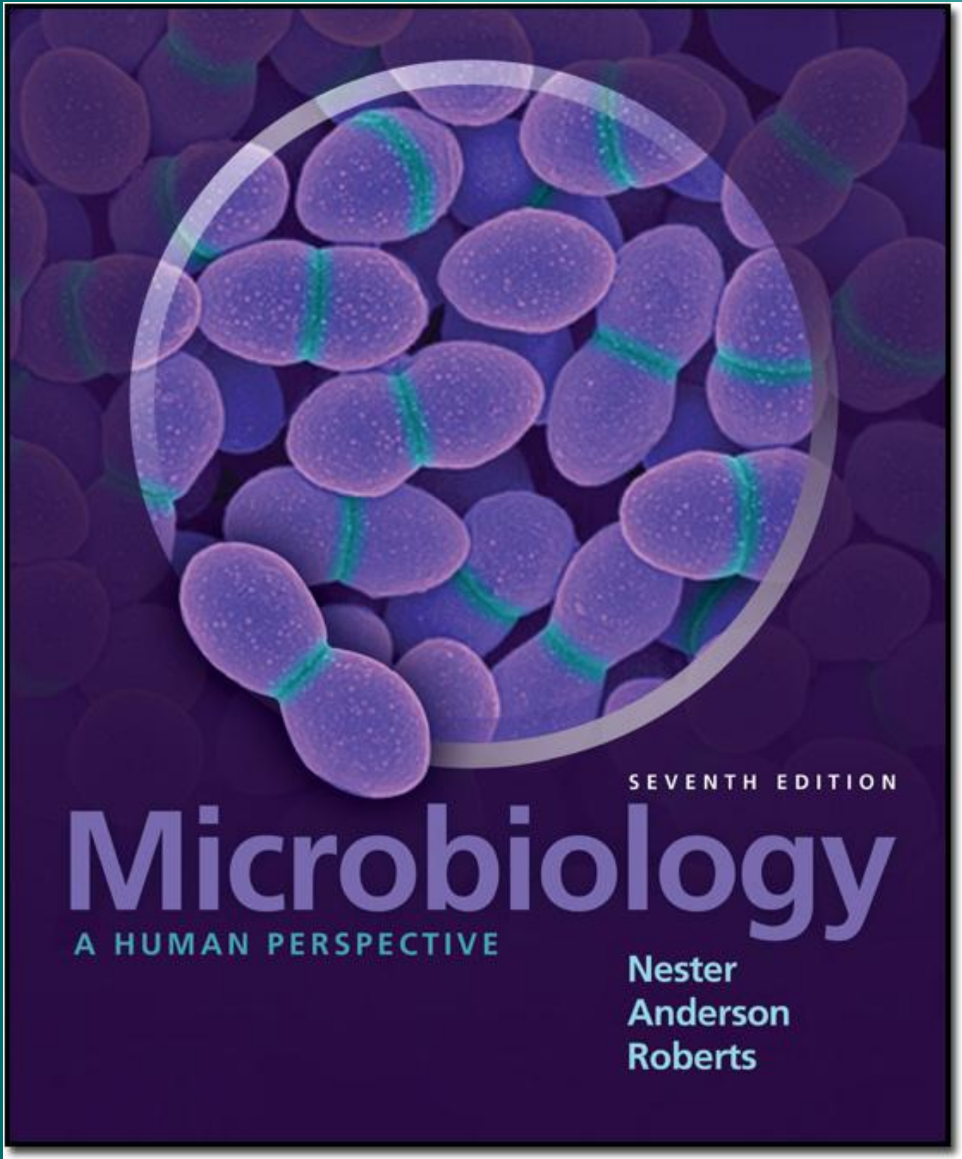
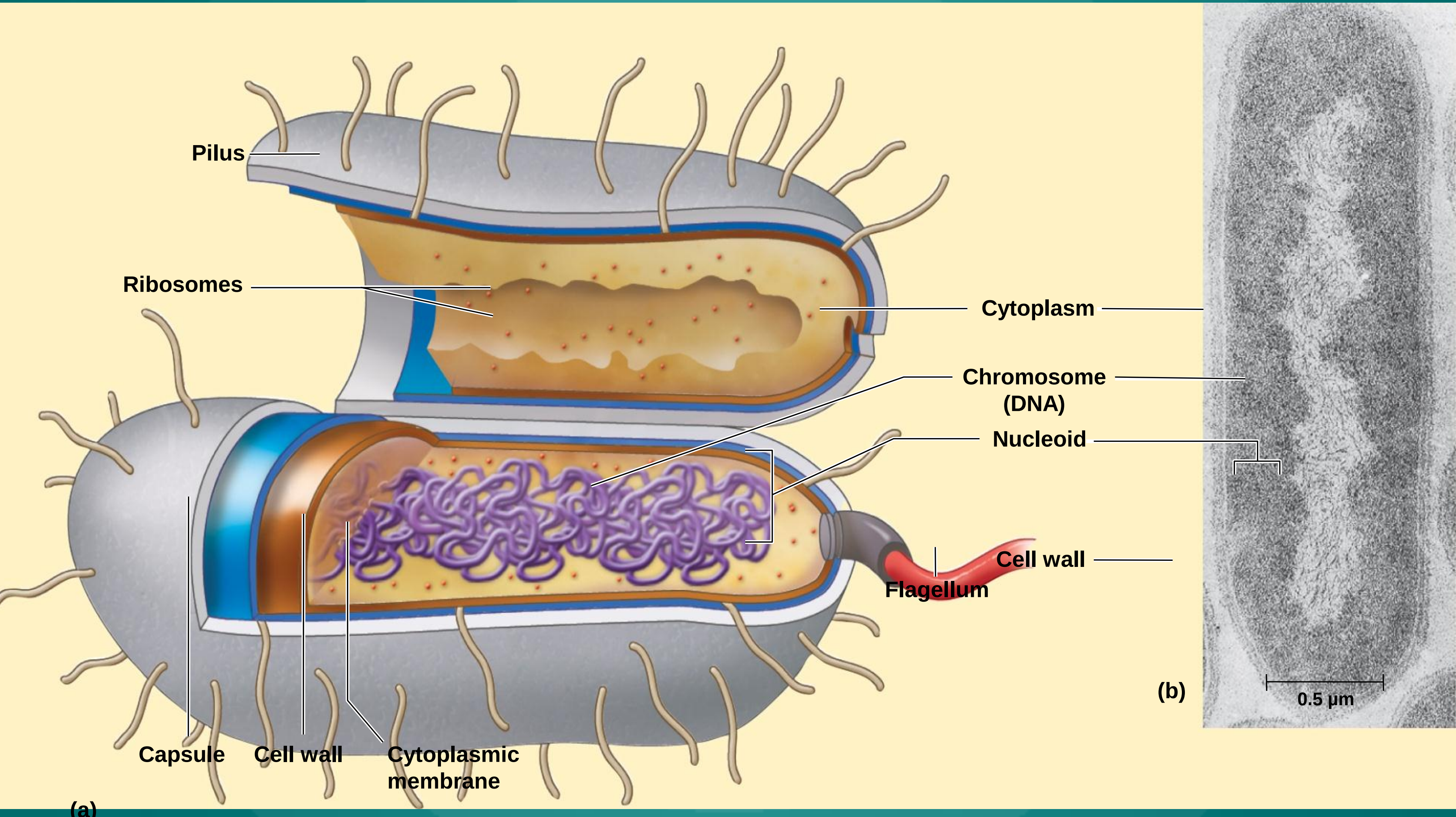


Chapter 03
Lecture

The Prokaryotic Cell



The Prokaryotic Cell

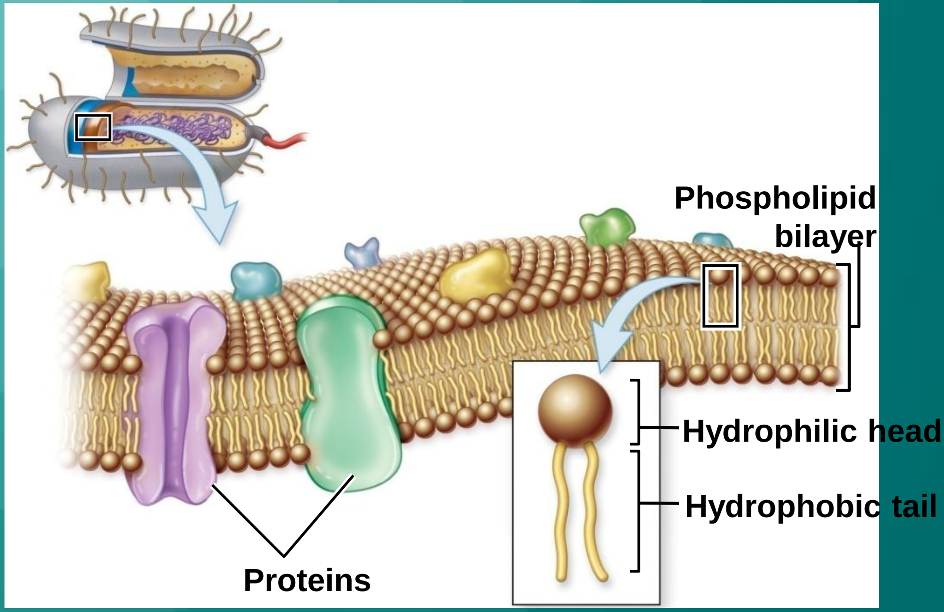
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

TABLE 3.3 A Summary of Typical Prokaryotic Cell Structures

Structure	Characteristics
Extracellular	
Filamentous appendages	Composed of protein subunits that form a helical chain.
Flagella	Provide the most common mechanism of motility.
Pili	Different types of pili have different functions. The common types, often called fimbriae, allow cells to adhere to surfaces. A few types are used for twitching or gliding motility. Sex pili join cells in preparation for DNA transfer.
Capsules and slime layers	Layers outside the cell wall, usually made of polysaccharide.
Capsule	Distinct and gelatinous. Allows bacteria to adhere to specific surfaces; allows some organisms to evade innate defense systems and thus cause disease.
Slime layer	Diffuse and irregular. Allows bacteria to adhere to specific surfaces.
Cell wall	Peptidoglycan provides rigidity to bacterial cell walls, preventing the cells from lysing.
Gram-positive	Thick layer of peptidoglycan that contains teichoic acids and lipoteichoic acids.
Gram-negative	Thin layer of peptidoglycan surrounded by an outer membrane. The outer layer of the outer membrane is lipopolysaccharide.
Cell Boundary	
Cytoplasmic membrane	Phospholipid bilayer embedded with proteins. Surrounds the cytoplasm, separating it from the outside environment. Also transmits information about the external environment to the inside of the cell.
Intracellular	
DNA	Contains the genetic information of the cell.
Chromosomal	Carries the genetic information required by a cell. Typically a single, circular, double-stranded DNA molecule.
Plasmid	Extrachromosomal DNA molecule. Generally carries only genetic information that may be advantageous to a cell in certain situations.
Endospore	A type of dormant cell. Generally extraordinarily resistant to heat, desiccation, ultraviolet light, and toxic chemicals.
Cytoskeleton	Involved in cell division and control of cell shape.
Gas vesicles	Small, rigid structures that provide buoyancy to a cell.
Granules	Accumulations of high-molecular-weight polymers, synthesized from a nutrient available in relative excess.
Ribosomes	Involved in protein synthesis. Two subunits, 30S and 50S, join to form the 70S ribosome.

3.4. The Cytoplasmic Membrane

- Cytoplasmic membrane defines boundary of cell
  - <u>Phospholipid bilayer</u> embedded with proteins
  - Hydrophobic tails face in; hydrophilic tails face out
  - Serves as semipermeable membrane
  - Proteins serve numerous functions
    - Selective gates
    - Sensors of environmental conditions
    - <u>Fluid mosaic model</u>: proteins drift about in lipid bilayer

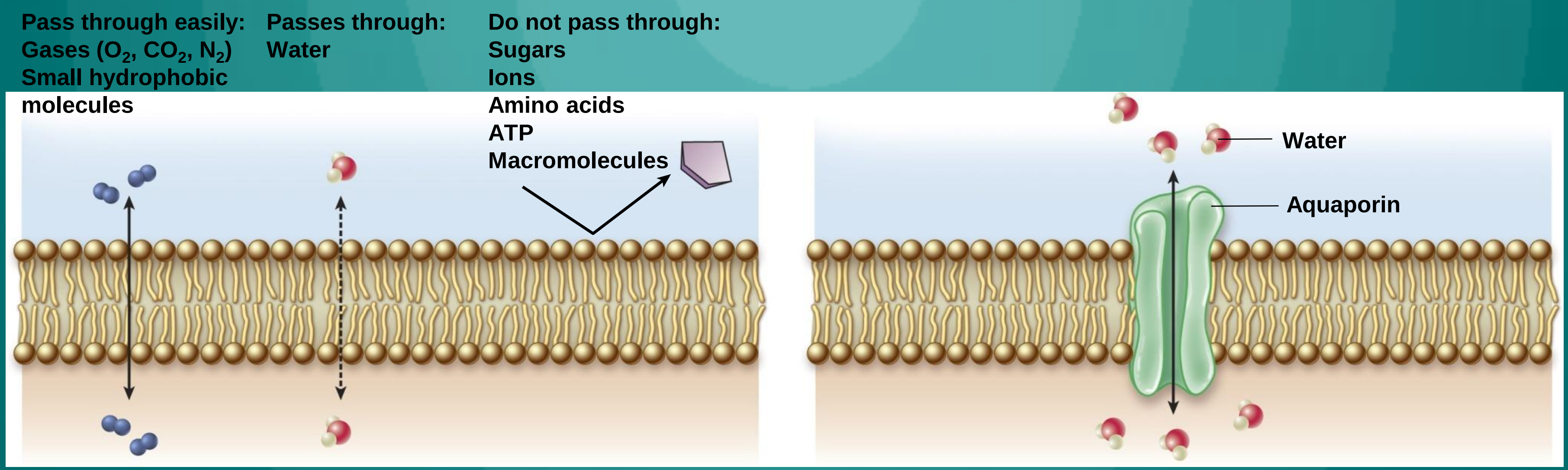


3.4. The Cytoplasmic Membrane

- Cytoplasmic membrane defines boundary of cell (continued…)
  - *Bacteria* and *Archaea* have same general structure of cytoplasmic membranes
    - Distinctly different lipid compositions
    - Lipid tails of *Archaea* are not fatty acids and are connected differently to glycerol

