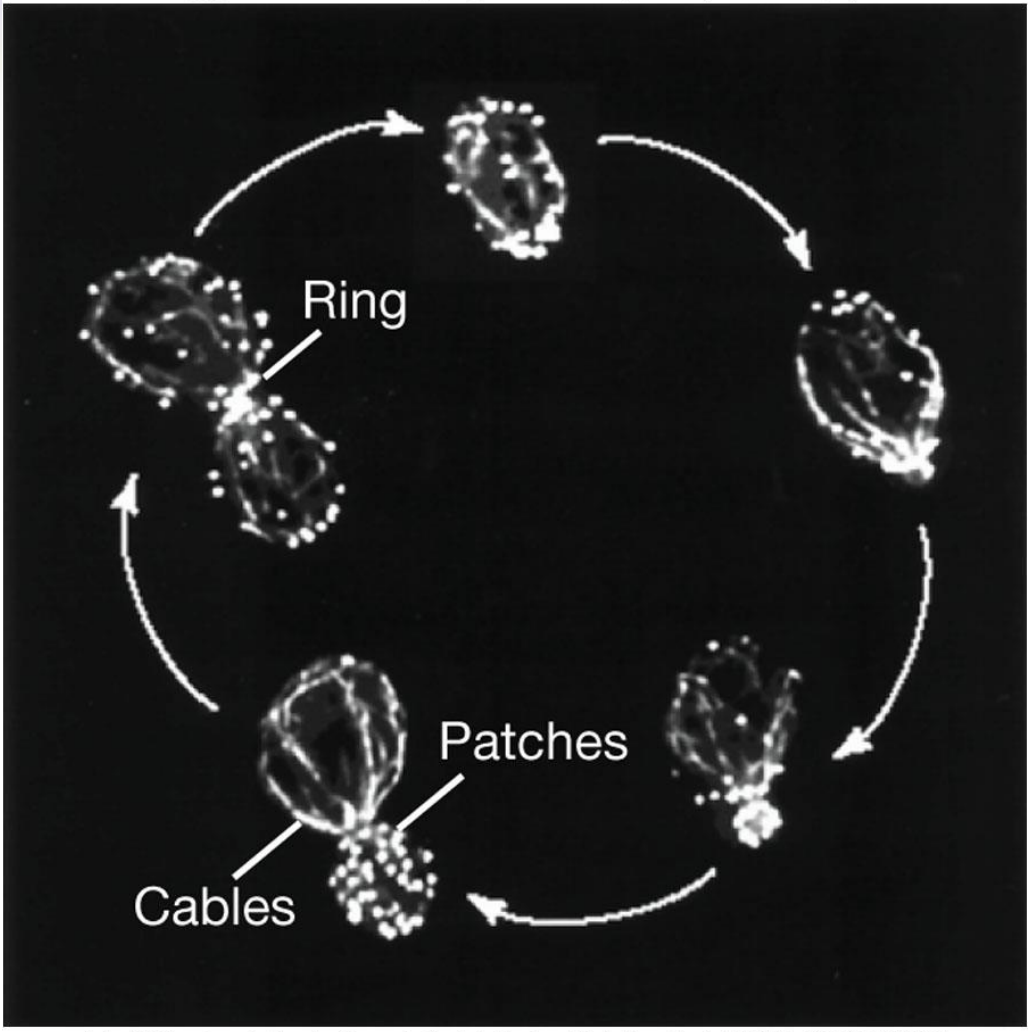
1. Describe the functions of the cytoplasm.
2. Identify the three filaments that make up the cytoskeleton of eukaryotic cells and describe their functions.

The Cytoplasm of Eukaryotes

- Consists of liquid, the cytosol, and many organelles
- Cytoskeleton
  - vast network of interconnected filaments within the cytoplasmic matrix
  - filaments that form the cytoskeleton: microfilaments (actin), microtubules, intermediate filaments, and motor proteins
  - plays role in both cell shape and cell movement



Microfilaments



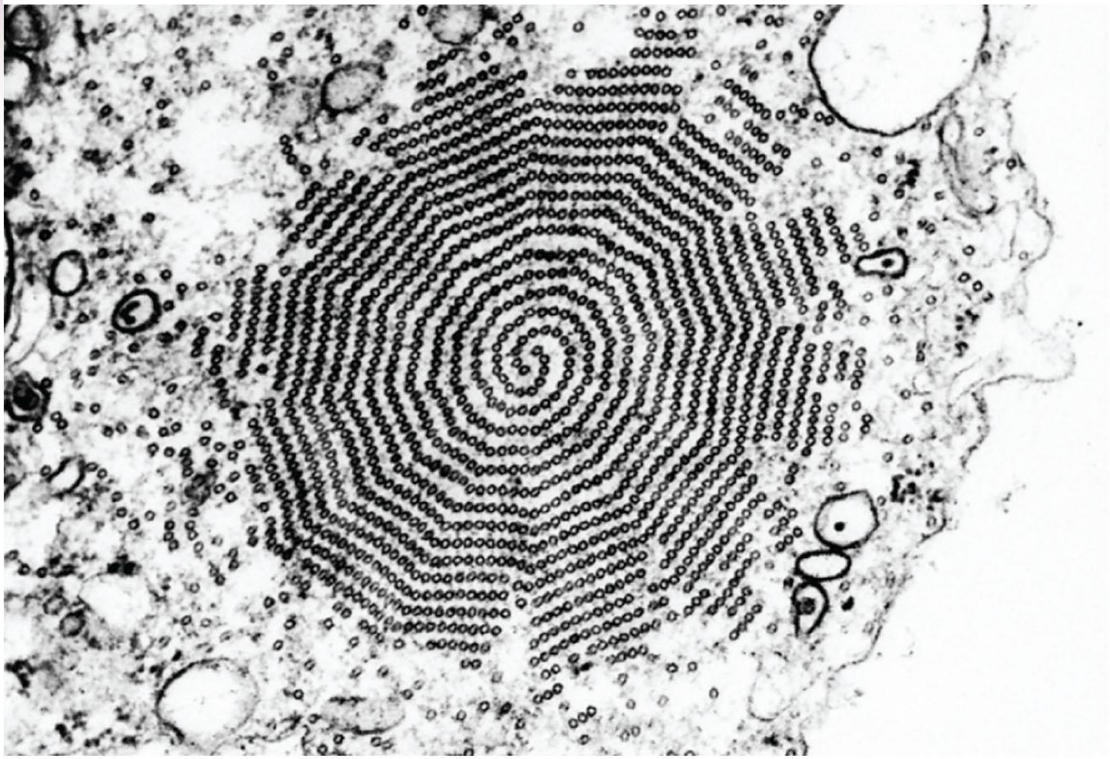
Amberg DC Three-dimensional imaging of the yeast actin cytoskeleton through the budding cell cycle. (1998) *Mol. Biol. Cell*; 9:3259–3262.
American Society for Cell Biology

- Small protein filaments, 4 to 7 nm in diameter
- Scattered within cytoplasmic matrix or organized into networks and parallel arrays
- Composed of actin protein
- Involved in cell motion and shape changes

Intermediate Filaments

- Heterogeneous elements of the cytoskeleton, ~10 nm in diameter
- Keratin and vimentin classes
- Role in cell is unclear
  - play structural role
  - some shown to form nuclear lamina
  - others help link cells together to form tissues

Microtubules



- Shaped like thin cylinders ~25 nm in diameter of σ- and β-tubulin
- Help maintain cell shape
- Involved with microfilaments in cell movements
- Participate in intracellular transport processes

5.4 Organelles of the secretory and endocytic pathways

1. Differentiate the two types of endoplasmic reticulum in terms of structure and function.
2. Outline the pathway of molecules through the secretory pathway, noting the structures involved and their role in the process.
3. List the endocytic pathways observed in mammalian cells, noting the structures involved and their role in the process, and noting those pathways that have been observed in eukaryotic microbes.

