Chapter 3

Prokaryote Cell Function and Structure

An Overview of Procaryotic Cell Structure

- ✓ a wide variety of sizes, shapes, and cellular aggregation patterns
- ✓ simpler than eucaryotic cell structure
- ✓ unique structures not observed in eucaryotes

Size, Shape, and Arrangement

- ✓ cocci (coccus) – spheres
  - ✑diplococci (diplococcus) – pairs
  - ✑streptococci – chains
  - ✑staphylococci – grape-like clusters
  - ✑tetrads – 4 cocci in a square
  - ✑sarcinae – cubic configuration of 8 cocci

Cell shapes

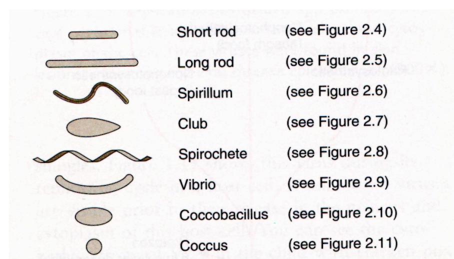
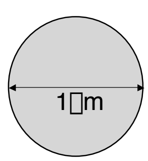


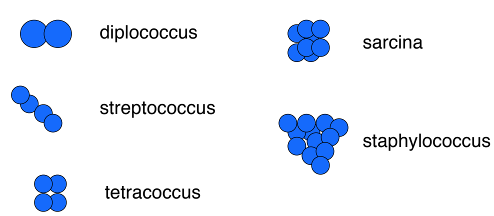
FIGURE 2.3 Cell shapes in bacteria. These drawings are intended for comparisons only and are not drawn to scale.

Cocci

One coccus, many cocci.



Arrangements of cocci

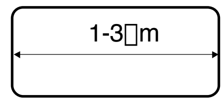


Size, Shape, and Arrangement

- ✓ bacilli (s., bacillus) – rods
  - coccobacilli – very short rods
  - vibrios – curved rods
- ✓ mycelium – network of long, multinucleate filaments

Bacilli

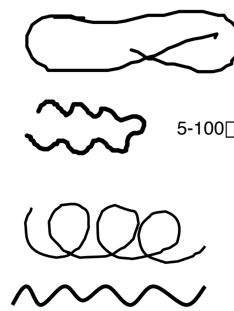
One bacillus, many bacilli.



Size, Shape, and Arrangement

- ✓ spirilla (spirillum) – rigid helices
- ✓ spirochetes – flexible helices
- ✓ pleomorphic – organisms that are variable in shape

Spirals



•largest – ~600 µm in •Length ~50 µm in diameter

• smallest – 0.3 µm in diameter

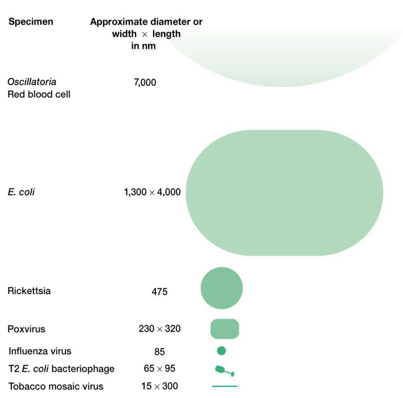
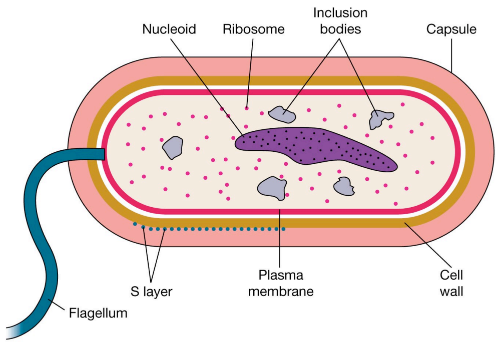
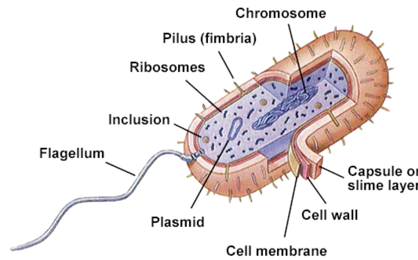


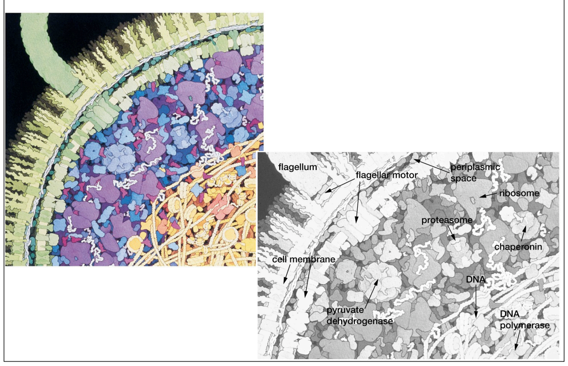
Table 3.1	Functions of Procaryotic Structures
Plasma membrane	Selectively permeable barrier, mechanical boundary of cell, nutrient and waste transport, location of many metabolic processes (respiration, photosynthesis), detection of environmental cues for chemotaxis
Gas vacuole	Buoyancy for floating in aquatic environments
Ribosomes	Protein synthesis
Inclusion bodies	Storage of carbon, phosphate, and other substances
Nucleoid	Localization of genetic material (DNA)
Periplasmic space	Contains hydrolytic enzymes and binding proteins for nutrient processing and uptake
Cell wall	Gives bacteria shape and protection from lysis in dilute solutions
Capsules and slime layers	Resistance to phagocytosis, adherence to surfaces
Fimbriae and pili	Attachment to surfaces, bacterial mating
Flagella	Movement
Endospore	Survival under harsh environmental conditions