Permeability of Lipid Bilayer

- Cytoplasmic membrane is selectively permeable
  - O_2, CO_2, N_2, small hydrophobic molecules, and water pass freely
  - Some cells facilitate water passage with aquaporins
  - Other molecules must be moved across membrane via transport systems

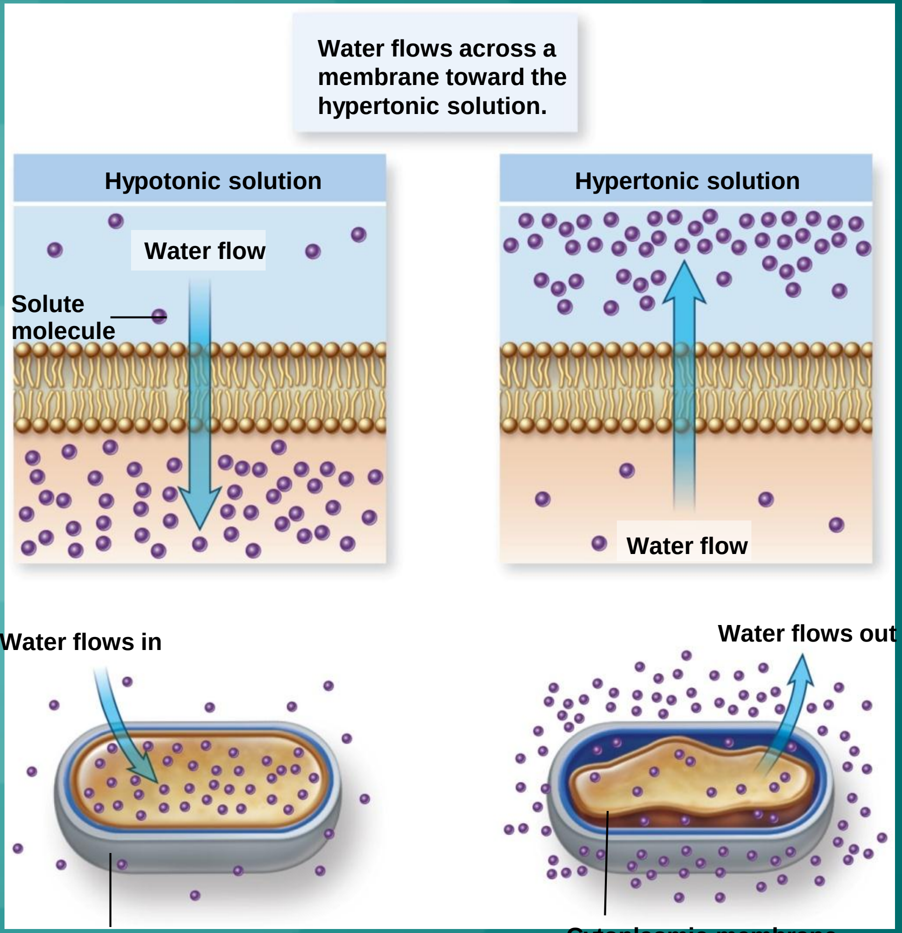


(a) The cytoplasmic membrane is selectively permeable. Gases, small hydrophobic molecules, and water are the only substances that pass freely through the phospholipid bilayer.

(b) Aquaporins allow water to pass through the cytoplasmic membrane more easily.

Permeability of Lipid Bilayer

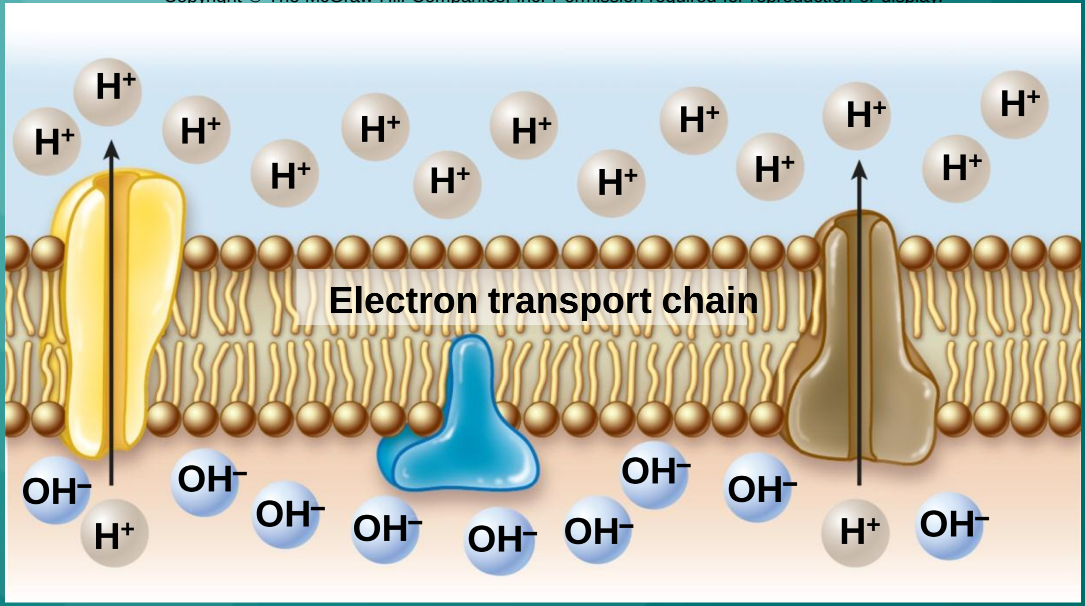
- <u>Simple Diffusion</u>
  - Movement from high to low concentration
  - Speed depends on concentration
- <u>Osmosis</u>
  - Diffusion of water across selectively permeable membrane due to unequal solute concentrations
    - Three terms:
      - Hypertonic
      - Isotonic
      - Hypotonic



Cytoplasmic Membrane and Energy Transformation

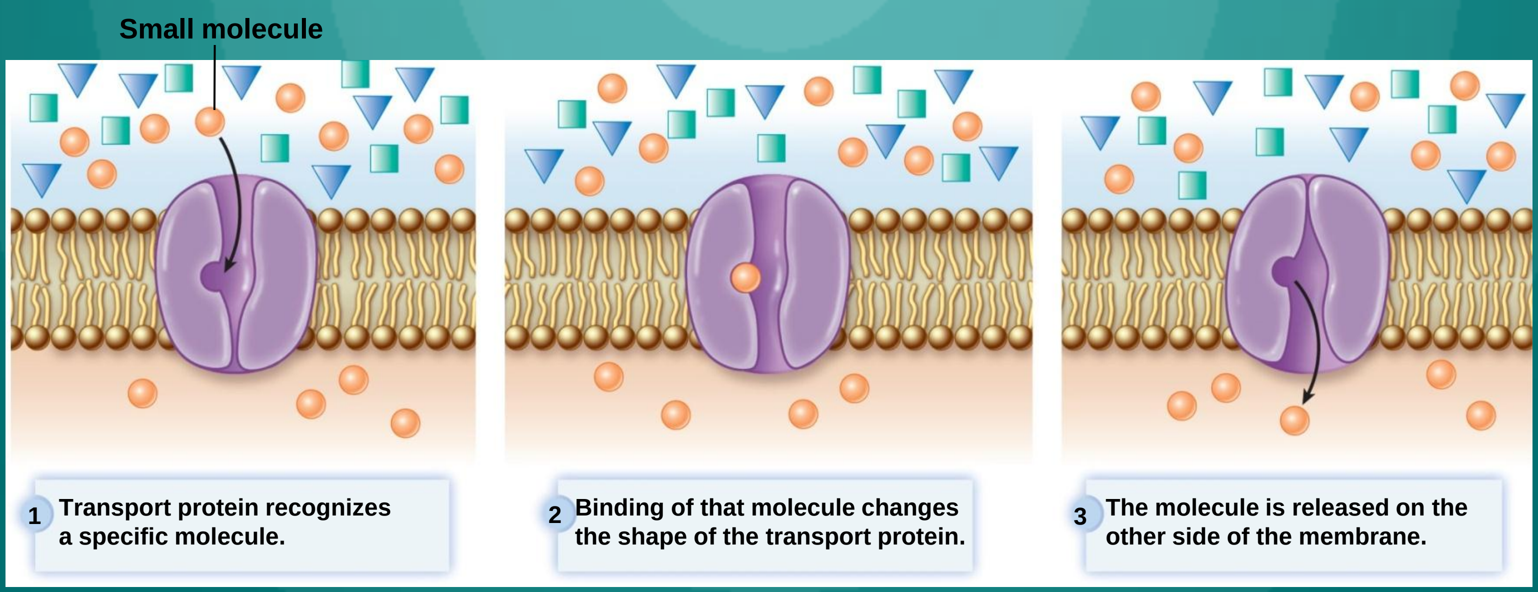
- Electron Transport Chain embedded in membrane
  - Critical role in converting energy into ATP
    - Eukaryotes use membrane-bound organelles
  - Use energy from electrons to move protons out of cell
  - Creates electrochemical gradient across membrane
    - Energy called proton motive force
    - Harvested to drive cellular processes including ATP synthesis and some forms of transport, motility

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



3.5. Directed Movement of Molecules Across Cytoplasmic Membrane

- Most molecules must pass through proteins functioning as selective gates
  - Termed transport systems
    - Proteins may be called permeases, carriers
  - Membrane-spanning
  - Highly specific: carriers transport certain molecule type



3.5. Directed Movement of Molecules Across Cytoplasmic Membrane

- Facilitated diffusion is a form of passive transport
  - Movement down gradient; no energy required
    - Not typically useful in low-nutrient environments
- Active transport requires energy
  - Movement against gradient
  - Two main mechanisms
    - Use proton motive force
    - Use ATP (ABC transporter)
- Group Translocation
  - Chemically alter compound
    - Phosphorylation common
      - Glucose, for example

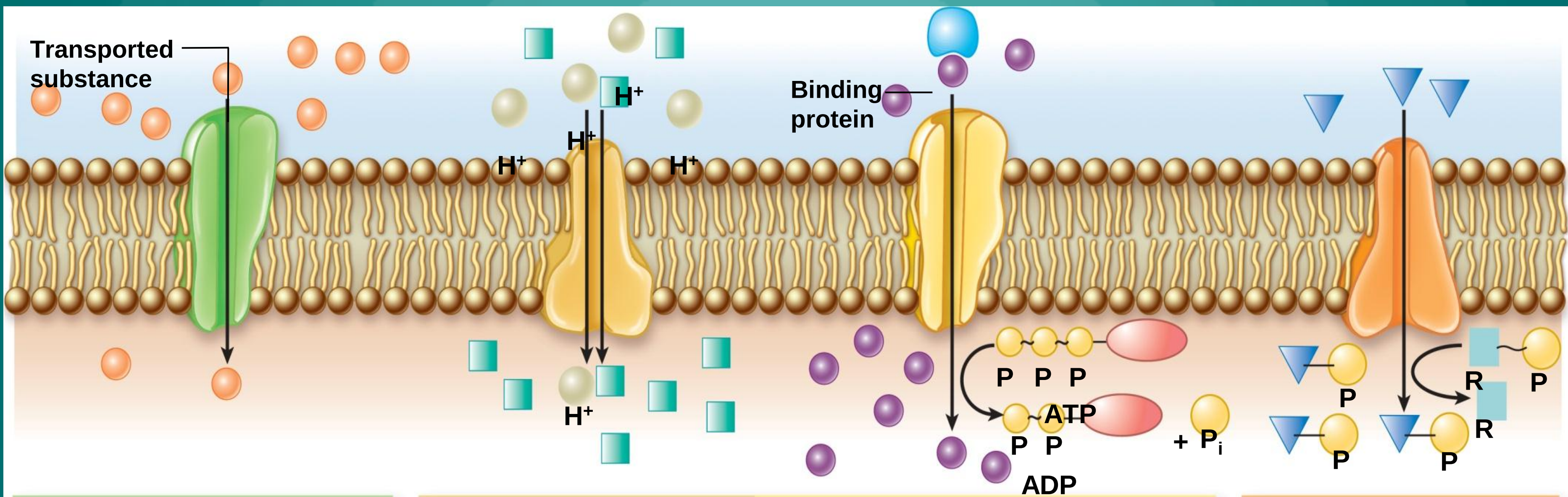
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

TABLE 3.4 A Summary of Transport Mechanisms Used by Prokaryotic Cells

Transport Mechanism	Characteristics
Facilitated Diffusion	Rarely used by prokaryotes. Exploits a concentration gradient to move molecules; can only eliminate a gradient, not create one. No energy is expended.
Active Transport	Energy is expended to accumulate molecules against a concentration gradient.
Transporters that use proton motive force	As a proton is allowed into the cell another substance is either brought along or expelled.
ABC transporters	ATP is used as an energy source. Extracellular binding proteins deliver a molecule to the transporter.
Group Translocation	The transported molecule is chemically altered as it passes into the cell.