Secretory Endocytic Pathway

- Intricate complex of membranous organelles and vesicles that move materials into the cell from outside, from inside to outside, and within the cell
- Endoplasmic reticulum (ER)
- Golgi apparatus
- Lysosomes

Endoplasmic Reticulum (ER)

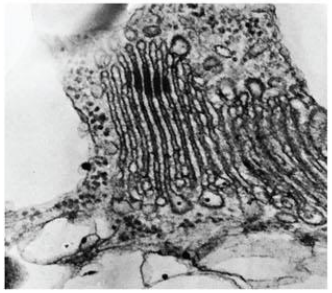
- Irregular network of branching and fusing membranous tubules and flattened sacs (cisternae – s., cisterna)
- Rough ER
  - ribosomes attached
  - synthesis of secreted proteins by ER-associated ribosomes
- Smooth ER
  - devoid of ribosomes
  - synthesis of lipids by ER-associated enzymes

Functions of ER

- Transports proteins, lipids, and other materials within cell
- Major site of cell membrane synthesis

The Golgi Apparatus

- Membranous organelle made of cisternae stacked on each other
- Cis and trans faces
- Dictyosomes=stacks of cisternae
- Involved in modification, packaging, and secretion of materials



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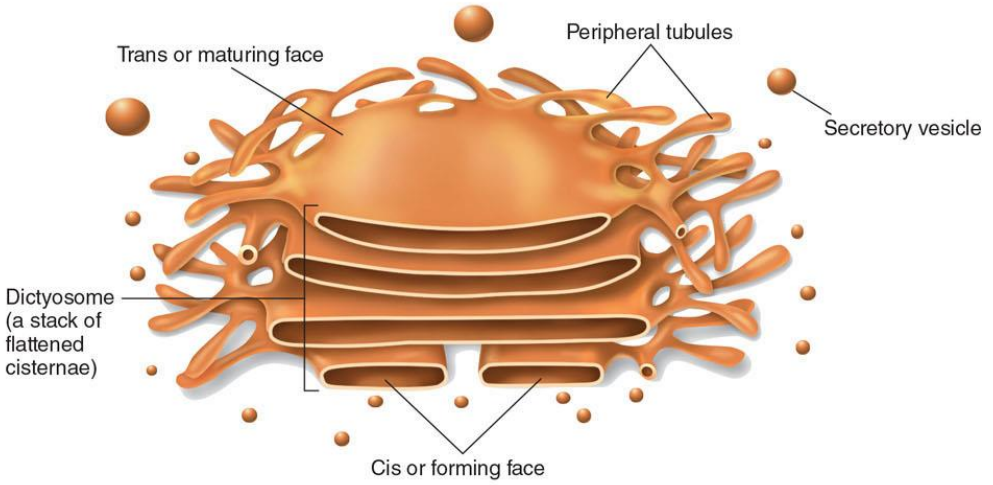
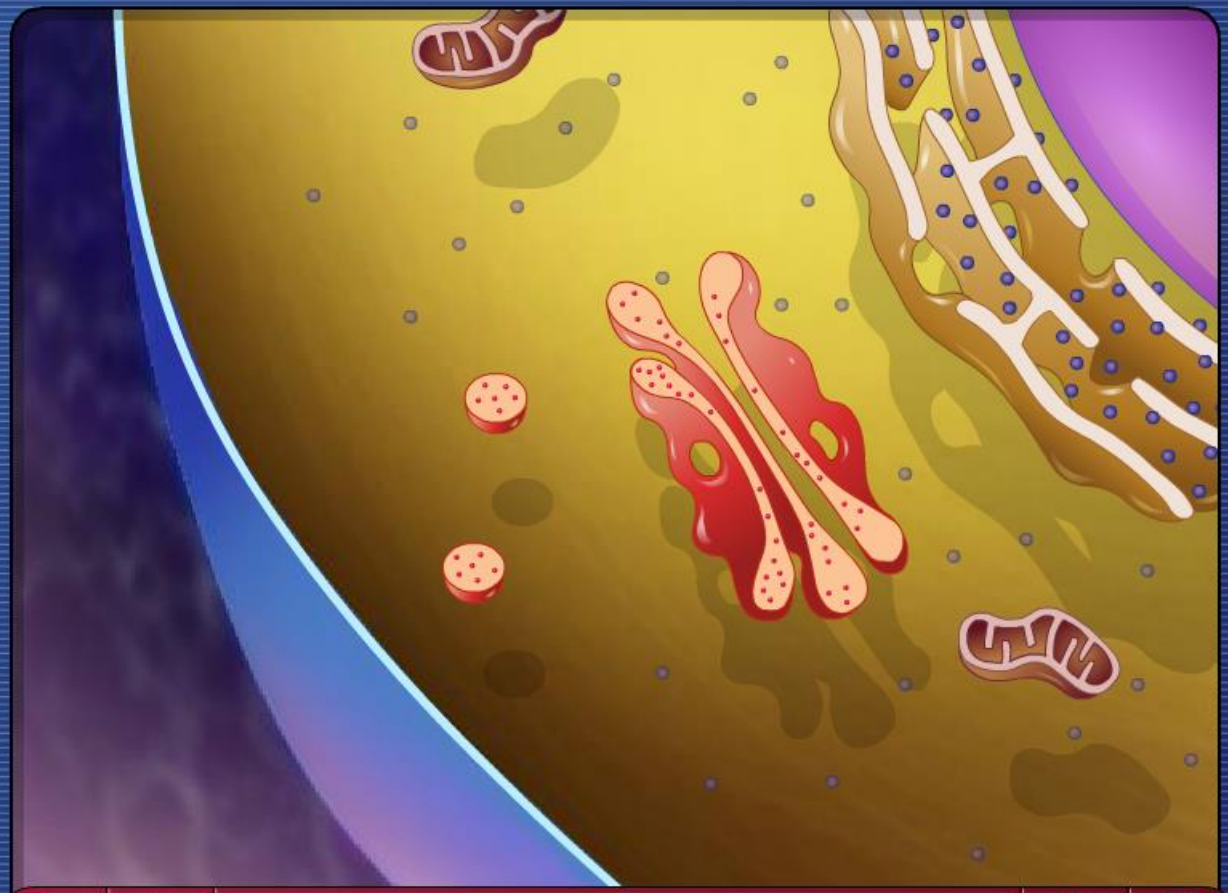


(b)

Lysosomes

- Membrane-bound vesicles found in most eukaryotes
- Involved in intracellular digestion
- Contain hydrolases, enzymes which hydrolyze molecules and function best under slightly acidic conditions
- Maintain an acidic environment by pumping protons into their interior

Lysosomes



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.