Prokaryotic cell



Procaryotic Cell Organization



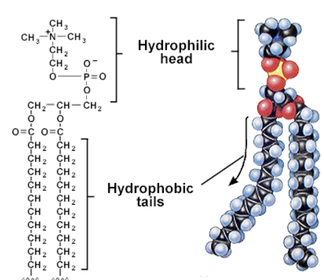
Prokaryotic Cell Membranes

- ✓ Outer layer/barrier of the cell
- ✓ plasma membrane encompasses the cytoplasm
- ✓ some procaryotes also have internal membrane systems

The Plasma Membrane

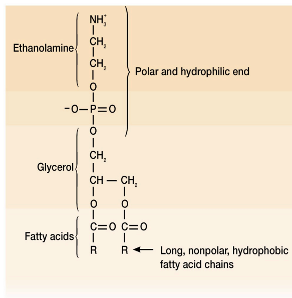
- ✓ contains lipids and proteins
  - ✒lipids usually form a bilayer
  - ✒proteins are embedded in or associated with lipids
- ✓ highly organized, asymmetric, flexible, and dynamic

Phospholipids



The asymmetry of most membrane lipids

- ✓ polar ends
  - interact with water
  - hydrophilic
- ✓ nonpolar ends
  - insoluble in water
  - hydrophobic



Other membrane lipids

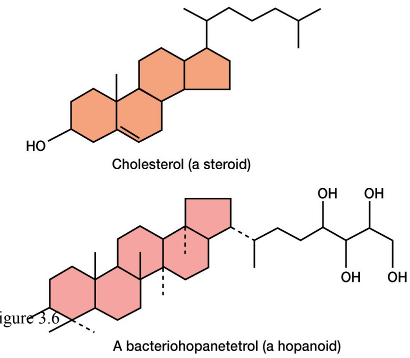
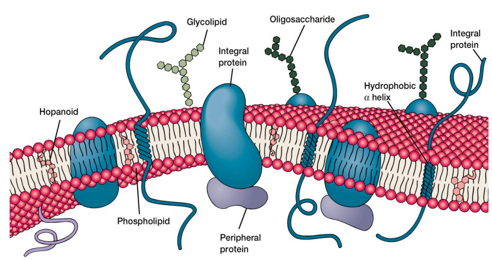


Figure 3.6

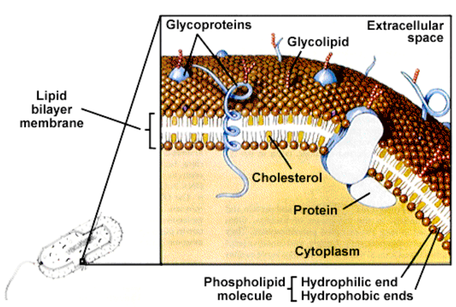
Membrane proteins

- ✓ peripheral proteins
  - loosely associated with the membrane and easily removed
- ✓ integral proteins
  - embedded within the membrane and not easily removed



Fluid mosaic model of membrane structure

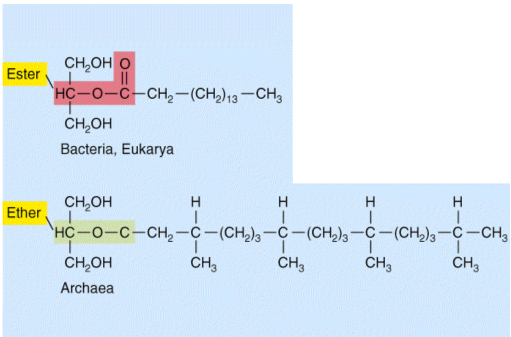
Fluid-mosaic model



Archaeal membranes

- ✓ composed of unique lipids
- ✓ some have a monolayer structure instead of a bilayer structure

Eubacteria vs Archaeabacteria



Membranes of archaeobacteria

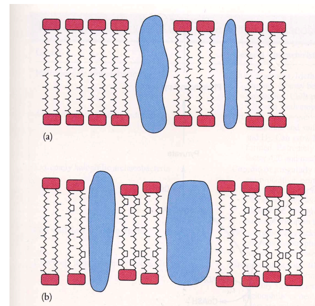


Figure 20.5 Examples of Archaeobacterial Membranes. (*a*) A membrane composed of integral proteins and a bilayer of C_{20} diethers. (*b*) A rigid monolayer composed of integral proteins and C_{40} tetraethers.