3.5. Directed Movement of Molecules Across Cytoplasmic Membrane

- Types of transport systems



(a) Facilitated diffusion

Transporter allows a substance to move across the membrane, but only down the concentration gradient.

(b) Active transport, using proton motive force as an energy source.

Active transport, using ATP as an energy source. A binding protein gathers the transported molecules.

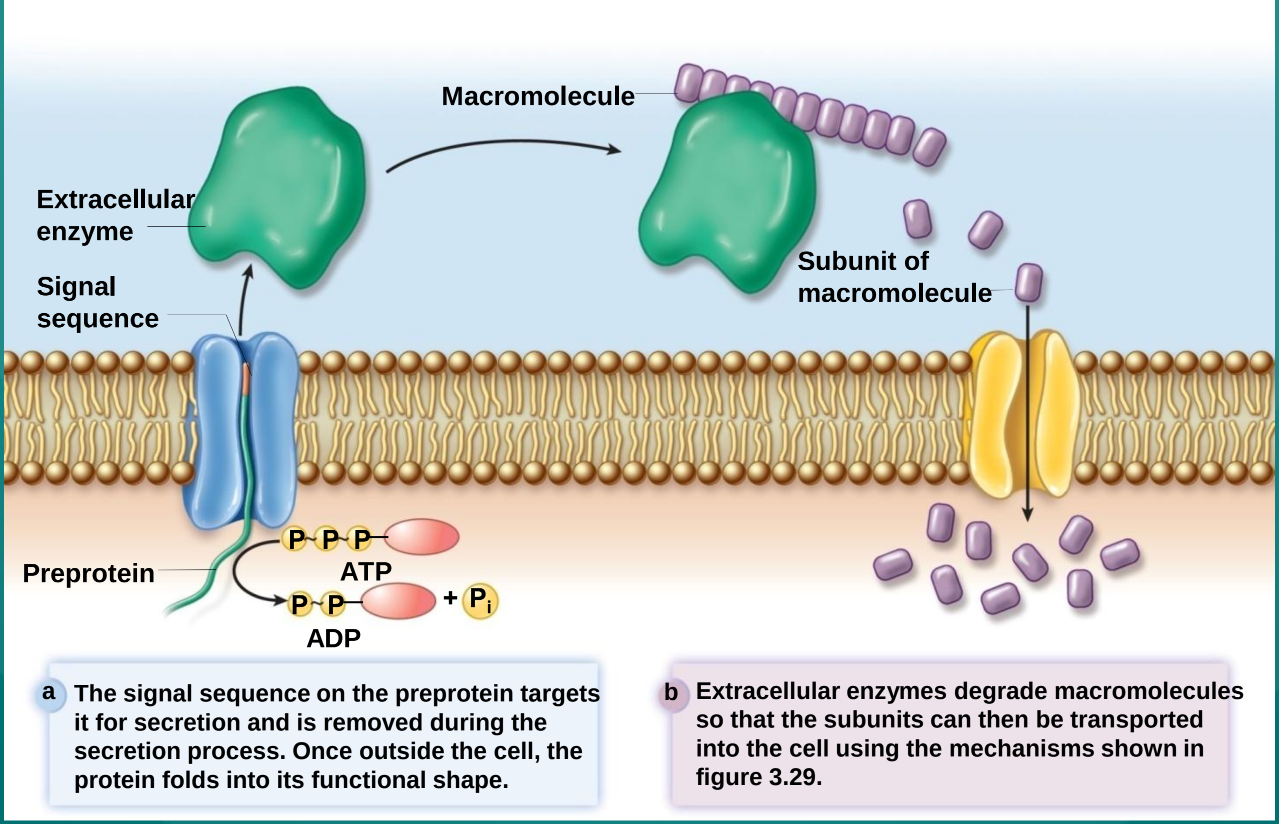
Transporter uses energy (ATP or proton motive force) to move a substance across the membrane and against a concentration gradient.

(c) Group translocation

Transporter chemically alters the substance as it is transported across the membrane.

3.5. Directed Movement of Molecules Across Cytoplasmic Membrane

- Protein secretion: active movement out of cell
  - Examples: extracellular enzymes, external structures
  - Proteins tagged for secretion via signal sequence of amino acids

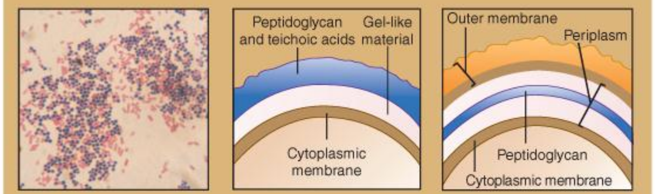


3.6. Cell Wall

- Cell wall is strong, rigid structure that prevents cell lysis
  - Architecture distinguishes two main types of bacteria
    - Gram-positive
    - Gram-negative
  - Made from peptidoglycan
    - Found only in bacteria

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

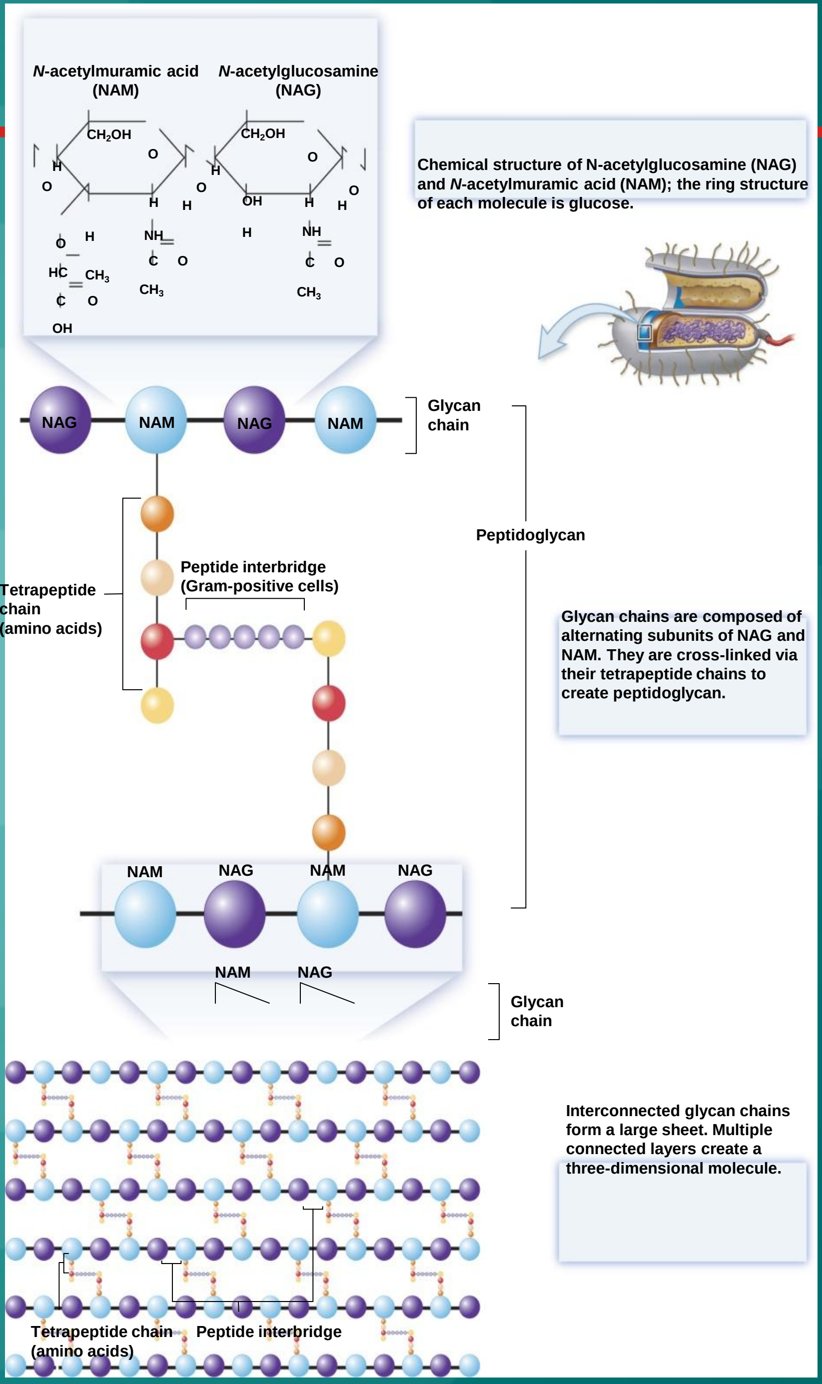
TABLE 3.5 Comparison of Features of Gram-Positive and Gram-Negative Bacteria



	Gram-Positive	Gram-Negative
Color of Gram-Stained Cell	Purple	Pink
Representative Genera	*Bacillus, Staphylococcus, Streptococcus*	*Escherichia, Neisseria, Pseudomonas*
Distinguishing Structures/Components		
Peptidoglycan	Thick layer	Thin layer
Teichoic acids	Present	Absent
Outer membrane	Absent	Present
Lipopolysaccharide (endotoxin)	Absent	Present
Porin proteins	Absent (unnecessary because there is no outer membrane)	Present; allow molecules to pass through outer membrane
General Characteristics		
Sensitivity to penicillin	Generally more susceptible (with notable exceptions)	Generally less susceptible (with notable exceptions)
Sensitivity to lysozyme	Yes	No

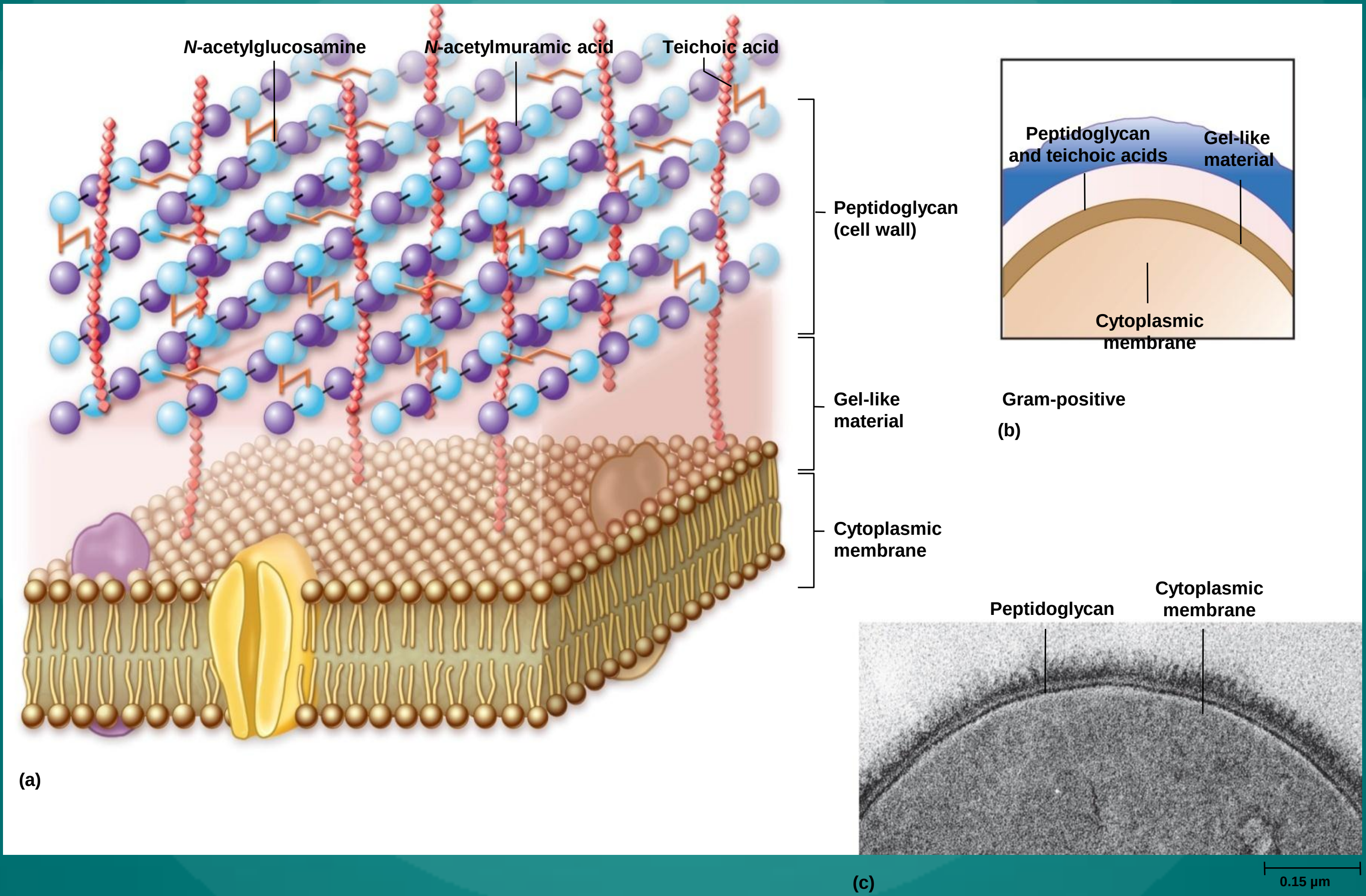
3.6. Cell Wall

- Cell wall is made from <u>peptidoglycan</u>
  - Alternating series of subunits form glycan chains
    - N-acetylmuramic acid (NAM)
    - N-acetylglucosamine (NAG)
  - Tetrapeptide chain (string of four amino acids) links glycan chains