The Secretory Pathway

- Used to move materials to various sites within the cell, as well as to either the plasma membrane or cell exterior
- Proteins destined for the cell membrane, endosomes, and lysosomes or secretion are synthesized by ribosomes on rough endoplasmic reticulum (RER)
- Targeted to RER lumen and are released in small budding vesicles from RER

Secretory Pathway - 2

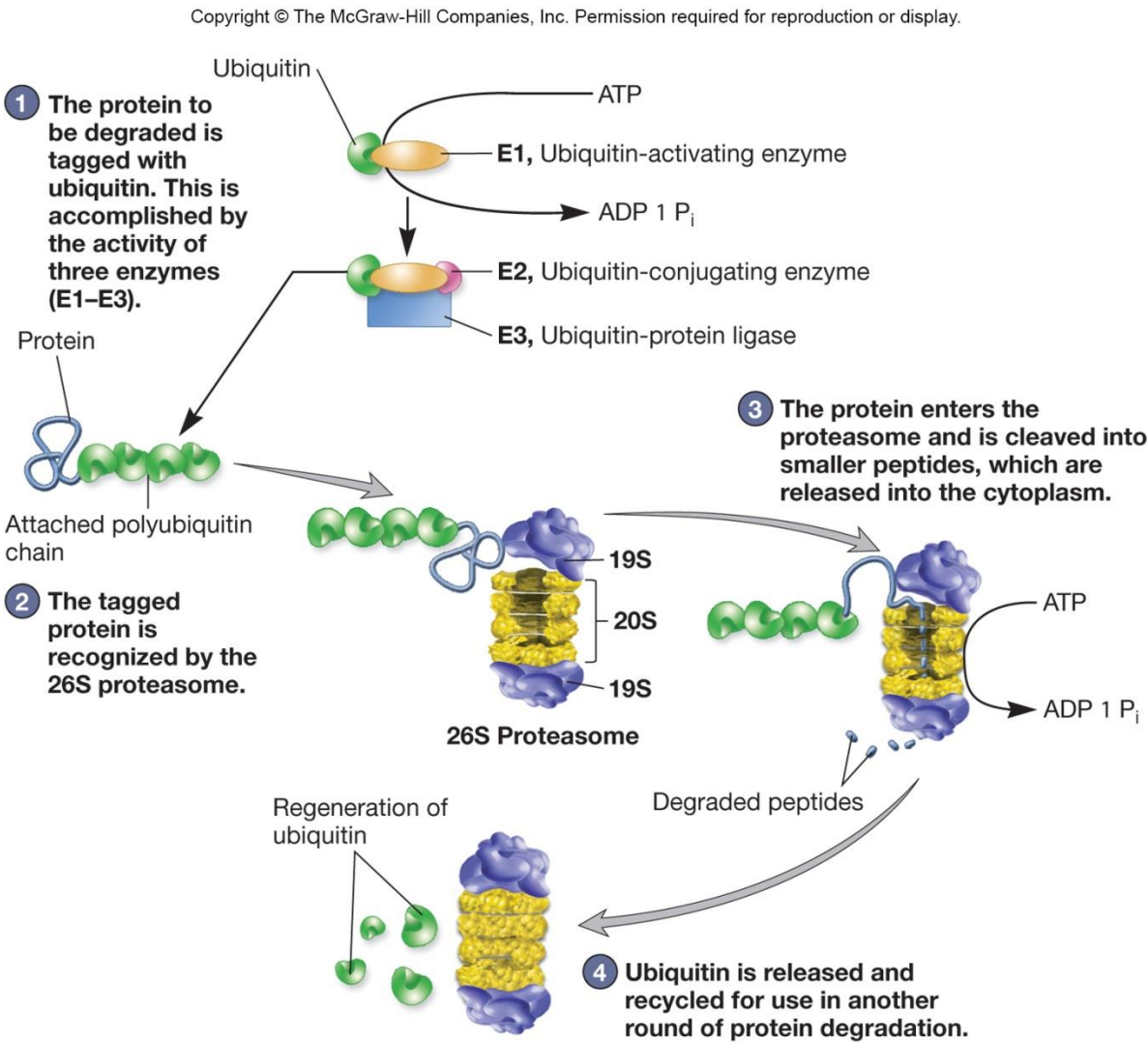
- Released in small vesicles → cis face of Golgi apparatus→ trans face of Golgi apparatus
  - modification of proteins occurs in Golgi; targets protein for final destination
- Transport vesicles released from trans face of Golgi

The Secretory Pathway - 3

- After release some vesicles deliver their contents to endosomes and lysosomes
- Two types of vesicles deliver proteins to cell membrane
  - constitutive delivery to membrane
  - secretory vesicles in multicellular eukaryotes store proteins until signal to release

The Secretory Pathway - 4

- Quality assurance mechanism
  - unfolded or misfolded proteins are secreted into cytosol, targeted for destruction by ubiquitin polypeptides
  - proteasomes destroy targeted proteins



The Endocytic Pathway

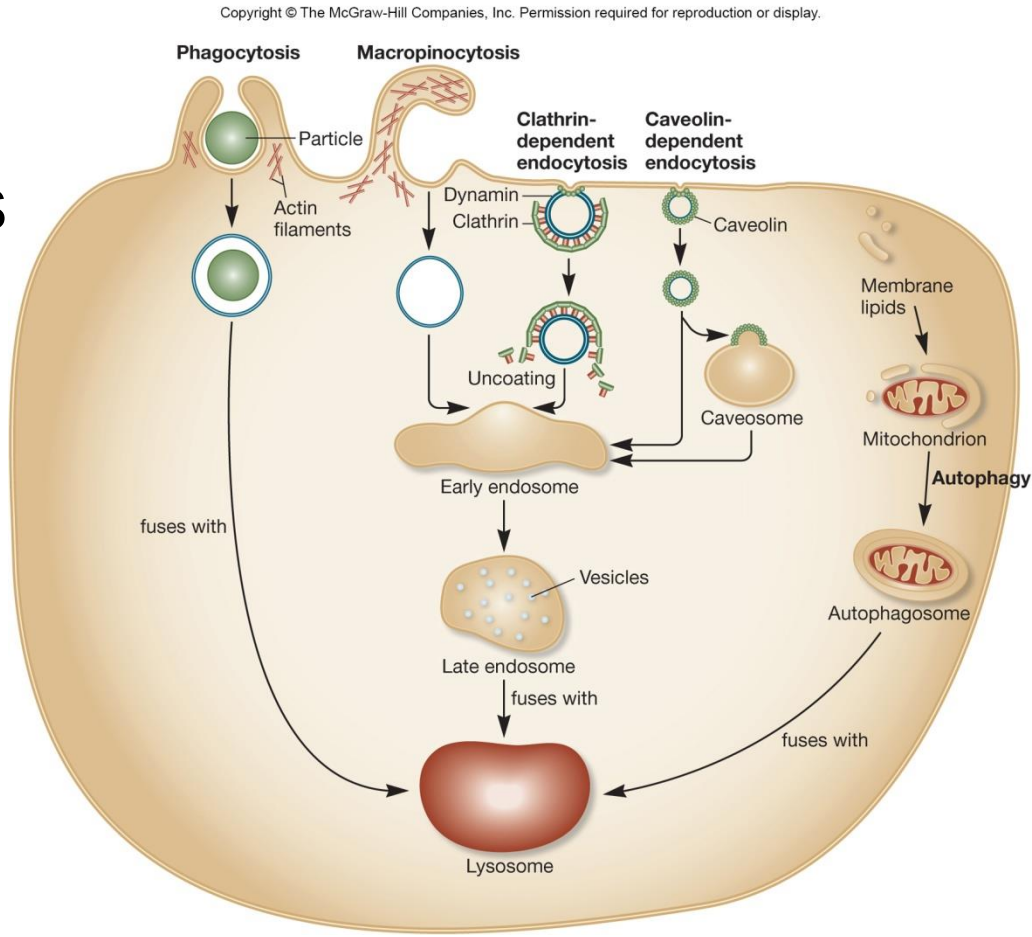
- Endocytosis
  - used by all eukaryotic cells
  - used to bring materials into the cell
  - solutes or particles taken up and enclosed in vesicles pinched from plasma membrane
  - in most cases materials are then delivered to lysosome and destroyed