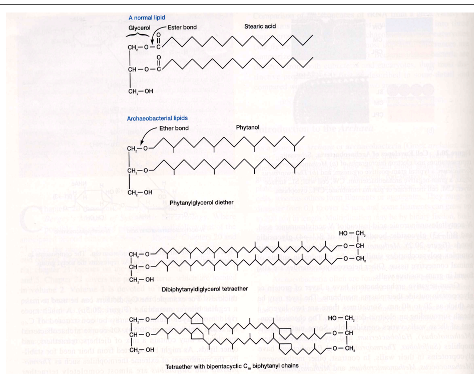


Figure 20.3 Archaeobacterial Membrane Lipids. An illustration of the difference between archaeobacterial lipids and those of other bacteria. Archaeobacterial lipids are derivatives of isopranyl glycerol ethers rather than the usual glycerol fatty acid esters. Three examples of common archaeobacterial glycerolipids are given.

Functions of the plasma membrane

- ✓ separation of cell from its environment
- ✓ selectively permeable barrier
  - ✑some molecules are allowed to pass into or out of the cell
  - ✑transport systems aid in movement of molecules
- ✓ location of crucial metabolic processes
- ✓ detection of and response to chemicals in surroundings with the aid of special receptor molecules in the membrane

Internal Membrane Systems

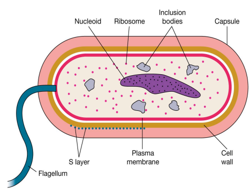
- ✓ mesosomes
  - ✑?may be invaginations of the plasma membrane (vesicles, tubules, lamellae)
    - ⇨possible roles
      - ✐cell wall formation during cell division
      - ✐chromosome replication and distribution
      - ✐secretory processes
  - ✑?may be artifacts of chemical fixation process

Other internal membrane systems

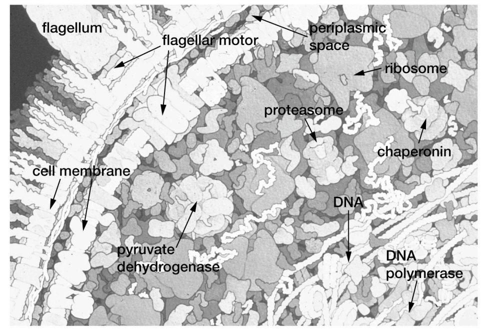
- ✓ complex infoldings of the plasma membrane
  - ✑observed in many photosynthetic bacteria and in prokaryotes with high respiratory activity
  - ✑may be aggregates of spherical vesicles, flattened vesicles, or tubular membranes
  - ✑Provide surface area

The Cytoplasmic Matrix

- ✓ substance between membrane and nucleoid
- ✓ packed with ribosomes and inclusion bodies
- ✓ No cytoskeleton
- ✓ However, it is highly organized with respect to protein location
- ✓ Protoplast



Cell matrix organization



Inclusion Bodies

- ✓ granules of organic or inorganic material that are stockpiled by the cell for future use
- ✓ Some not bound by a membrane/protein
- ✓ some are enclosed by a single-layered membrane
  - ✑membranes vary in composition
  - ✑some made of proteins; others contain lipids

Organic inclusion bodies

- ✓ glycogen
  - ✑polymer of glucose units
- ✓ poly-ß-hydroxybutyrate (PHB)
  - ✑polymers of ß-hydroxybutyrate

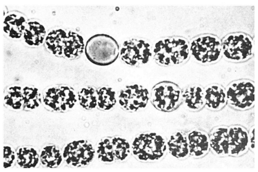
Organic inclusion bodies (cyanobacteria)

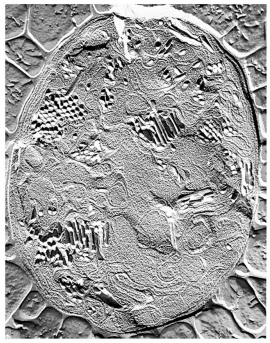
- ✓ cyanophycin granules (cyanobacteria)
  - ✑large polypeptides containing about equal quantities of arginine and aspartic acid
- ✓ Carboxysomes (cyanobacteria and others)
  - ✑contain the enzyme ribulose-1,5,-bisphosphate carboxylase

Organic inclusion bodies

- ✓ gas vacuoles
  - ✑found in cyanobacteria and some other aquatic procaryotes
  - ✑provide buoyancy
  - ✑aggregates of hollow cylindrical structures called gas vesicles

Gas vacuoles

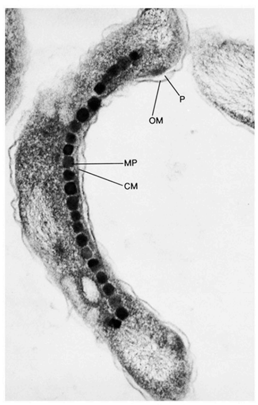




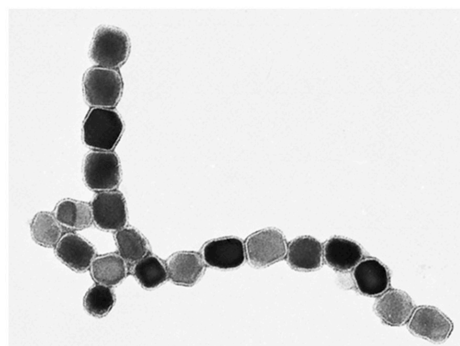
Inorganic inclusion bodies

✓ polyphosphate granules
  - ✒also called volutin granules and metachromatic granules
  - ✒linear polymers of orthophosphates (PO_4^{3-})
  - ✒aka metachromatic granules
✓ sulfur granules
✓ magnetosomes
  - ✒contain iron in the form of magnetite
  - ✒used to orient cells in magnetic fields