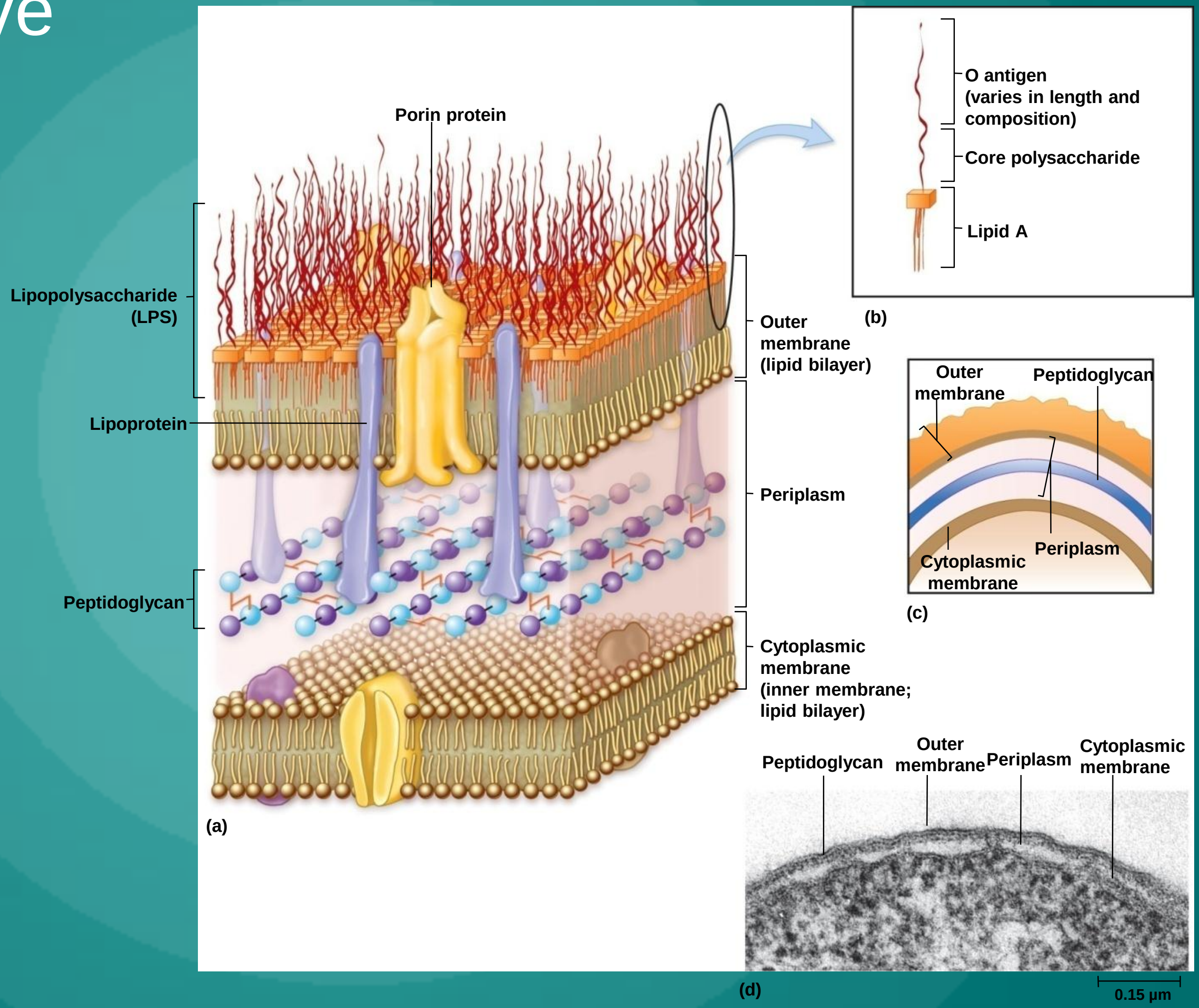
The Gram-Positive Cell Wall

- Gram-positive cell wall has thick peptidoglycan layer



The Gram-Negative Cell Wall

- Gram-negative cell wall has thin peptido-glycan layer
- Outside is unique <u>outer membrane</u>



The Gram-Negative Cell Wall

- Outer membrane
  - Bilayer made from lipopolysaccharide (LPS)
  - Important medically: signals immune system of invasion by Gram-negative bacteria
    - Small levels elicit appropriate response to eliminate
    - Large amounts accumulating in bloodstream can yield deadly response
    - LPS is called endotoxin
    - Includes Lipid A (immune system recognizes) and O antigen (can be used to identify species or strains)

The Gram-Negative Cell Wall

- Outer membrane (continued…)
  - Outer membrane blocks passage of many molecules including certain antibiotics
    - Small molecules and ions can cross via porins
    - Secretion systems important in pathogenesis
  - Between cytoplasmic membrane and outer membrane is periplasmic space
    - Filled with gel-like periplasm
    - Periplasm filled with proteins because exported proteins accumulate unless specifically moved across outer membrane

Antibacterial Substances That Target Peptidoglycan

- Peptidoglycan makes good target since unique to bacteria
  - Can weaken to point where unable to prevent cell lysis
- Penicillin interferes with peptidoglycan synthesis
  - Prevents cross-linking of adjacent glycan chains
  - Usually more effective against Gram-positive bacteria than Gram-negative bacteria
    - Outer membrane of Gram-negatives blocks access
    - Derivatives have been developed that can cross
- Lysozyme breaks bonds linking glycan chain
  - Enzyme found in tears, saliva, other bodily fluids
  - Destroys structural integrity of peptidoglycan molecule

Cell Wall Type and the Gram Stain

- Crystal violet stains inside of cell, not cell wall
  - Gram-positive cell wall prevents crystal violet–iodine complex from being washed out
    - Decolorizing agent thought to dehydrate thick layer of peptidoglycan; desiccated state acts as barrier
  - Solvent action of decolorizing agent damages outer membrane of Gram-negatives
    - Thin layer of peptidoglycan cannot retain dye complex

Bacteria That Lack a Cell Wall

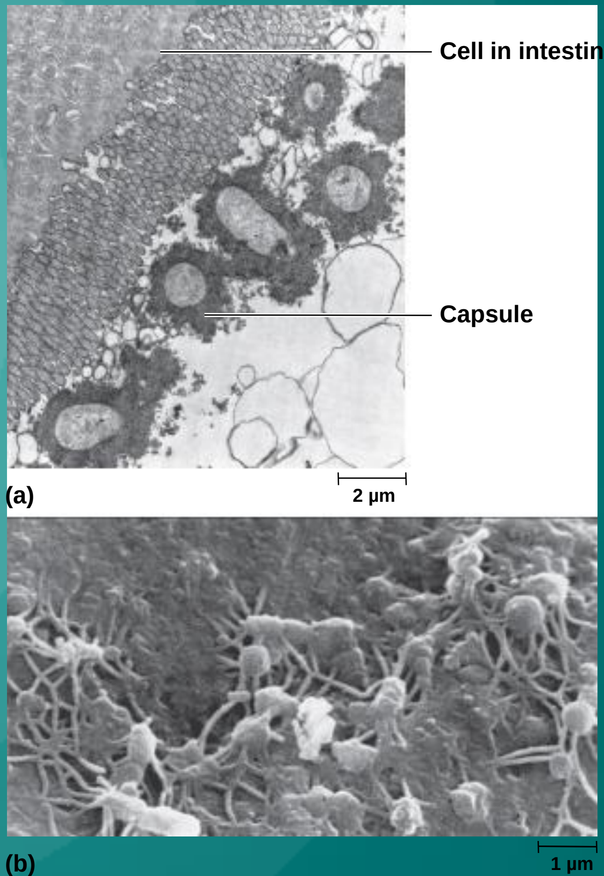
- Some bacteria lack a cell wall
  - Mycoplasma species have extremely variable shape
  - Penicillin, lysozyme do not affect
  - Cytoplasmic membrane contains sterols that increase strength

Cell Walls of the Domain *Archaea*

- Members of *Archaea* have variety of cell walls
  - Probably due to wide range of environments
    - Includes extreme environments
  - However, *Archaea* less well studied than *Bacteria*
  - No peptidoglycan
  - Some have similar molecule pseudopeptidoglycan
  - Many have S-layers that self-assemble
    - Built from sheets of flat protein or glycoprotein subunits

3.7. Capsules and Slime Layers

- Gel-like layer outside cell wall that protects or allows attachment to surface
  - Capsule: distinct, gelatinous
  - Slime layer: diffuse, irregular
  - Most composed of glycocalyx (sugar shell) although some are polypeptides
  - Allow bacteria to adhere to surfaces
  - Once attached, cells can grow as biofilm
    - Polysaccharide encased community
    - Example: dental plaque
  - Some capsules allow bacteria to evade host immune system

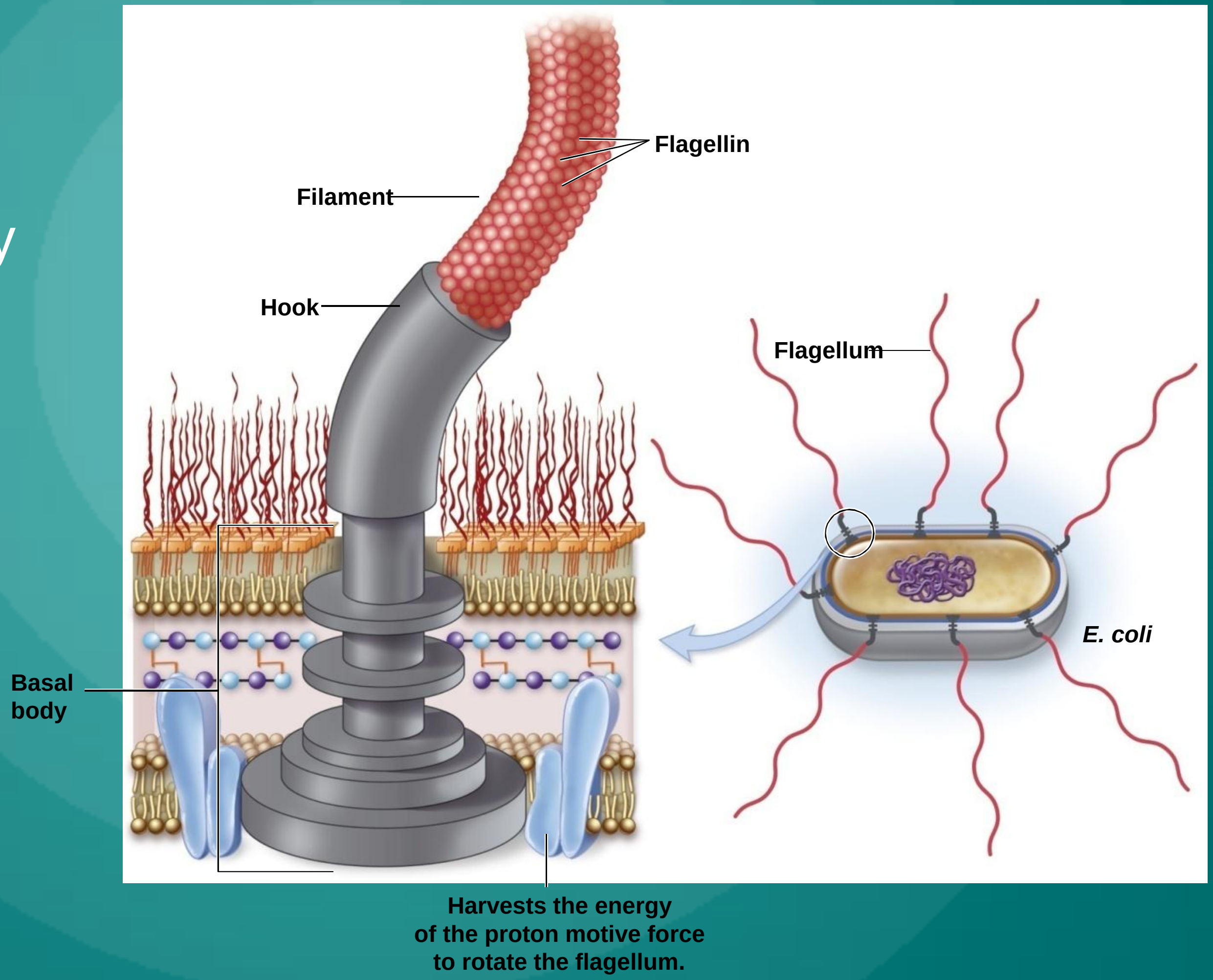


3.8. Filamentous Protein Appendages

- Appendages not essential, but give advantage
- Flagella involved in motility
  - Spin like propellers to move cell
  - Some important in disease
  - Numbers and arrangements help with characterization
  - Peritrichous: distributed over entire surface
  - Polar flagellum: single flagellum at one end of cell
  - Some bacteria have tuft at one or both ends