Types of Endocytosis

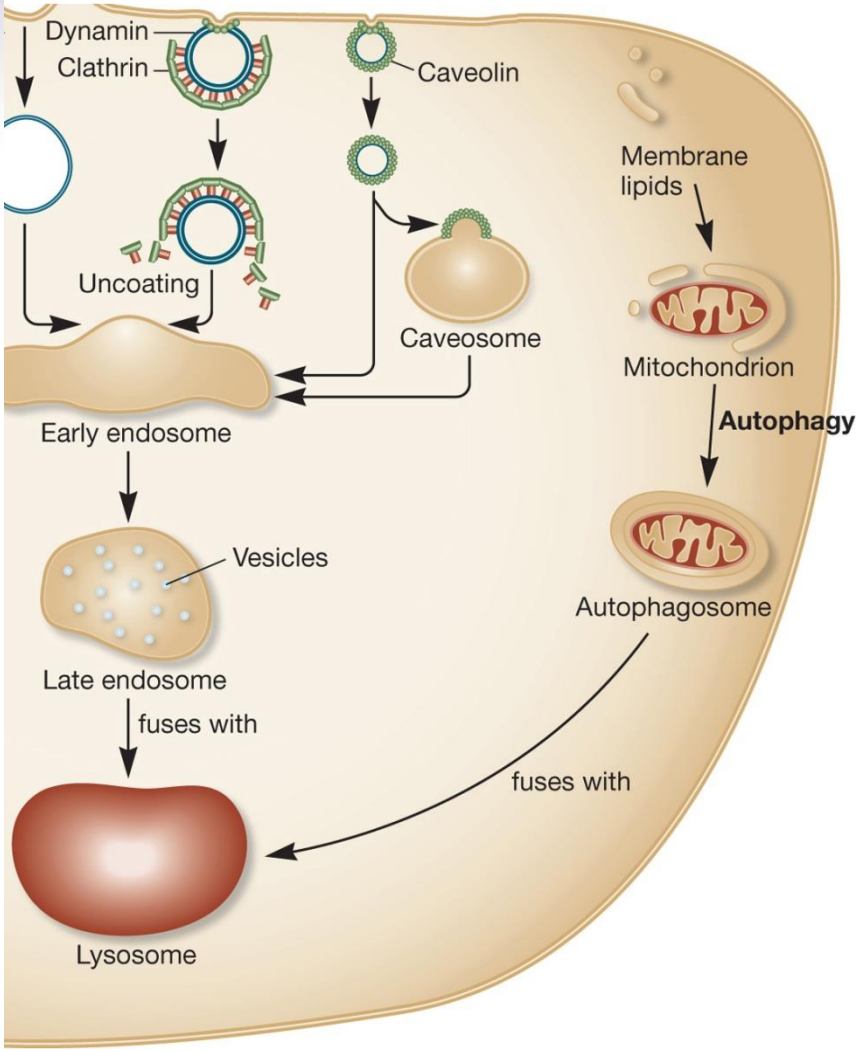
- Phagocytosis: use of cell surface protrusions to surround and engulf particles
- Clathrin-dependent: clathrin protein-coated pits have external receptors that specifically bind macromolecules
- Caveolae-dependent endocytosis: may play role in signal transduction, transport of small as well as macromolecules

Endocytosis

- Clathrin-coated vesicles and some caveolin-coated vesicles deliver contents to endosomes (organelles with hydrolytic enzymes)
- Early endosomes develop into late endosomes which fuse with lysosomes
- Caveosomes fuse with early endosomes



Autophagy



- Delivery of materials to be digested by route that does not involve endocytosis
- Macroautophagy involves digestion and recycling of cytoplasmic components
- Double membrane surrounds cell component forming an autophagosome
- Autophagosome fuses with a lysosome

Once Lysosome Is Formed…

- Digestion occurs without release of lysosome enzymes into cytoplasmic matrix
- As contents are digested, products leave lysosome and can be used as nutrients
- Resulting lysosome called a residual body which can release contents to cell exterior by process called lysosome secretion

5.5 Organelles involved in genetic control of the cell

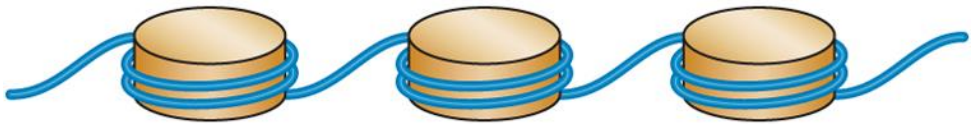
1. Describe the structure of the nucleus, chromosomes, nucleolus, and eukaryotic ribosomes.
2. Compare and contrast the chromosomes and ribosomes of bacterial, archaeal, and eukaryotic cells.

Organelles Involved in Genetic Control of the Cell

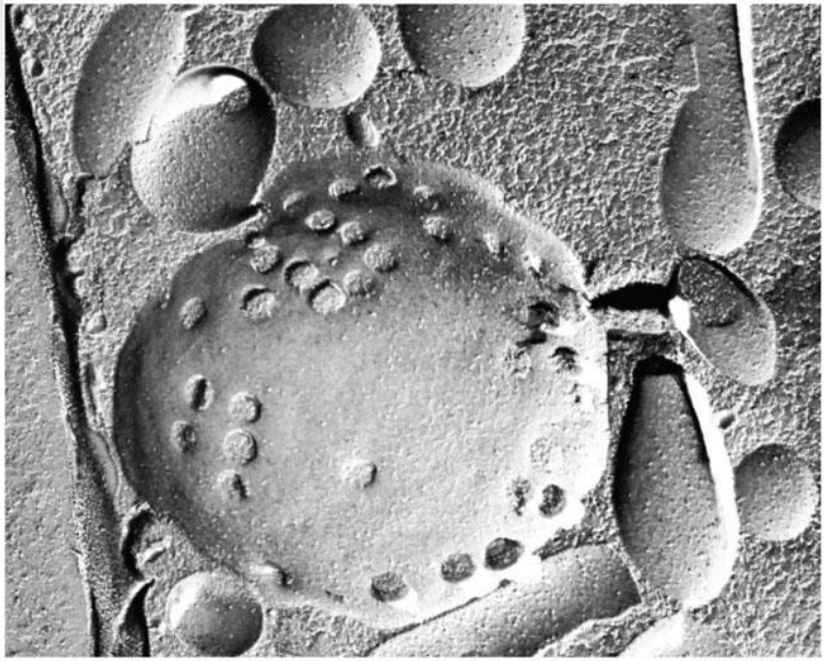
- **Nucleus**
- **Ribosomes**

The Nucleus - 1

- Membrane-bound spherical structure that houses genetic material of eukaryotic cell
- Contains dense fibrous material called chromatin
  - complex of DNA, histones, and other proteins
  - five types of histones form nucleosomes
    - H1, H2A, H2B, H3, and H4
  - chromatin condenses into chromosomes during division



The Nucleus - 2



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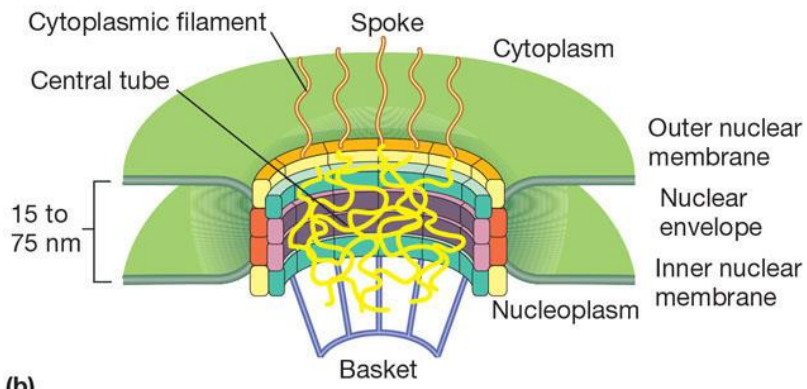