Magnetosome of *Aquaspirillum magnetotacticum*



Chain of cells with isolated magnetosomes



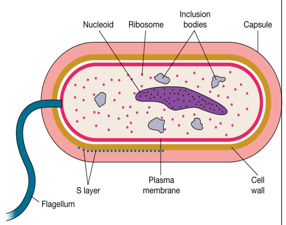
Waves of bacteria oriented to a magnetic field

Ribosomes

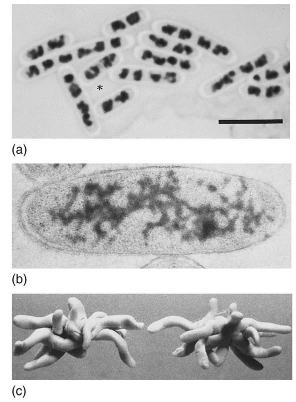
✓ complex structures consisting of protein and RNA
✓ sites of protein synthesis
✓ smaller than eucaryotic ribosomes
  - ✒Prokaryotic ribosome ➠ 70S
  - ✒Eukaroyotic ribosomes ➠ 80S
  - ✒S = Svedburg unit

The Nucleoid

- ✓ irregularly shaped region
- ✓ location of chromosome
  - ✒usually 1/cell
- ✓ not membrane-bound
- ✓ Plasmids may be present



In actively growing cells, the nucleoid has projections; these probably contain DNA being actively transcribed



The procaryotic chromosome

- ✓ a closed circular, double-stranded DNA molecule
- ✓ looped and coiled extensively
- ✓ nucleoid proteins probably aid in folding
  - ✒nucleoid proteins differ from histones
  - ✒Topoisomerases?

Unusual nucleoids

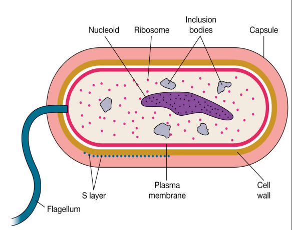
- ✓ some procaryotes have > 1 chromosome
  - ✒*Vibrio cholerae*
- ✓ some procaryotes have chromosomes composed of linear double-stranded DNA
  - ✒Borrelia burgdorferi (Lyme disease)
- ✓ a few genera have membrane bound nucleoids
  - ✒*Pirellula* (one membrane)
  - ✒*Gemmata scuriglobus* (two membranes)

Plasmids

- ✓ usually small, closed circular DNA molecules
- ✓ exist and replicate independently of chromosome
- ✓ not required for growth and reproduction
- ✓ may carry genes that confer selective advantage (e.g., drug resistance)

The Procaryotic Cell Wall

- ✓ rigid structure that lies just outside the plasma membrane
- ✓ Eubacteria it is composed of peptidoglycan
- ✓ Archaeobacteria it is protein, glycoproteins, or polysaccharides



Functions of cell wall

✓provides characteristic shape to cell
✓protects the cell from osmotic lysis
✓may also contribute to pathogenicity
✓may also protect cell from toxic substances

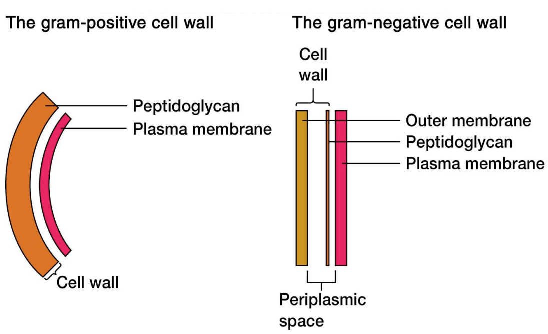
✓Exceptions are mycoplasmas and some Archae

Cell walls of Bacteria

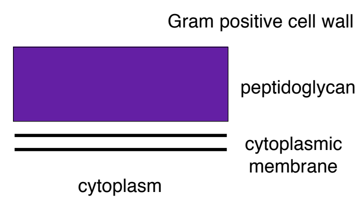
✓Bacteria are divided into two major groups based on the response to Gram-stain procedure.
- Gram (+) stain purple
- Gram (-) stain pink/red

✓Stain due to cell wall structure

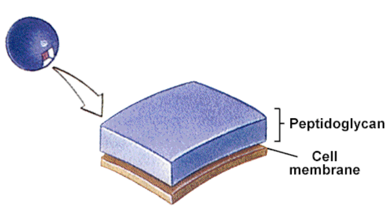
Cell wall



Gram positive



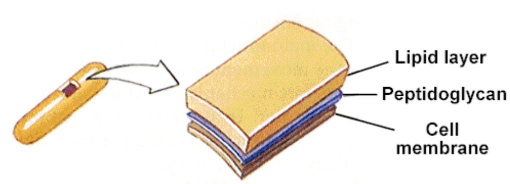
Gram (+)



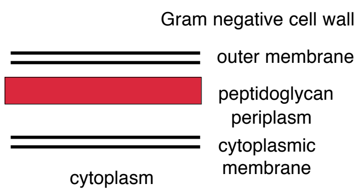
Acid fast bacteria

Acid fast bacteria are Gram + bacteria with a lipid layer of mycolic acid on the outside.