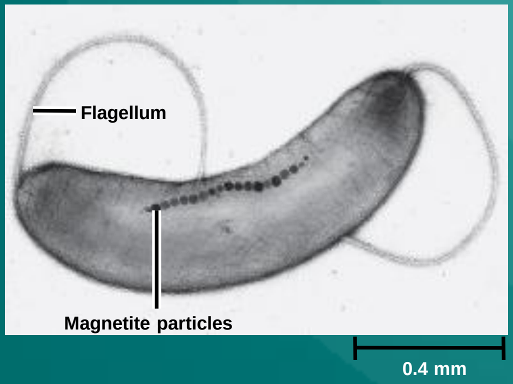
3.8. Filamentous Protein Appendages

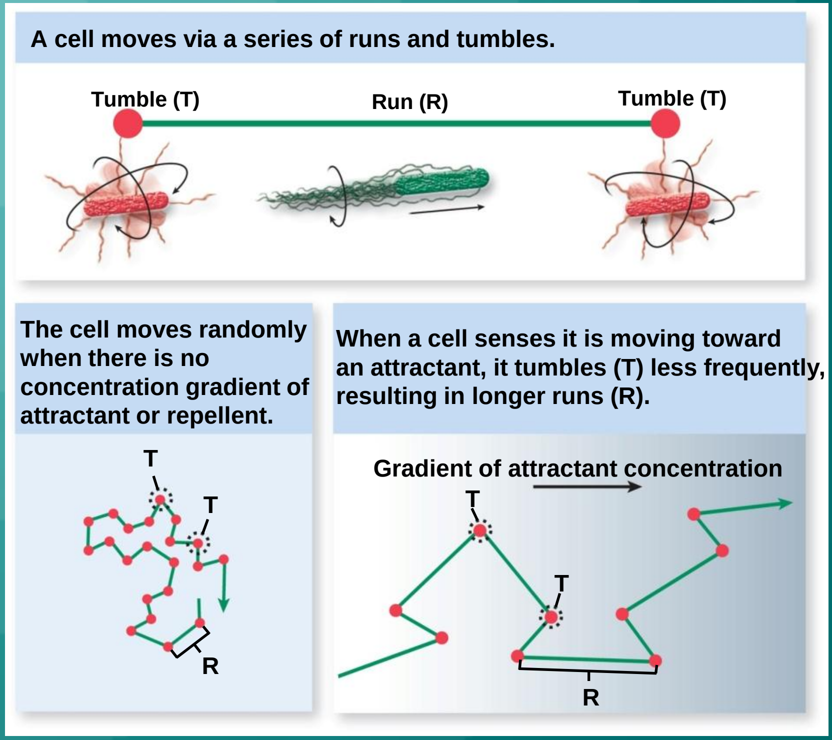
- Flagella (continued…)
  - Three parts
    - Filament
    - Hook
    - Basal body



3.8. Filamentous Protein Appendages

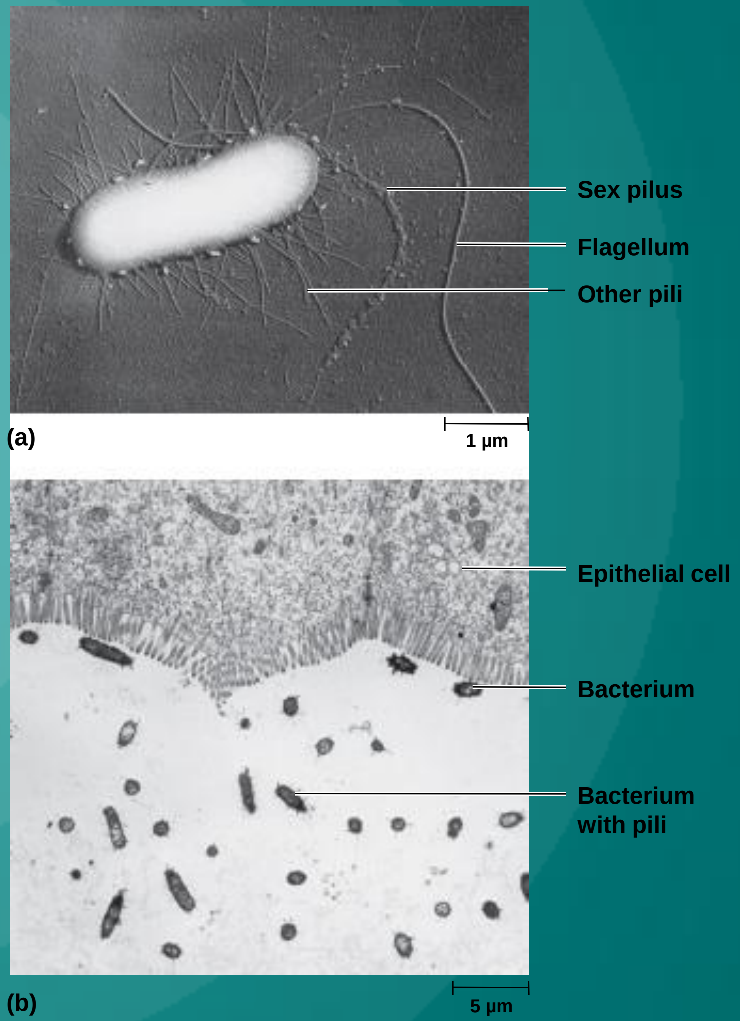
- Chemotaxis
  - Bacteria sense chemicals and move accordingly
    - Nutrients may attract, toxins may repel
  - Movement is series of runs and tumbles
  - Other responses observed
    - Aerotaxis
    - Magnetotaxis
    - Thermotaxis
    - Phototaxis





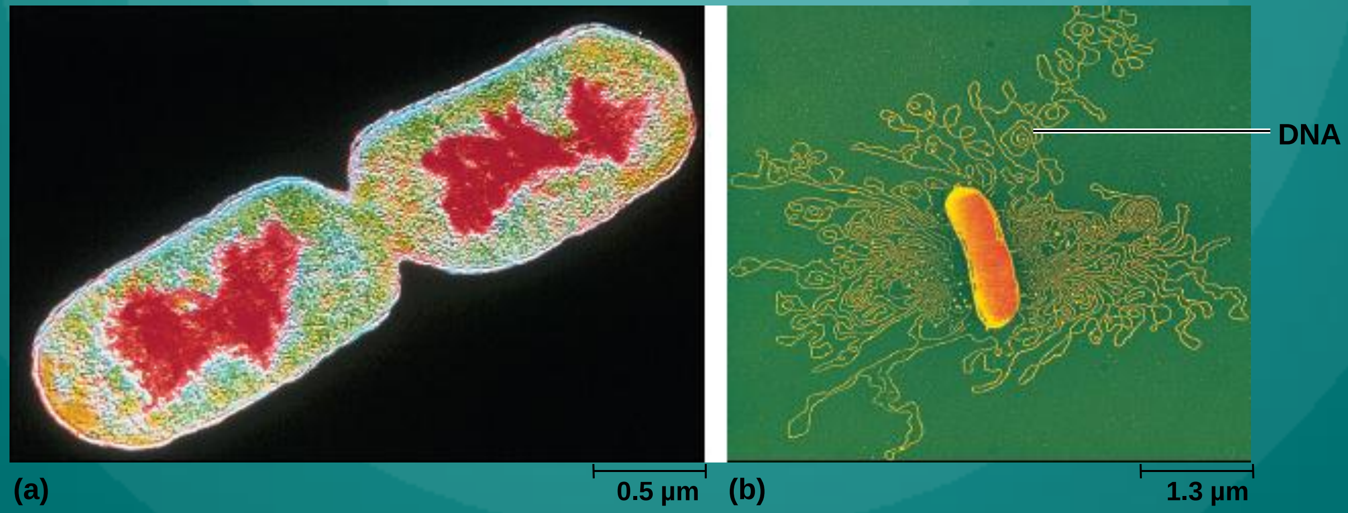
3.8. Filamentous Protein Appendages

- Pili are shorter than flagella
- Types that allow surface attachment termed fimbriae
- Twitching motility, gliding motility involve pili
- Sex pilus used to join bacteria for DNA transfer



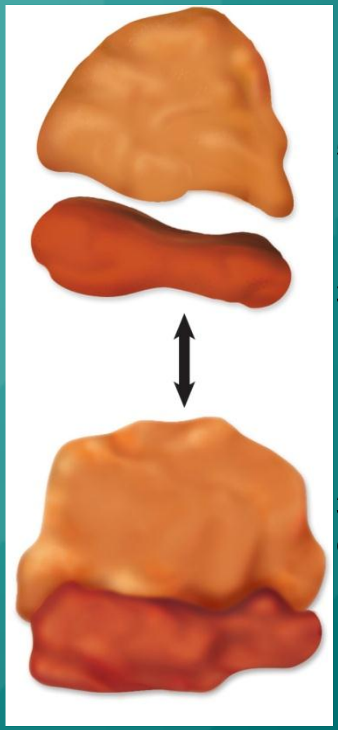
3.9. Internal Structures

- Chromosome forms gel-like region: the nucleoid
  - Single circular double-stranded DNA
    - Packed tightly via binding proteins and supercoiling
- Plasmids are circular, supercoiled, dsDNA
  - Usually much smaller; few to several hundred genes
    - May share with other bacteria; antibiotic resistance can spread this way



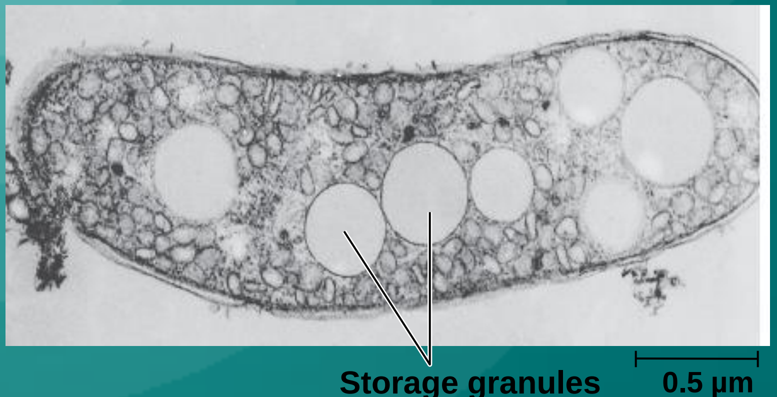
3.9. Internal Structures

- <u>Ribosomes</u> are involved in protein synthesis
  - Facilitate joining of amino acids
  - Relative size expressed as S (Svedberg)
    - Reflects density: how fast they settle when centrifuged
  - Prokaryotic ribosomes are 70S
    - Made from 30S and 50S
  - Eukaryotic ribosomes are 80S
    - Important medically: antibiotics impacting 70S ribosome do not affect 80S ribosome



3.9. Internal Structures

- Cytoskeleton: internal protein framework
  - Once thought bacteria lacked this
  - Bacterial proteins similar to eukaryotic cytoskeleton have been characterized
    - Likely involved in cell division and controlling cell shape
- Storage granules: accumulations of polymers
  - Synthesized from nutrients available in excess
    - E.g., carbon, energy storage:
      - Glycogen
      - Poly-β-hydroxybutyrate
- Gas vesicles: controlled to provide buoyancy

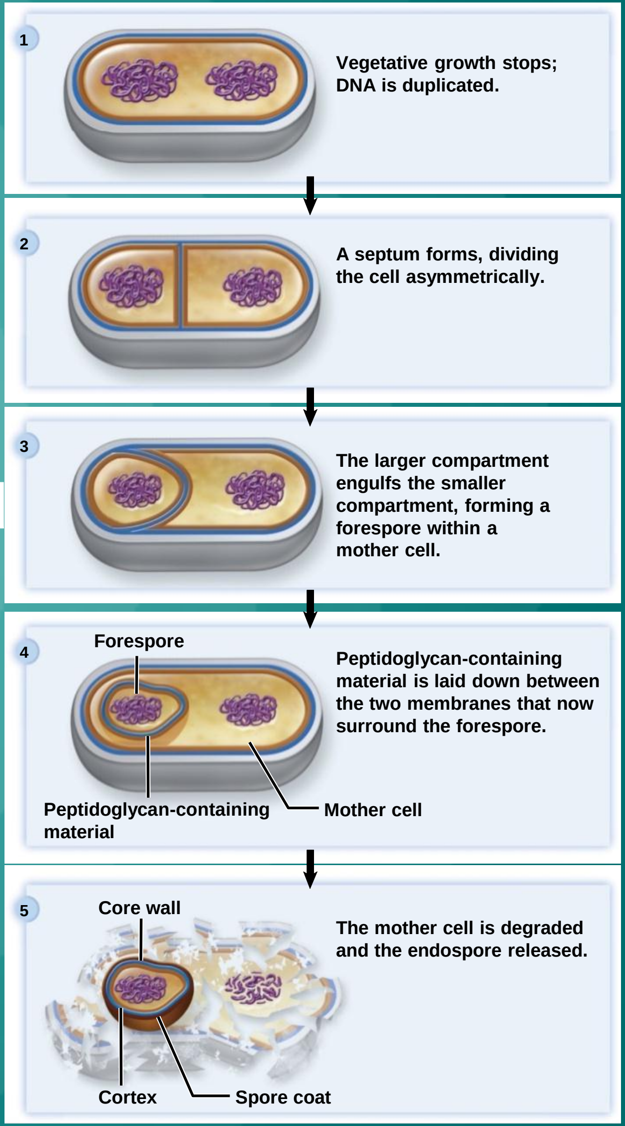


3.9. Internal Structures

- Endospores: unique type of dormant cell
  - Members of *Bacillus*, *Clostridium* produce
  - May remain dormant for 100 years or longer
  - Extremely resistant to heat, desiccation, chemicals, ultraviolet light, boiling water
    - Endospores that survive can germinate to become vegetative cell
  - Found virtually everywhere