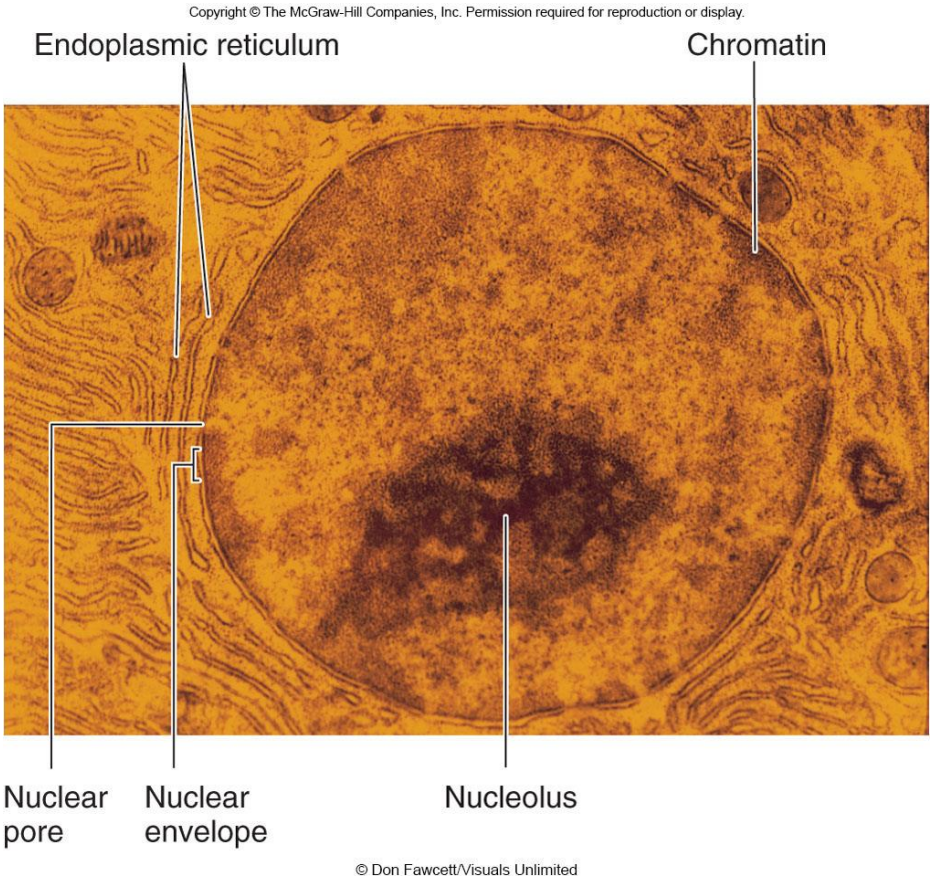
(b)

Courtesy of Dr. Garry T. Cole, Univ. of Texas Austin

- Nuclear envelope
  - double membrane structure that delimits nucleus
  - continuous with ER
  - penetrated by nuclear pores
    - associated proteins make up the nuclear pore complex
    - pores allow materials to be transported into or out of nucleus

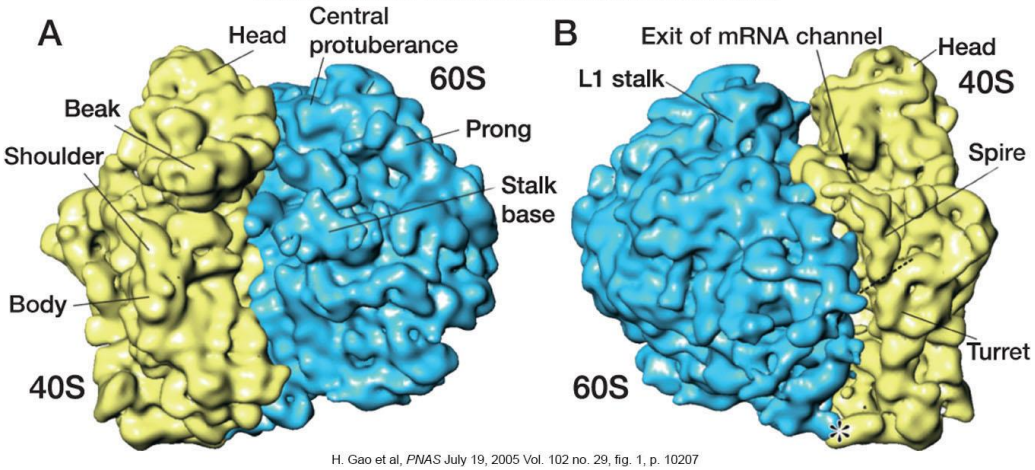
The Nucleolus

- ≥ 1 nucleolus/nucleus
- Organelle but not membrane enclosed
- Important in ribosome synthesis
  - directs synthesis and processing of rRNA
  - directs assembly of rRNA to form partial ribosomal subunits
  - ribosomes mature in cytoplasm



Eukaryotic Ribosomes - 1

- Larger (more mass) than the 70S bacterial and archaeal ribosomes
- 80S in size
  - 60S + 40S subunits
- May be attached to ER or free in cytoplasmic matrix
- 60S is bound subunit to ER



H. Gao et al, *PNAS* July 19, 2005 Vol. 102 no. 29, fig. 1, p. 10207

Eukaryotic Ribosomes - 2

- Proteins made on ribosomes of RER are often secreted or inserted into ER membrane as integral membrane proteins
- Free ribosomes synthesize nonsecretory and nonmembrane proteins
  - some proteins are inserted into organelles

5.6 Organelles involved in energy conservation

1. Draw a mitochondrion and identify its component parts.
2. Compare and contrast mitochondria and hydrogenosomes in terms of their structure and the chemical processes they carry out.
3. Draw a chloroplast and identify its component parts.

Organelles Involved in Energy Conservation

- **Mitochondria**
- **Hydrogenosomes**
- **Chloroplasts**

Endosymbiotic Hypothesis

- Mitochondria, hydrogenosomes, and chloroplasts are all thought to have evolved from bacterial cells that invaded or were ingested by early ancestors of eukaryotic cells
  - mitochondria and chloroplasts are very similar to extant bacteria and cyanobacteria, respectively

Mitochondria

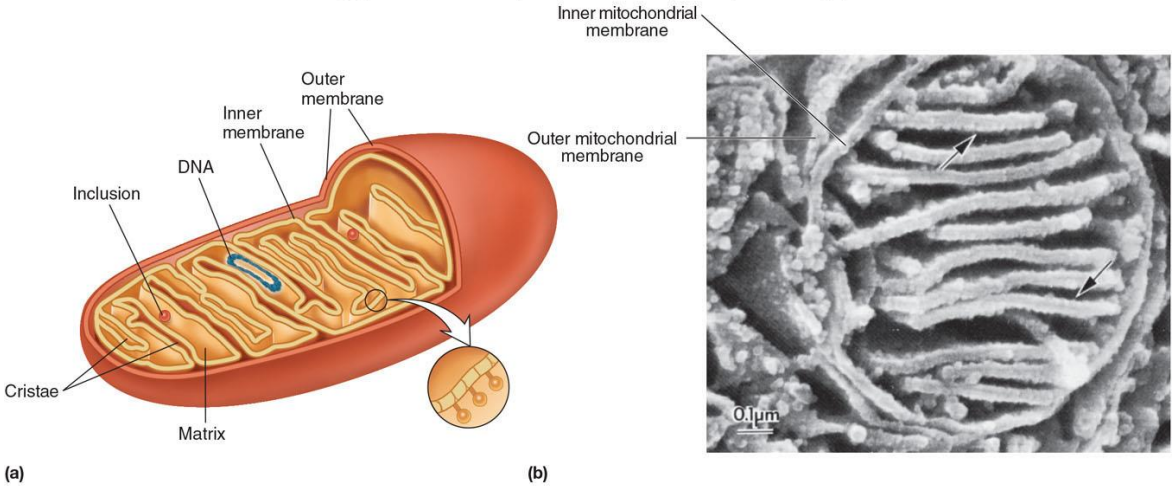
- “The power houses of the cell” are found in most eukaryotic cells
- Site of tricarboxylic acid cycle activity
- Site where ATP is generated by electron transport and oxidative phosphorylation
- About the same size as bacterial cells
- Reproduce by binary fission as do bacterial cells