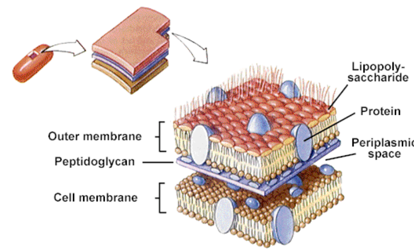
Carbolfuchsin gets into the cytoplasm and resists decoloration by the acid alcohol



Gram negative



Gram (-)



Periplasmic space

- ✓ gap between plasma membrane and cell wall (gram-positive bacteria) or between plasma membrane and outer membrane (gram-negative bacteria)
- ✓ periplasm
  - substance that occupies periplasmic space

Periplasmic enzymes

- ✓ found in periplasm of gram-negative bacteria
- ✓ some of their functions
  - nutrient acquisition
  - electron transport
  - peptidoglycan synthesis
  - modification of toxic compounds

Exoenzymes

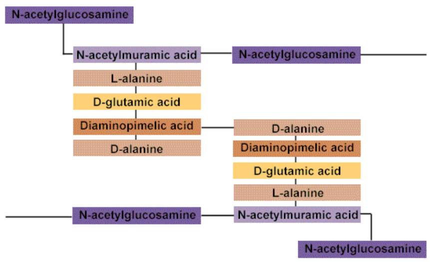
- ✓ secreted by gram-positive bacteria
- ✓ perform many of the same functions that periplasmic enzymes do for gram-negative bacteria

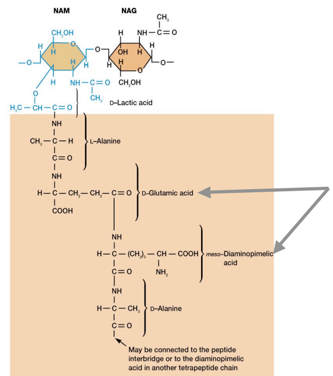
Peptidoglycan

peptidoglycan contains cross-linked modified sugar subunits:

N-acetylglucosamine (NAG)
N-acetylmuramic acid (NAM)

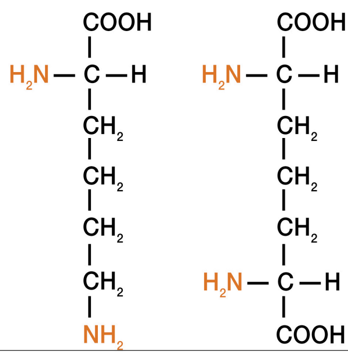
Gram (-) peptidoglycan

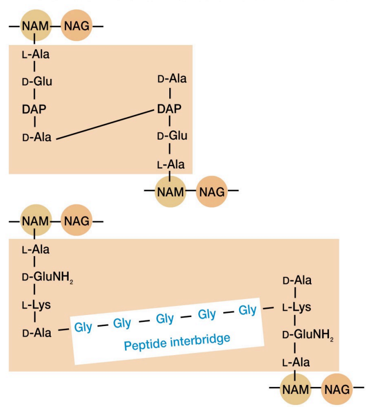




Unique amino acids are not observed in proteins

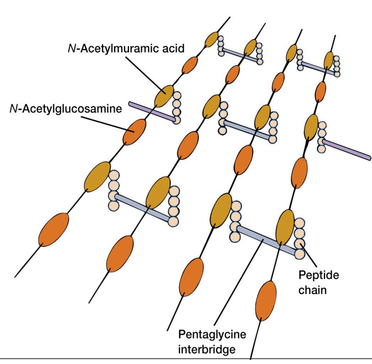
meso-Diaminopemelic acid





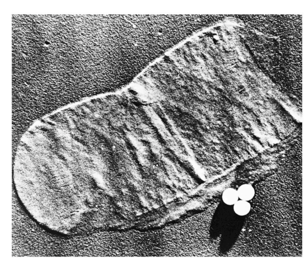
Cross linking of peptidoglycan in *E. coli* and *Staphylococcus aureus*

Peptidoglycan structure

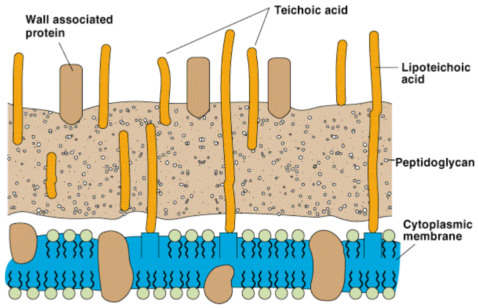


Gram-Positive Cell Walls

- ✓ Isolated G+ cell wall
  - ✑Maintains shape
  - ✑Porous
  - ✑Elastic
- ✓ also contain large amounts of teichoic acids