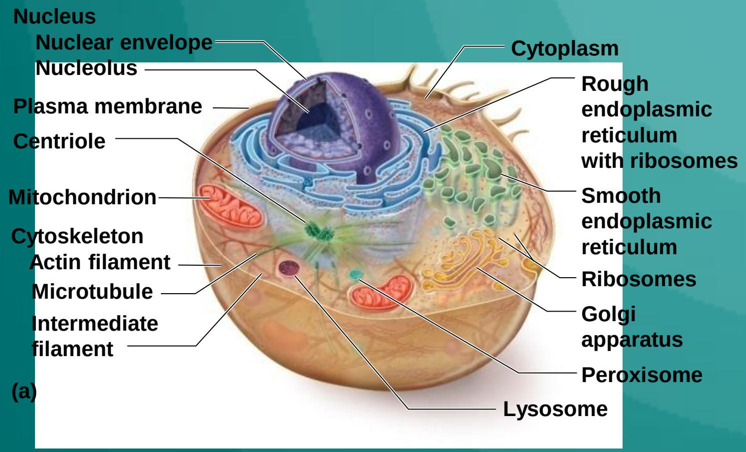
3.9. Internal Structures

- Sporulation triggered by carbon, nitrogen limitation
  - Starvation conditions begin 8-hour process
  - Endospore layers prevent damage
    - Exclude molecules (e.g., lysozyme)
  - Cortex maintains core in dehydrated state, protects from heat
  - Core has small proteins that bind and protect DNA
  - Calcium dipicolinate seems to play important protective role
- Germination triggered by heat, chemical exposure

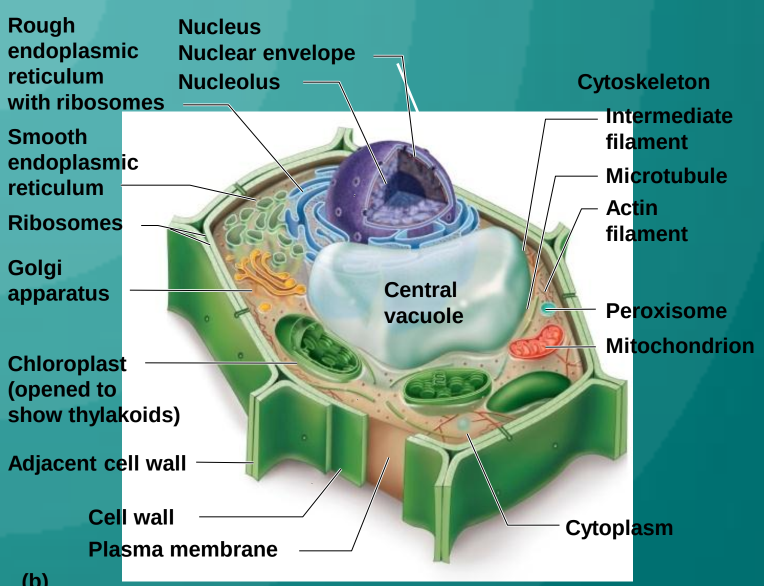


The Eukaryotic Cell

- Eukaryotic cells larger than prokaryotic cells
  - Internal structures far more complex
  - Have abundance of membrane-enclosed compartments termed organelles
  - Animal, plant cells share similarities, have differences



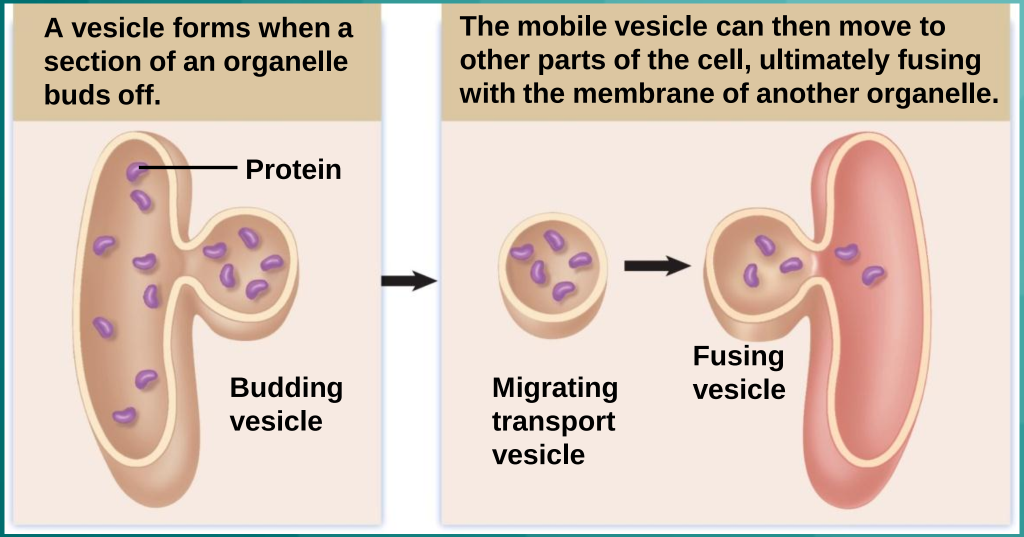
(a)

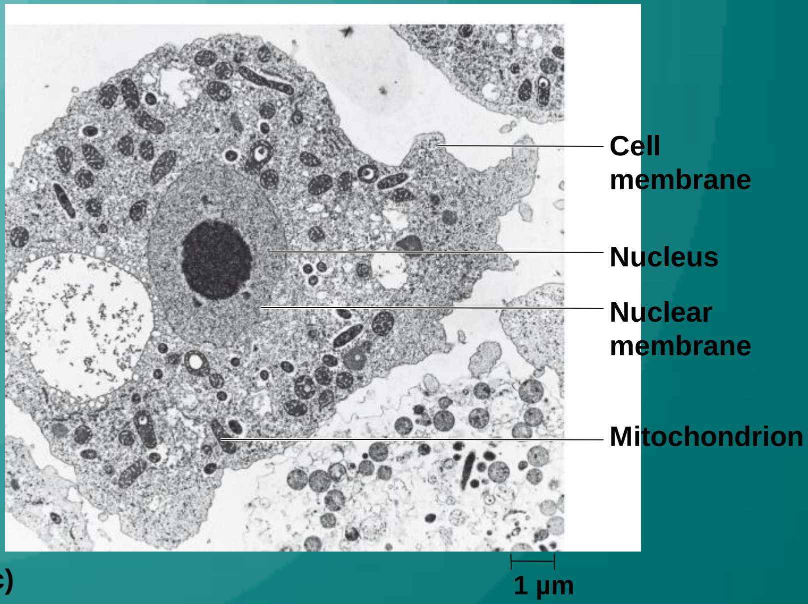


(b)

The Eukaryotic Cell

- Organelles compartmentalize functions
  - Vesicles can transport compounds between
    - Buds off from organelle, fuses with membrane of another





(c)

The Eukaryotic Cell

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

TABLE 3.6 A Summary of Typical Eukaryotic Cell Structures

Structure	Characteristics
Plasma Membrane	Asymmetric lipid bilayer embedded with proteins. Permeability barrier, transport, and cell-to-cell communication.
Internal Protein Structures	
Cilia	Beat in synchrony to provide movement. Composed of microtubules in a 9 + 2 arrangement.
Cytoskeleton	Dynamic filamentous network that provides structure to the cell.
Flagella	Propel or push the cell with a whiplike or thrashing motion. Composed of microtubules in a 9 + 2 arrangement.
Ribosomes	Two subunits, 60S and 40S, join to form the 80S ribosome.
Membrane-Bound Organelles	
Chloroplasts	Site of photosynthesis; the organelle harvests the energy of sunlight to generate ATP, which is then used to convert CO_2 to carbohydrates.
Endoplasmic reticulum	Site of synthesis of macromolecules destined for other organelles or the external environment.
Rough	Attached ribosomes thread proteins they are synthesizing into the lumen of the organelle.
Smooth	Site of lipid synthesis and degradation, and calcium ion storage.
Golgi apparatus	Site where macromolecules synthesized in the endoplasmic reticulum are modified before being transported in vesicles to other destinations.
Lysosome	Digestion of macromolecules.
Mitochondria	Harvest the energy released during the degradation of organic compounds to generate ATP.
Nucleus	Contains the genetic information (DNA).
Peroxisome	Site where oxidation of lipids and toxic chemicals occurs.

Comparisons of Eukaryotic and Prokaryotic Cells

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

TABLE 3.7 Comparison of Typical Prokaryotic and Eukaryotic Cell Structures/Functions

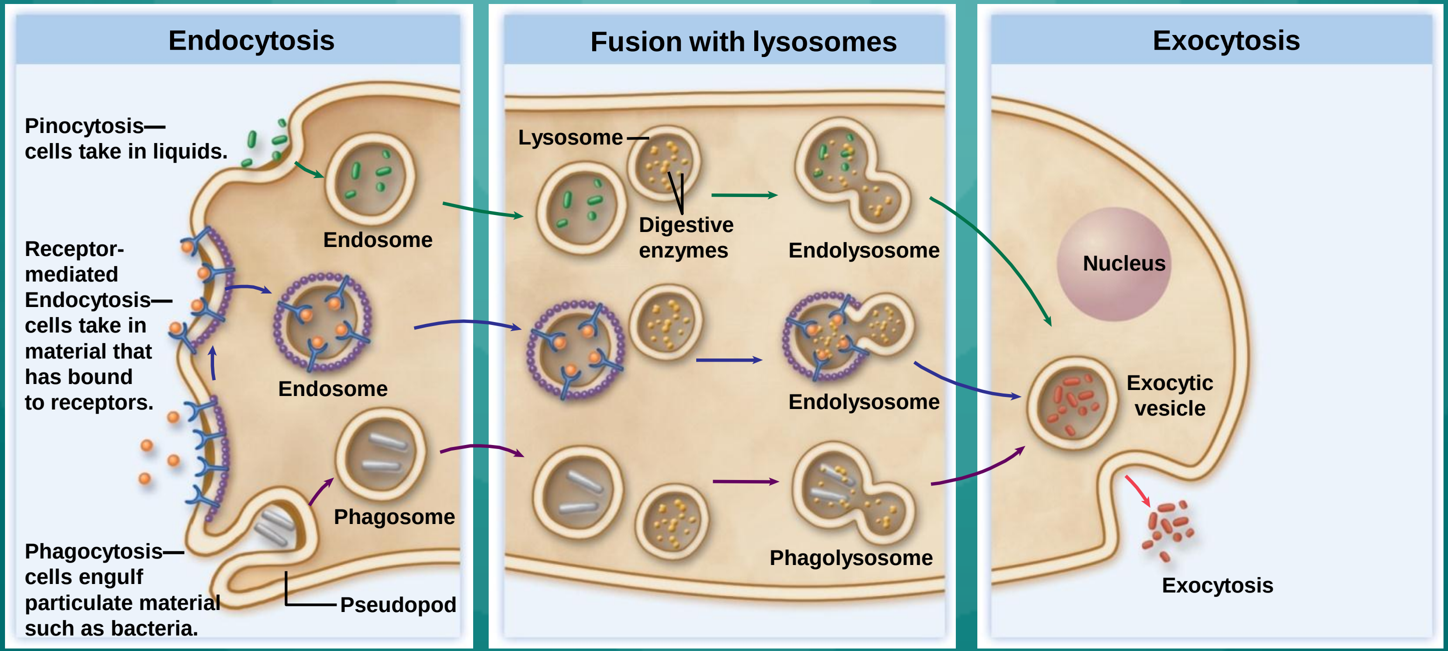
	Prokaryotic	Eukaryotic
General Characteristics		
Size	Generally 0.3–2 μm in diameter.	Generally 5–50 μm in diameter.
Cell division	Chromosome replication followed by binary fission.	Chromosome replication and mitosis followed by division.
Chromosome location	Located in the nucleoid, which is not membrane-bound.	Contained within the membrane-bound nucleus.
Structures		
Cell membrane	Relatively symmetric with respect to the lipid content of the bilayers.	Highly asymmetric; lipid composition of outer layer differs significantly from that of inner layer.
Cell wall	Composed of peptidoglycan (*Bacteria*); Gram-negative bacteria have an outer membrane as well.	Absent in animal cells; composition in other cell types may include chitin, glucans and mannans (fungi), and cellulose (plants).
Chromosome	Single, circular DNA molecule is typical.	Multiple, linear DNA molecules. DNA is wrapped around histones.
Flagella	Composed of protein subunits; attached to the cell envelope.	Made up of a 9 + 2 arrangement of microtubules; covered by an extension of the plasma membrane.
Membrane-bound organelles	Absent.	Present; includes the nucleus, mitochondria, chloroplasts (only in plant cells), endoplasmic reticulum, Golgi apparatus, lysosomes, and peroxisomes.
Nucleus	Absent; DNA resides as an irregular mass forming the nucleoid region.	Present.
Ribosomes	70S ribosomes, which are made up of 50S and 30S subunits.	80S ribosomes, which are made up of 60S and 40S subunits. Mitochondria and chloroplasts have 70S ribosomes.
Functions		
Degradation of extracellular substances	Enzymes are secreted that degrade macromolecules outside of the cell. The resulting small molecules are transported into the cell.	Macromolecules can be brought into the cell by endocytosis. Lysosomes carry digestive enzymes.
Motility	Generally involves flagella, which are composed of protein subunits. Flagella rotate like propellers.	Involves cilia and flagella, which are made up of a 9 + 2 arrangement of microtubules. Cilia move in synchrony; flagella propel a cell with a whiplike motion or thrash back and forth to pull a cell forward.
Protein secretion	Secretion systems transport proteins across the cytoplasmic membrane.	Secreted proteins are moved to the lumen of the rough endoplasmic reticulum as they are being synthesized. From there, they are transported to the Golgi apparatus for processing and packaging.
Strength and rigidity	Peptidoglycan-containing cell wall (*Bacteria*).	Cytoskeleton composed of microtubules, intermediate filaments, and microfilaments. Some have a cell wall; some have sterols in the membrane.
Transport	Primarily active transport. Group translocation.	Facilitated diffusion and active transport. Ion channels.