Mitochondrial Structure

- Outer membrane
  - contains porins similar to the outer membrane of Gram-negative bacteria
- Inner membrane
  - highly folded to form cristae (s., crista)
  - location of enzymes and electron carriers for electron transport and oxidative phosphorylation

Mitochondrial Structure…

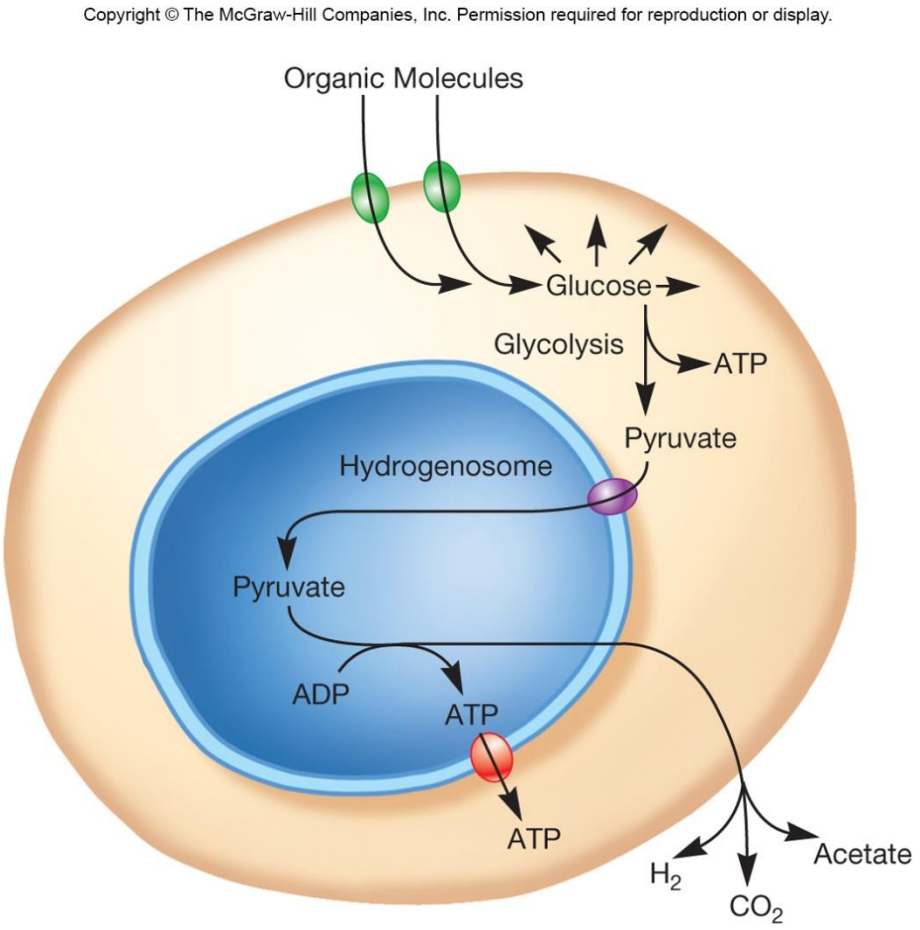
- Matrix enclosed by inner membrane
  - contains ribosomes (same size as bacterial), mitochondrial DNA (may be closed circular like bacterial DNA)
  - contains enzymes of the tricarboxylic acid cycle and enzymes involved in catabolism of fatty acids



International Review of Cytology, Vol. 68, p. 111. Academic Press, 1980

Hydrogenosomes

- Small energy conservation organelles in some anaerobic protists
- Descended from common mitochondrial ancestor
  - double membrane, no cristae, usually lack DNA
  - ATP is generated by fermentation process rather than respiration
  - CO_2, H_2, and acetate are products



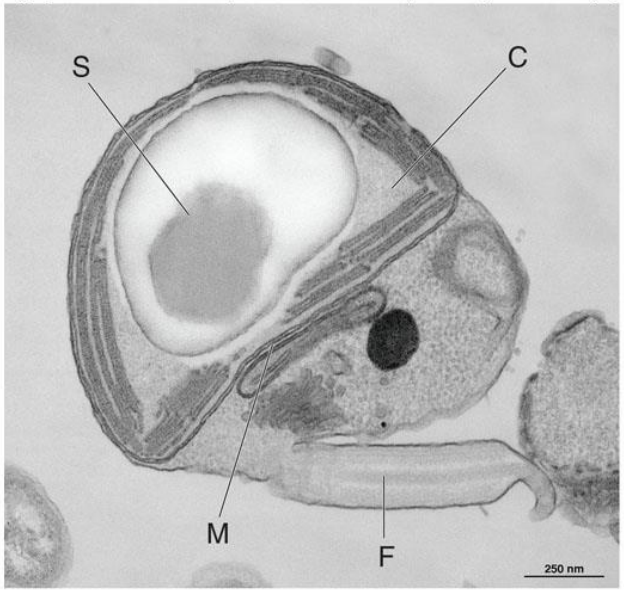
Chloroplasts

- Type of plastid
  - pigment-containing organelles observed in plants and algae
- Site of photosynthetic reactions
- Surrounded by double membrane

Chloroplast Structure

- The stroma (a matrix) is within inner membrane
  - contains DNA, ribosomes, lipid droplets, starch granules, and thylakoids
    - thylakoids
      - flattened, membrane-delimited sacs
      - grana (s., granum) – stacks of thylakoids
      - site of light reactions (trapping of light energy to generate ATP, NADPH, and oxygen)

Chloroplast Structure



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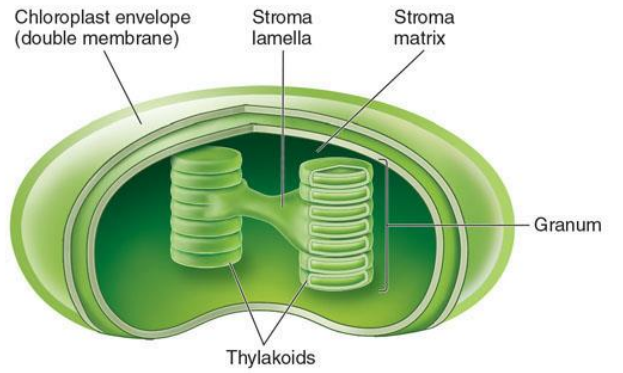


(b)

Thomas Deerinck/Visuals Unlimited, Inc.

- Stroma is site of dark reactions of photosynthesis (formation of carbohydrates from water and carbon dioxide)
- Algal chloroplasts many contain a pyrenoid
  - participates in polysaccharide synthesis