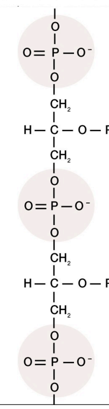


Gram (+) cell wall

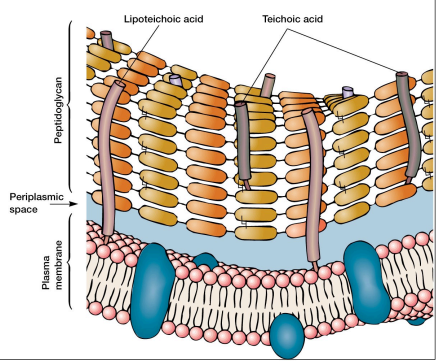


Teichoic acids

• polymers of glycerol or ribitol joined by phosphate groups



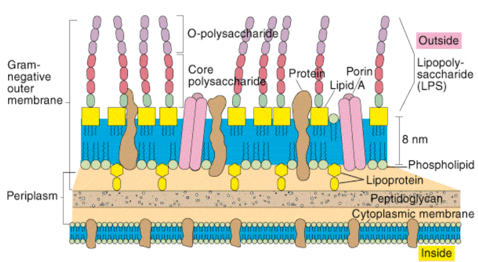
Gram +



Gram-Negative Cell Walls

✓ consist of a thin layer of peptidoglycan surrounded by an outer membrane
✓ outer membrane composed of lipids, lipoproteins, and lipopolysaccharide (LPS)
✓ no teichoic acids

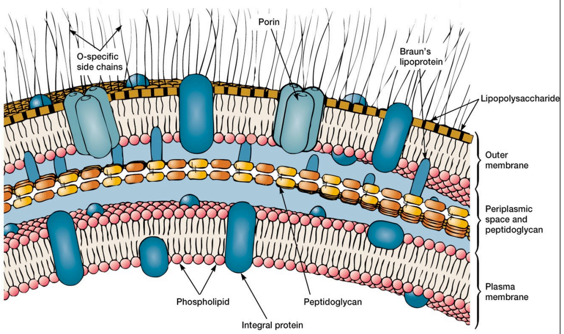
Gram (-) cell wall



Important connections

✓ Braun's lipoproteins connect outer membrane to peptidoglycan
✓ Adhesion sites
- sites of direct contact (possibly true membrane fusions) between plasma membrane and outer membrane
- substances may move directly into cell through adhesion sites

Gram -

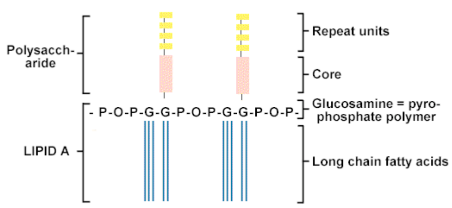


Lipopolysaccharides (LPSs)

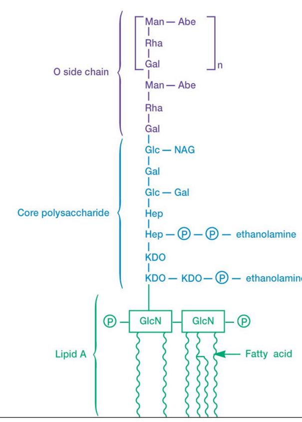
✓consist of three parts

- ✑lipid A
- ✑core polysaccharide
- ✑O side chain (O antigen)

Lipopolysaccharide (endotoxin)



LPS structure from *Salmonella*



Importance of LPS

✓protection from host defenses (O antigen)

✓contributes to negative charge on cell surface (core polysaccharide)

✓helps stabilize outer membrane structure (lipid A)

✓can act as an endotoxin (lipid A)

Other characteristics of outer membrane

✓more permeable than plasma membrane due to presence of porin proteins and transporter proteins

- ✑porin proteins form channels through which small molecules (600-700 daltons) can pass
- ✑Blocks bile salts, antibiotics, & other toxins

The Mechanism of Gram Staining

✓thought to involve constriction of the thick peptidoglycan layer of gram-positive cells
- ✑constriction prevents loss of crystal violet during decolorization step

✓thinner peptidoglycan layer of gram-negative bacteria does not prevent loss of crystal violet

The Cell Wall and Osmotic Protection

✓osmosis
- ✑movement of water across selectively permeable membrane from dilute solutions to more concentrated solutions

✓cells are often in hypotonic solutions

$[\text{solute}]_{\text{outside cell}} < [\text{solute}]_{\text{inside cell}}$

The Cell Wall and Osmotic Protection

✓osmotic lysis
- ✑can occur when cells are in hypotonic solutions
- ✑movement of water into cell causes swelling and lysis due to osmotic pressure

✓cell wall protects against osmotic lysis

Cell walls do not protect against plasmolysis

✓plasmolysis
- ✑occurs when cells are in hypertonic solutions

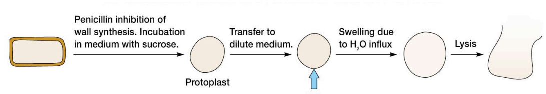
  $[\text{solute}]_{\text{outside cell}} > [\text{solute}]_{\text{inside cell}}$
- ✑water moves out of cell causing cytoplasm to shrivel and pull away from cell wall