3.10. The Plasma Membrane

- Plasma membrane similar to prokaryotic cells
  - Phospholipid bilayer embedded with proteins
    - But: layer facing cytoplasm differs from that facing outside
  - Proteins in outer layer serve as receptors
    - Bind specific molecule termed ligand
    - Important in cell communication
  - Membranes of many eukaryotes contain sterols
    - Provide strength to otherwise fluid structure
      - Cholesterol in mammals, ergosterol in fungi
  - Lipid rafts: allow cell to detect, respond to signals
    - Many viruses use to enter, exit cells
  - Electrochemical gradient maintained via sodium or proton pumps
    - Membrane not involved in ATP synthesis
      - Mitochondria perform

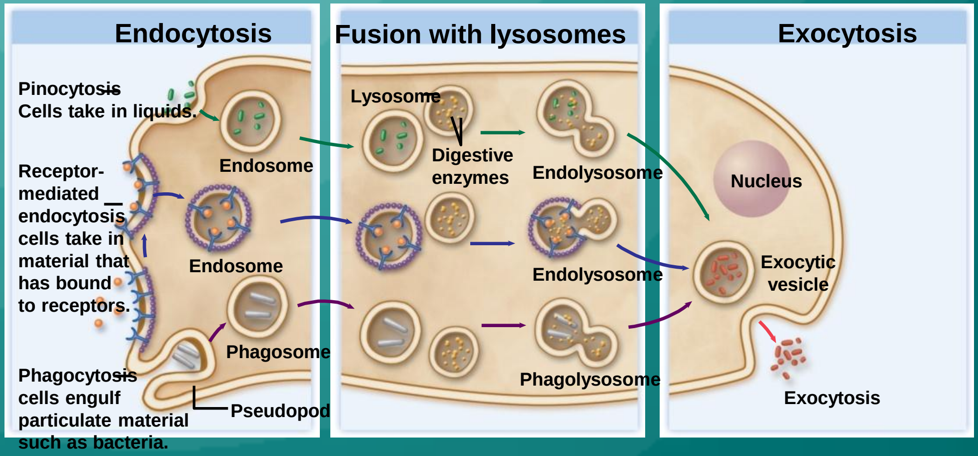
3.11. Transfer of Molecules Across Plasma Membrane

- Transport proteins similar to prokaryotes
  - Carriers: facilitated diffusion, active transport
  - Channels: form small gated pores, allow ions to diffuse
  - Aquaporins
- Endocytosis and exocytosis additional processes



3.11. Transfer of Molecules Across Plasma Membrane

- Endocytosis: take up materials via invaginations
  - Pinocytosis most common in animal cells
    - Forms endosome, which fuses to lysosomes
  - Receptor-mediated endocytosis is variation
    - Cell internalizes extracellular ligands binding to surface
  - Phagocytosis used by protozoa, phagocytes to engulf
    - Pseudopods surround, bring material into phagosome
    - Phagosome fuses with lysosome → phagolysosome
- Exocytosis
  - Reverse of endocytosis

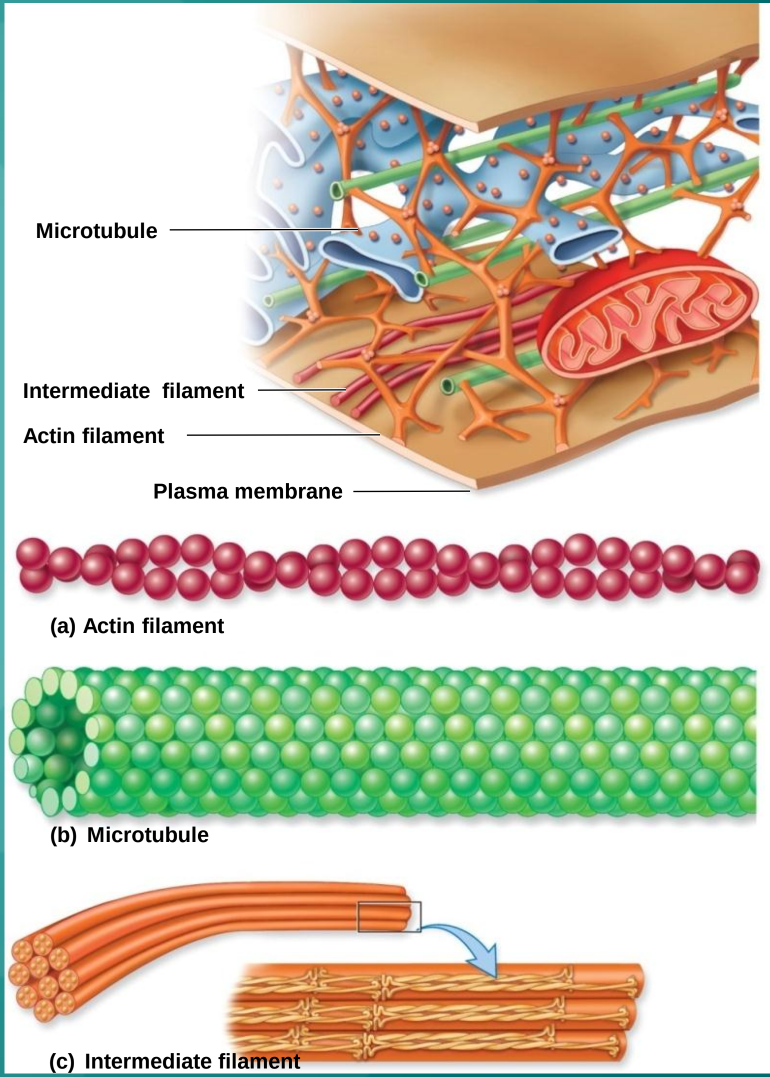


3.12. Protein Structures Within the Cell

- Ribosomes: protein synthesis
  - Eukaryotic is 80S, made from 60S plus 40S
    - Prokaryotic are 70S

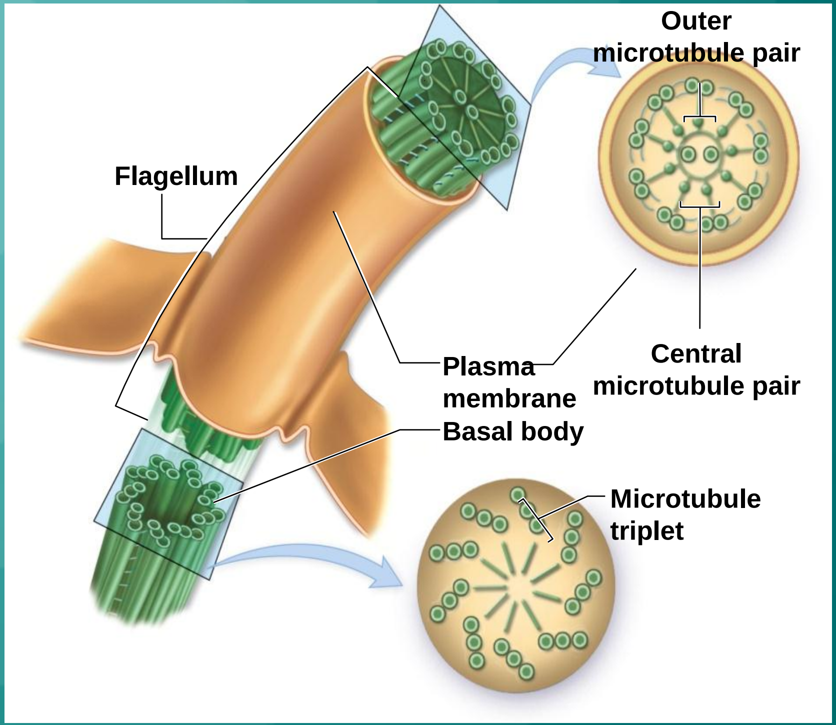
3.12. Protein Structures Within the Cell

- Cytoskeleton: cell framework
  - Actin filaments allow movement
    - Polymers of actin polymerize and depolymerize
  - Microtubules are thickest component
    - Long hollow structures made from tubulin
    - Make up mitotic spindles
    - Cilia, flagella
    - Framework for organelle and vesicle movement
  - Intermediate filaments provide mechanical support



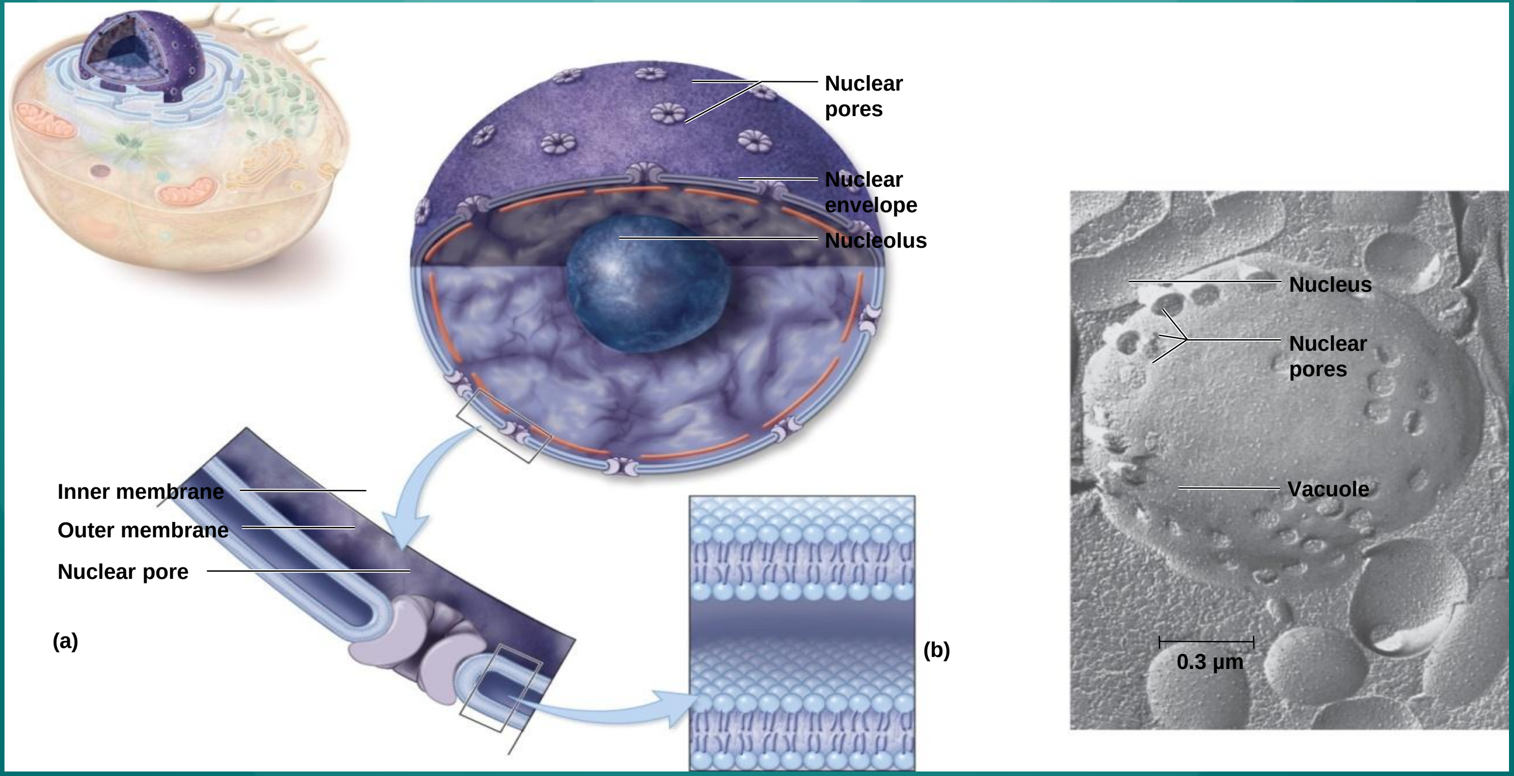
3.12. Protein Structures Within the Cell

- Flagella and cilia appear to project out of cell
  - Covered by extensions of plasma membrane
  - Comprised of microtubules in 9 + 2 arrangement
  - Flagella function in motility
    - Very different than prokaryotic flagella
    - Propel via whiplike motion or thrash back and forth to pull cell forward
  - Cilia are shorter, move synchronously
    - Can move cell forward or move material past stationary cell