5.7 External structures

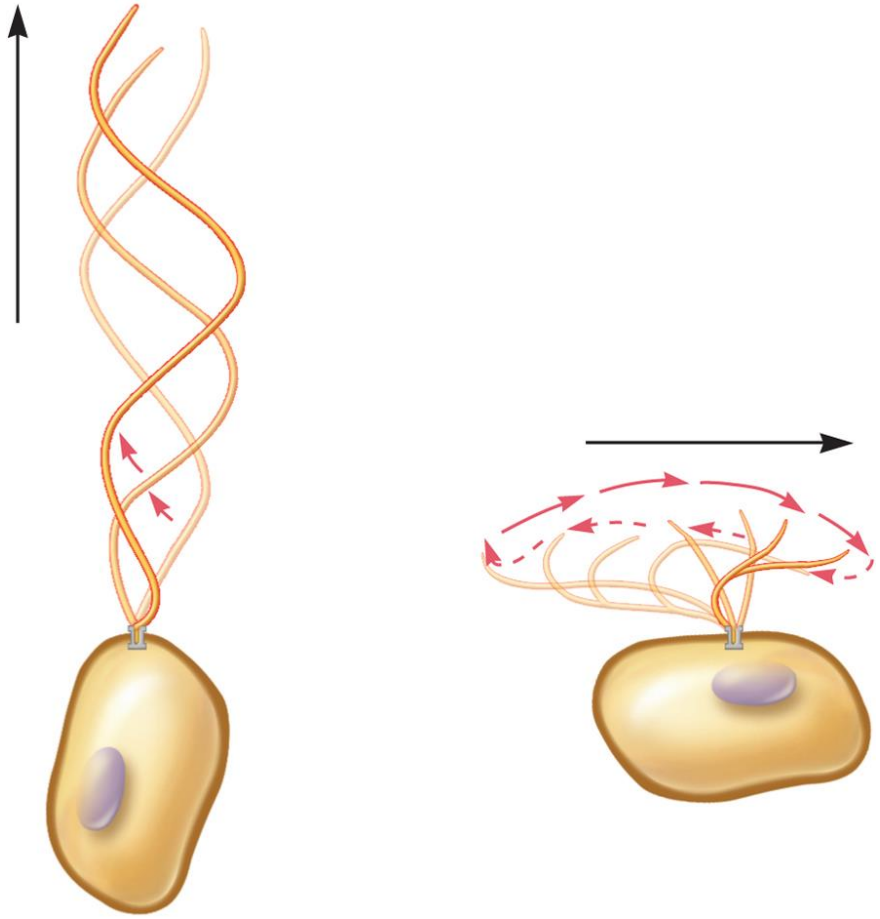
1. Describe the structures of eukaryotic flagella and cilia.
2. Compare and contrast bacterial, archaeal, and eukaryotic flagella.
3. List the types of motility observed in eukaryotic microbes.

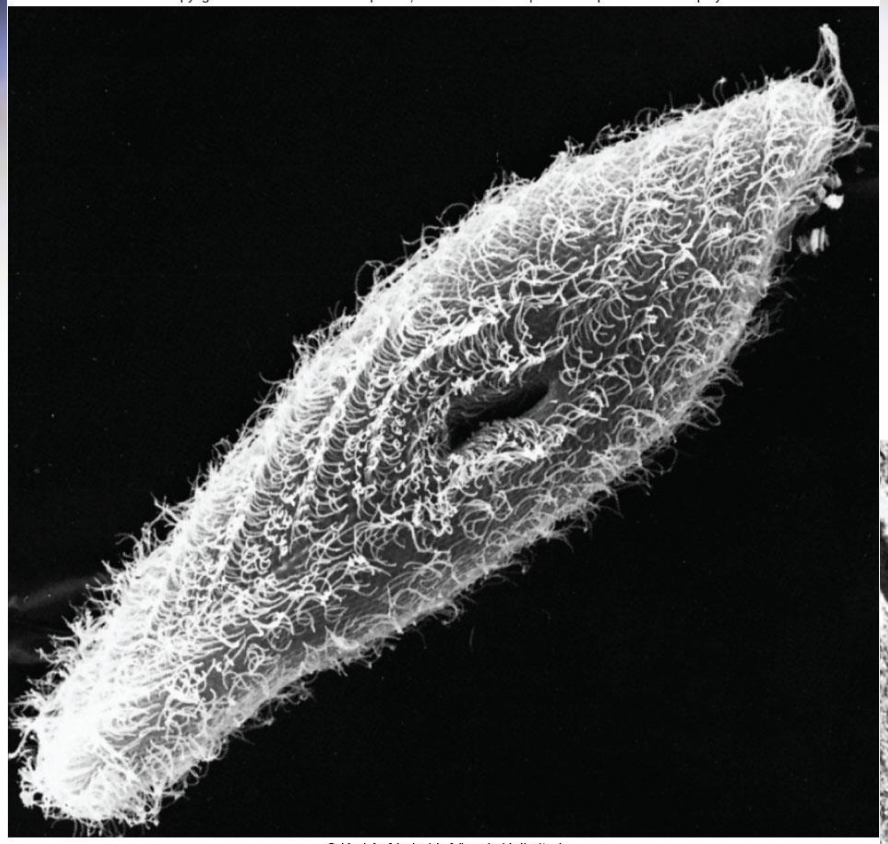
External Cell Covering

- **Cilia**
- **Flagella**

Cilia and Flagella

- Flagella (s., flagellum)
  - 100-200 μm long
  - move in undulating fashion
- Cilia (s., cilium)
  - 5-20 μm long
  - beat with two phases, working like oars





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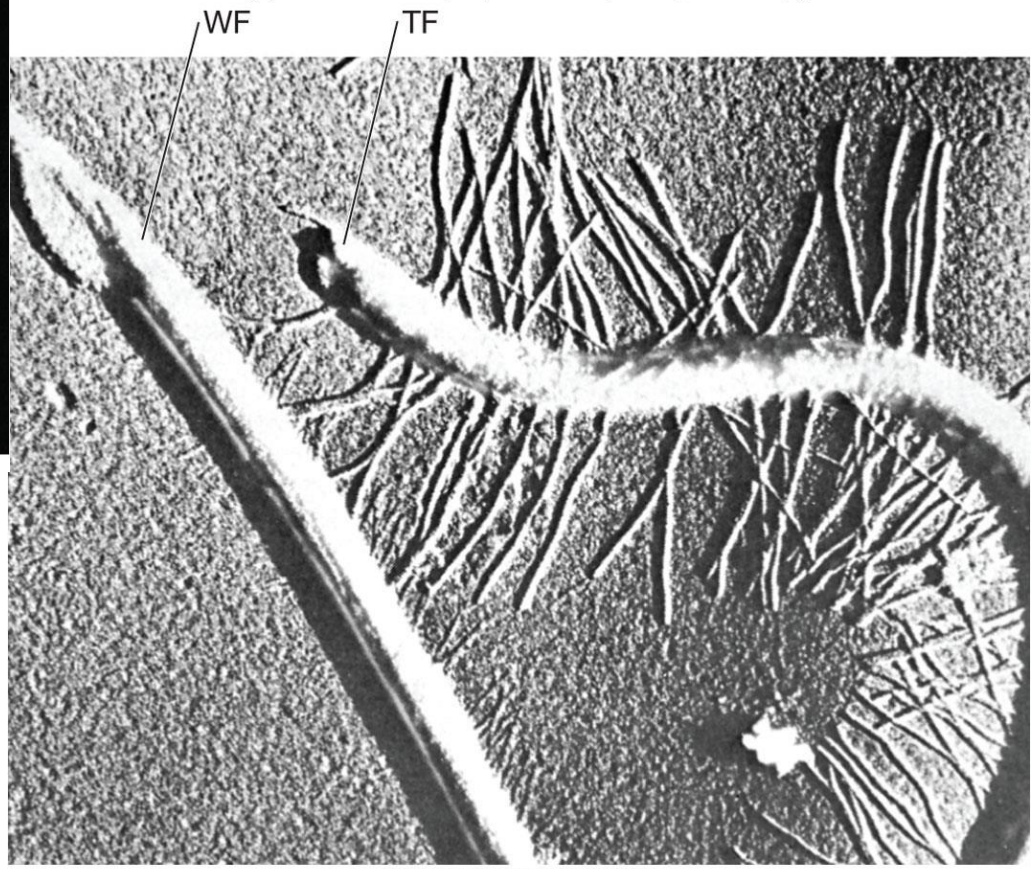
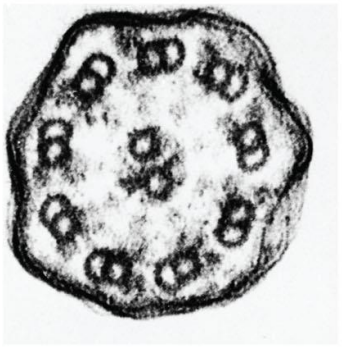