Practical importance of plasmolysis and osmotic lysis

✓plasmolysis
- ✑useful in food preservation
- ✑e.g., dried foods and jellies

✓osmotic lysis
- ✑basis of lysozyme and penicillin action

Action of penicillin or lysozyme



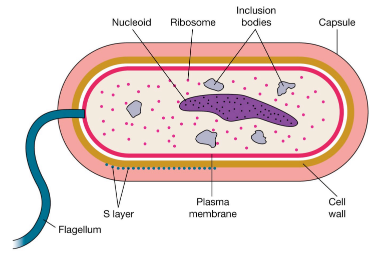
•protoplast – cell completely lacking cell wall (Gram +)

•spheroplast – cell with outer membrane (some cell wall) remaining (Gram -)
•Mycoplasmas- no cell wall

Archaeal cell walls

- ✓ lack peptidoglycan
- ✓ can be composed of proteins, glycoproteins, or polysaccharides

Components External to Cell Wall



Capsules, Slime Layers, and S-Layers

- ✓ layers of material lying outside the cell wall
  - capsules
    - usually composed of polysaccharides
    - well organized and not easily removed from cell
  - slime layers
    - similar to capsules except diffuse, unorganized and easily removed

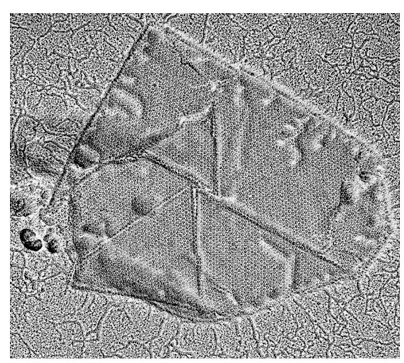
Capsules, Slime Layers, and S-Layers

- ✓ glycocalyx
  - network of polysaccharides extending from the surface of the cell
  - a capsule or slime layer composed of polysaccharides can also be referred to as a glycocalyx

Capsules, Slime Layers, and S-Layers

- ✓ S-layers
  - regularly structured layers of protein or glycoprotein (floor tiles)
  - common among Archaea, where they may be the only structure outside the plasma membrane

S-layer in Deinococcus radiolarans



Functions of capsules, slime layers, and S-layers

- ✓ protection from host defenses (e.g., phagocytosis)
- ✓ protection from harsh environmental conditions (e.g., desiccation)
- ✓ attachment to surfaces

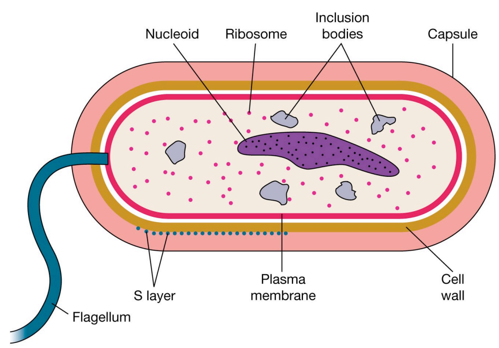
More functions…

- ✓ protection from viral infection or predation by bacteria
- ✓ protection from chemicals in environment (e.g., detergents)
- ✓ motility of gliding bacteria
- ✓ protection against osmotic stress

Pili and Fimbriae

- ✓ fimbriae (s., fimbria)
  - ✒short, thin, hairlike, proteinaceous appendages
    - ⇨up to 1,000/cell
  - ✒mediate attachment to surfaces
- ✓ sex pili (s., pilus)
  - ✒similar to fimbriae except longer, thicker, and less numerous (1-10/cell)
  - ✒required for mating

Flagella and Motility



Patterns of arrangement

- ✓ monotrichous – one flagellum
- ✓ polar flagellum – flagellum at end of cell
- ✓ amphitrichous – one flagellum at each end of cell
- ✓ lophotrichous – cluster of flagella at one or both ends
- ✓ peritrichous – spread over entire surface of cell

Monotrichous

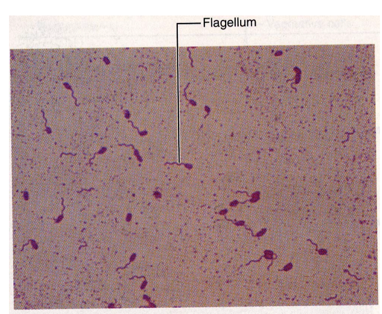


FIGURE 3.33 Monotrichous flagellation in *Pseudomonas aeruginosa* (3600×).

Amphitrichous

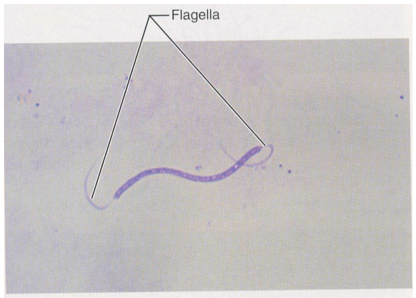


FIGURE 3.34 Amphitrichous flagella of *Spirillum volutans* (3600×).