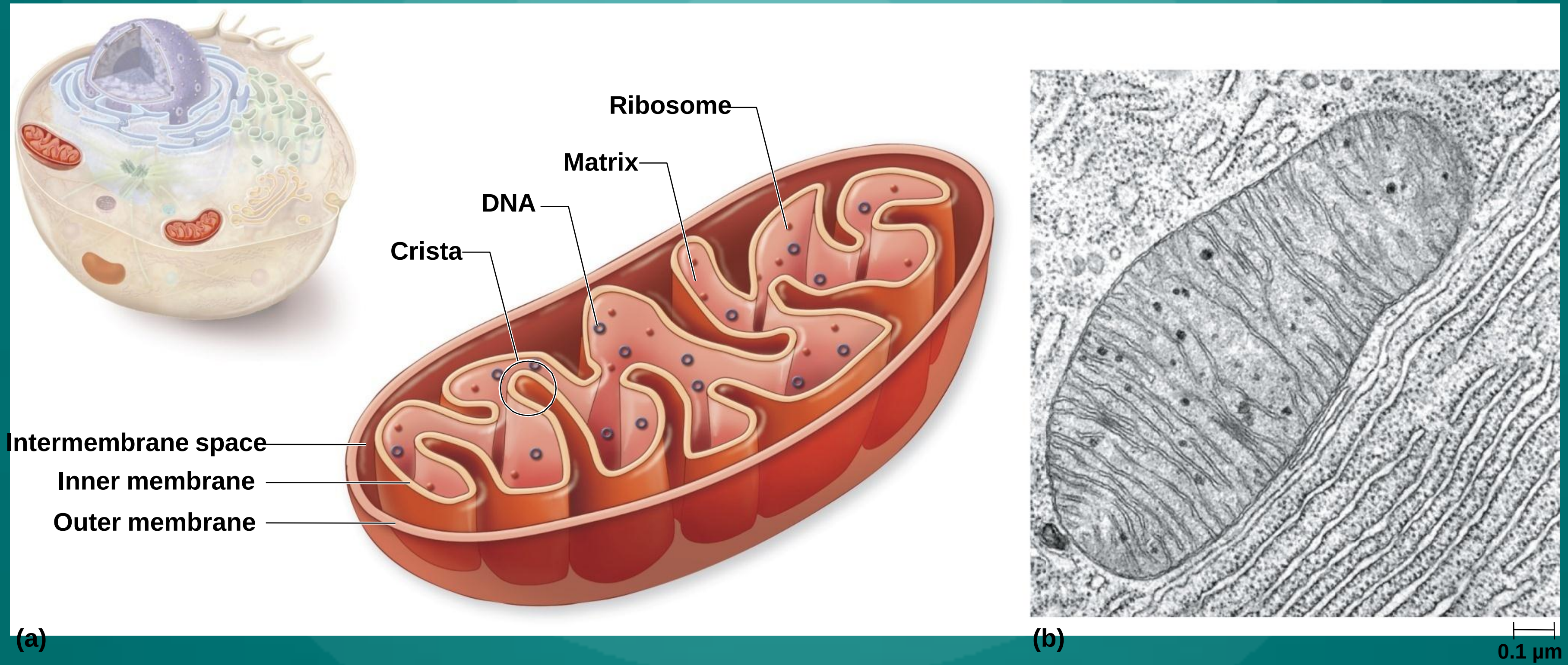
3.13. Membrane-Bound Organelles

- Nucleus contains DNA
  - Surrounded by two lipid bilayer membranes
  - Nuclear pores allow large molecules to pass
  - Nucleolus is region where ribosomal RNAs synthesized



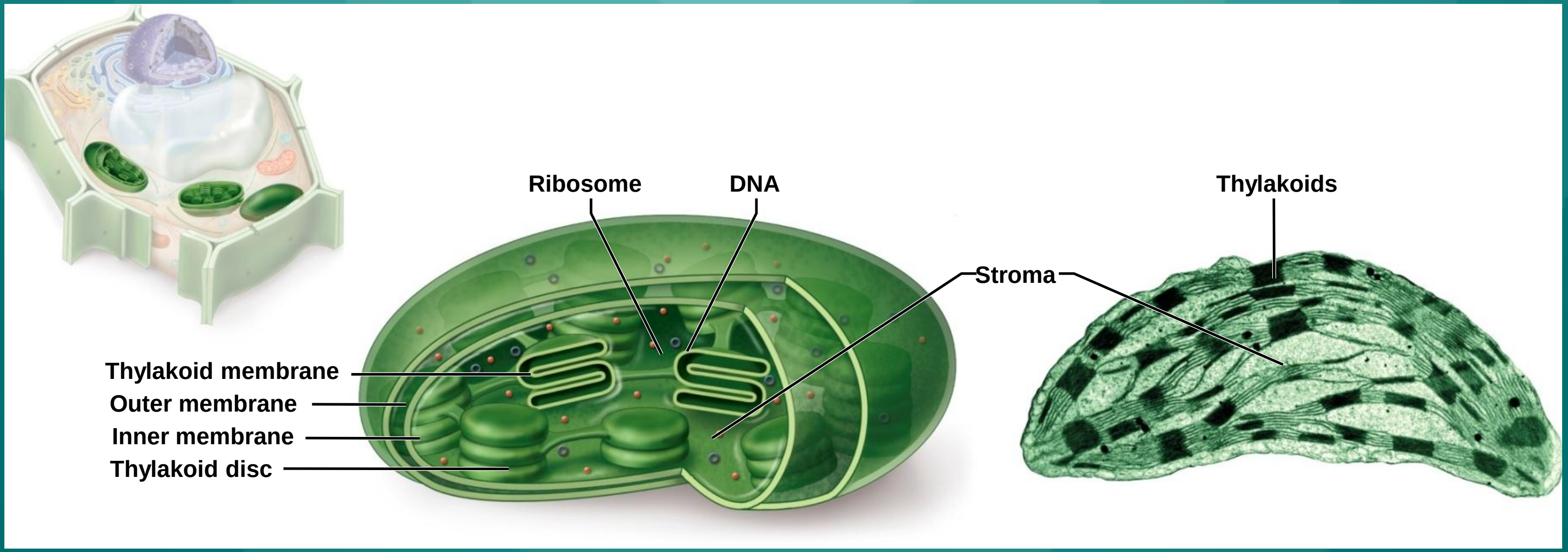
3.13. Membrane-Bound Organelles

- Mitochondria generate ATP
  - Bounded by two lipid bilayers
  - Mitochondrial matrix contains DNA, 70S ribosomes
    - <u>Endosymbiotic theory</u>: evolved from bacterial cells



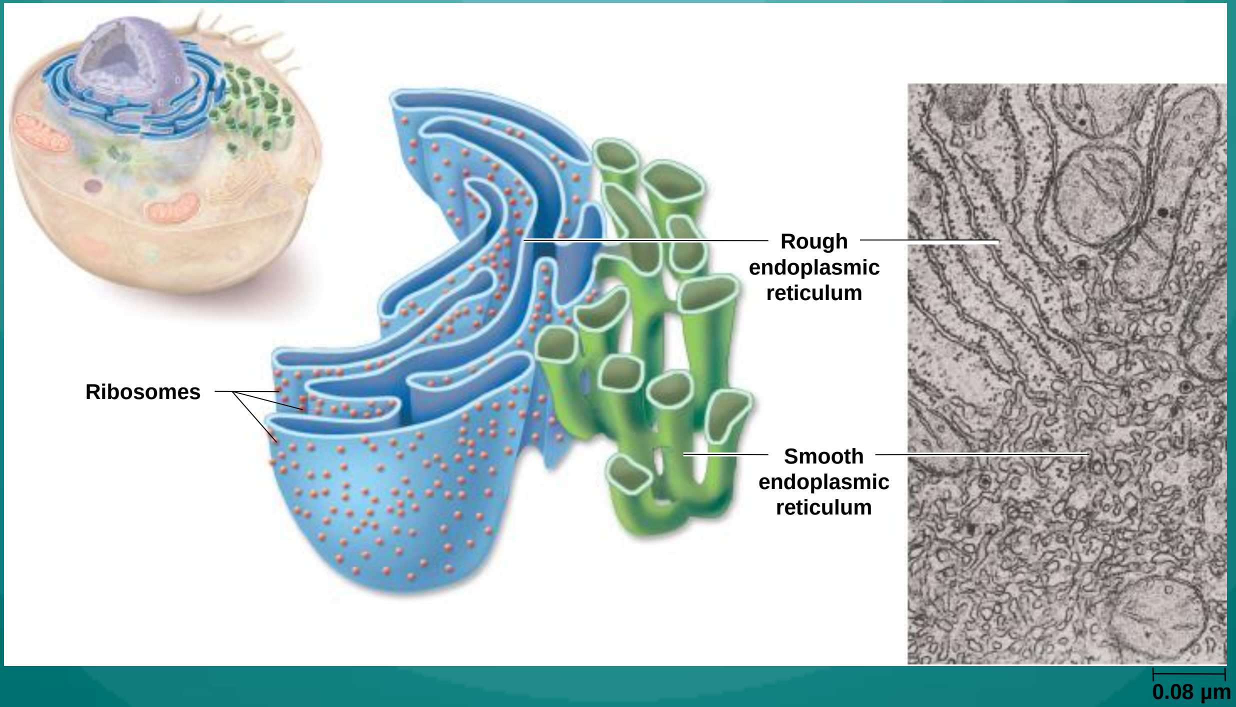
3.13. Membrane-Bound Organelles

- Chloroplasts are site of photosynthesis
  - Found only in plants, algae
  - Harvest sunlight to generate ATP
    - ATP used to convert CO_2 to sugar and starch
  - Contain DNA and 70S ribosomes, two lipid bilayers
    - Endosymbiotic theory: evolved from cyanobacteria



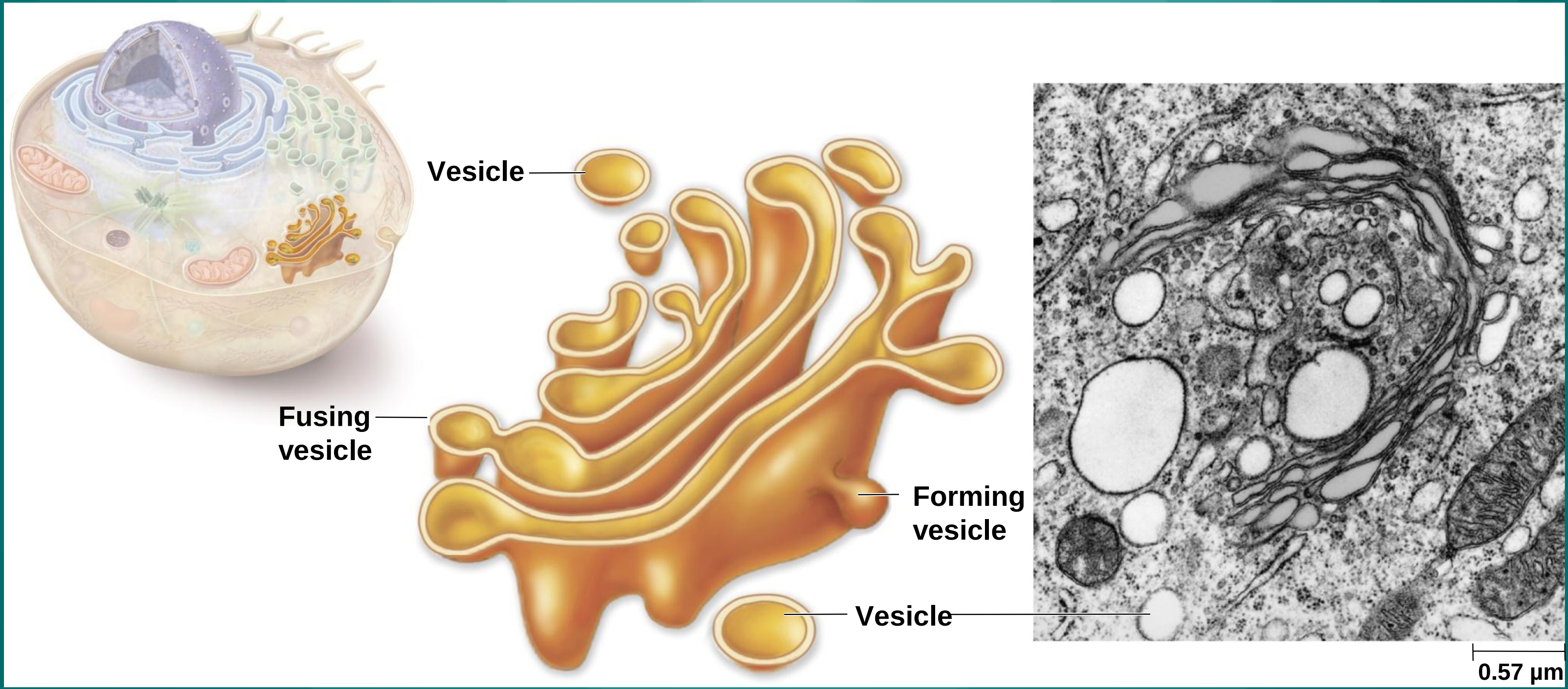
3.13. Membrane-Bound Organelles

- Endoplasmic reticulum (ER)
  - System of flattened sheets, sacs, tubes
  - Rough ER dotted with ribosomes
    - Synthesize proteins not destined for cytoplasm
  - Smooth ER: lipid synthesis and degradation



3.13. Membrane-Bound Organelles

- The Golgi Apparatus
  - Membrane-bound flattened compartments
  - Macromolecules synthesized in ER are modified
    - Addition of carbohydrate, phosphate groups



3.13. Membrane-Bound Organelles

- Lysosomes contain degradative enzymes
  - Could destroy cell if not contained
  - Endosomes, phagosomes fuse with lysosomes
    - Material taken up by cell is degraded
    - Similarly, old organelles, vesicles can fuse: autophagy
- Peroxisomes use O_2 to degrade lipids, detoxify chemicals
  - Enzymes generate hydrogen peroxide, superoxide
  - Peroxisome contains and ultimately degrades
    - Protects cell from toxic effects

The Origins of Mitochondria and Chloroplasts

- Endosymbiotic theory: ancestors of mitochondria and chloroplasts were bacteria
  - Resided in other cells in mutually beneficial partnership
  - Each partner became indispensable to the other
    - Endosymbiont lost key features (cell wall, replication)
- Several lines of evidence support
  - Mitochondria, chloroplasts carry DNA for some ribosomal proteins, ribosomal RNA for 70S ribosomes
    - Nuclear DNA encodes some parts
  - Double membrane surrounds both
    - Present-day endosymbionts similarly retain
  - Division is by binary fission
  - Mitochondrial DNA sequences comparable to obligate intracellular parasites: rickettsias