National Research Council of Canada

Ultrastructure of Flagella and Cilia

- Membrane-bound cylinders ~2 μm in diameter
- Axoneme: set of microtubules in a 9+2 arrangement
- Basal body
  - at base of flagellum or cilium
  - directs synthesis of flagella and cilia



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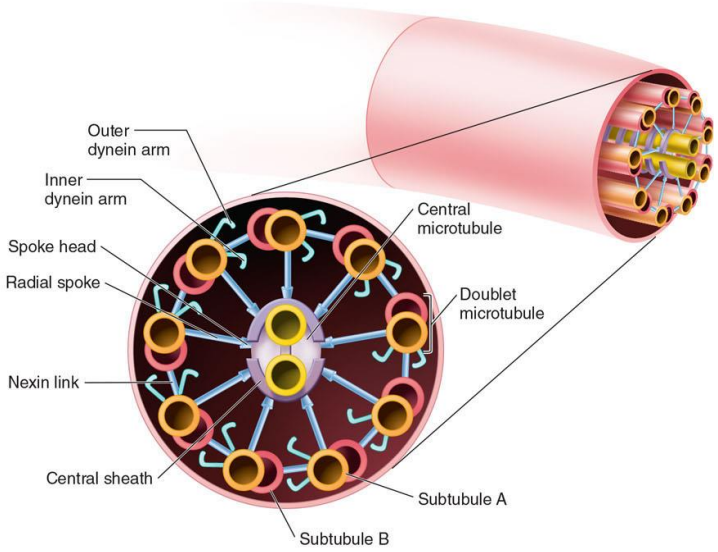


(b)

5.8 Comparison of bacterial, archaeal, and eukaryotic cells

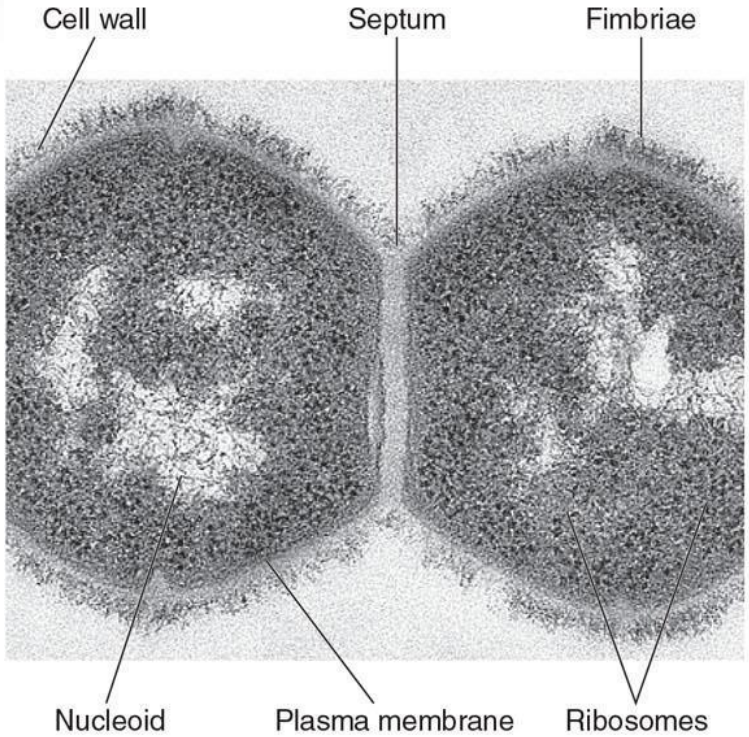
1. Create a Venn diagram or concept map that clearly distinguishes bacterial, archaeal, and eukaryotic cells in terms of their genome organization, organelles, cell envelopes, ribosome size and component molecules, and cytoskeleton.
2. Determine the type of microbe when given a description of a newly discovered microbe.

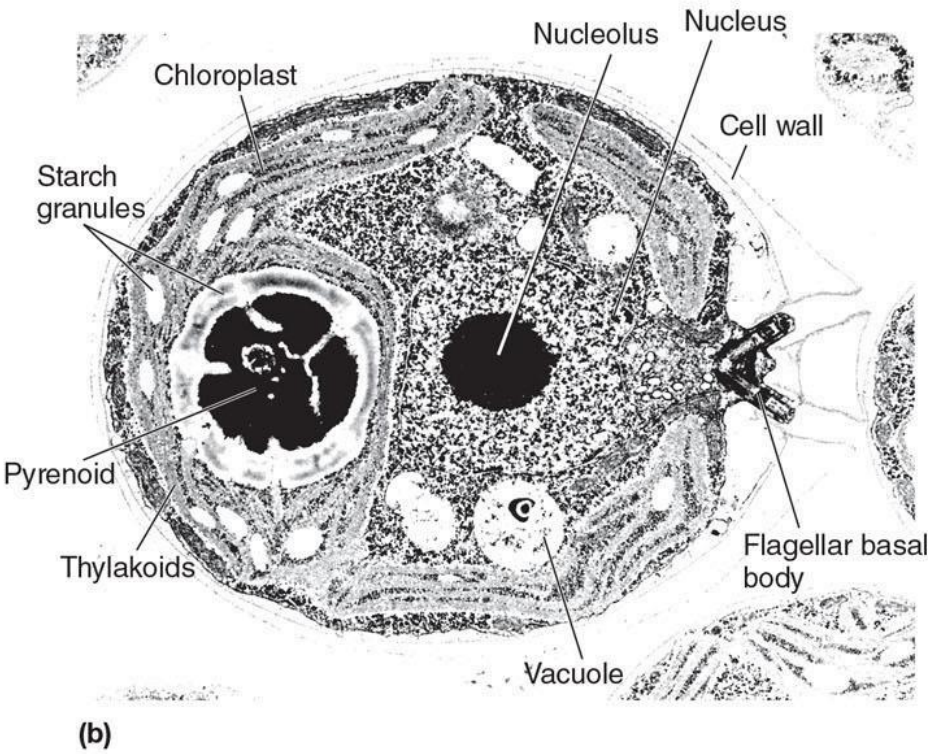
Comparison of Bacterial, Archaeal, and Eukaryotic Cells

- Differences in eukaryotic cells
  - eukaryotic nucleus
  - larger, more complex
  - meiosis, mitosis
  - complex processes
- Molecular unity basic to all three cells
  - biochemical processes, metabolic pathways
  - genetic code

Table 5.2 Comparison of Bacterial, Archaeal, and Eukaryotic Cells

Property	Bacteria	Archaea	Eukaryotes
Organization of Genetic Material			
True membrane-bound nucleus	No	No	Yes
DNA complexed with histones	No	Some	Yes
Chromosomes	Usually one circular chromosome	One circular chromosome	More than one; chromosomes are linear
Plasmids	Very common	Very common	Rare
Introns in genes	Rare	Rare	Yes
Nucleolus	No	No	Yes
Mitochondria, Chloroplasts, Endoplasmic Reticulum, Golgi, and Lysosomes Observed	No	No	Yes
Plasma Membrane Lipids	Ester-linked phospholipids and hopanoids; some have sterols	Glycerol diethers and diglycerol tetraethers	Ester-linked phospholipids and sterols
Flagella	Submicroscopic in size; filament composed of single type of flagellin	Submicroscopic in size; filament composed of multiple different flagellins	Microscopic in size; membrane bound; usually 20 microtubules in 9 + 2 pattern
Peptidoglycan in Cell Walls	Yes	No	No
Ribosome Size and Structure	70S; 3 rRNAs; ~55 ribosomal proteins	70S; most have 3 rRNAs; ~68 ribosomal proteins	80S; 4 rRNAs and ~80 ribosomal proteins
Cytoskeleton	Rudimentary	Rudimentary	Yes
Gas Vesicles	Yes	Yes	No





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