Lophotrichous

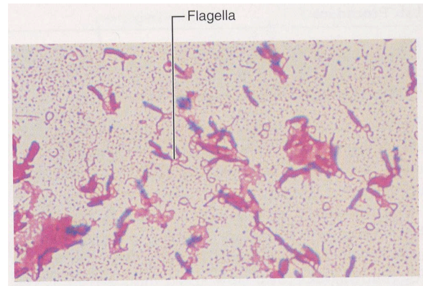


FIGURE 3.35 Lophotrichous flagella of *Pseudomonas marginalis* (3600×).

Peritrichous

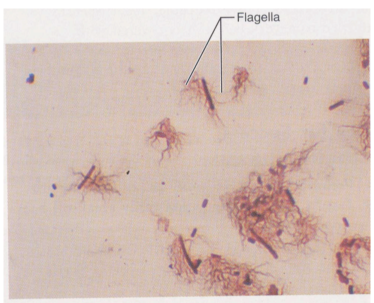
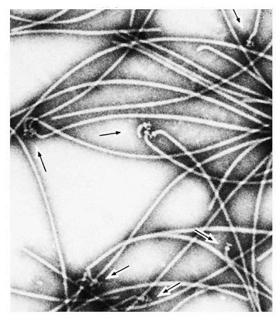
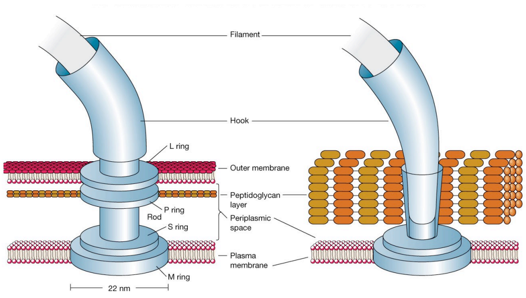


FIGURE 3.36 Peritrichous flagella of *Proteus vulgaris* (3600×).

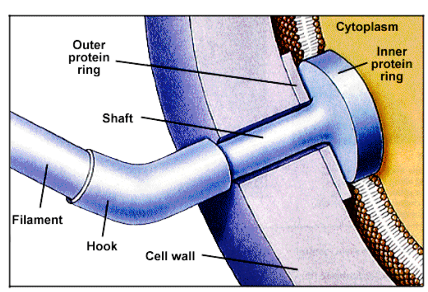
Flagellar Ultrastructure

✓ 3 parts
- filament
- basal body
- hook

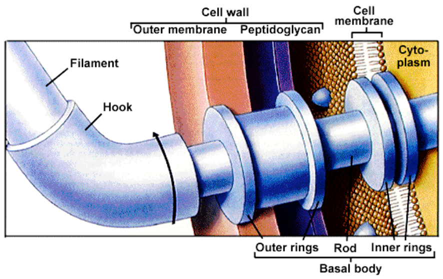




Flagellum in Gram (+)



Flagellum in Gram (-)

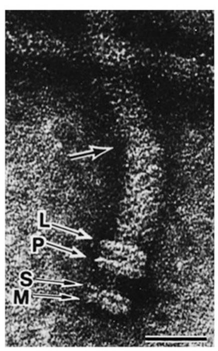


The filament

✓ hollow, rigid cylinder
✓ composed of the protein flagellin
✓ some procaryotes have a sheath around filament

The hook and basal body

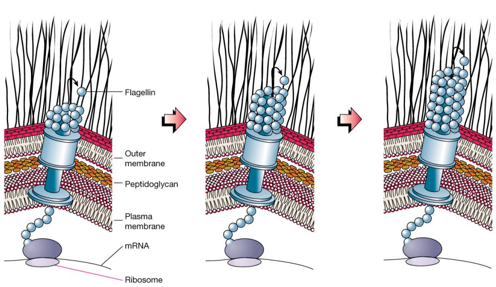
✓ hook
  ✒ links filament to basal body
✓ basal body
  ✒ series of rings that drive flagellar motor



Flagellar Synthesis

✓ an example of self-assembly
✓ complex process involving many genes and gene products
✓ new molecules of flagellin are transported through the hollow filament
✓ growth is from tip, not base

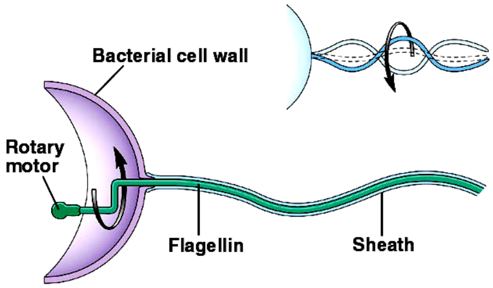
Flagellum synthesis



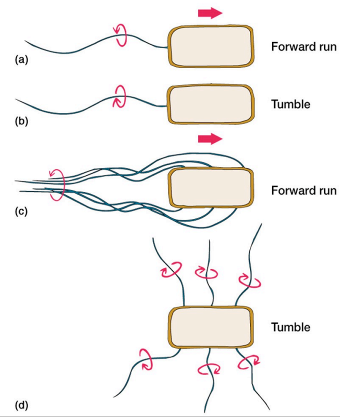
The Mechanism of Flagellar Movement

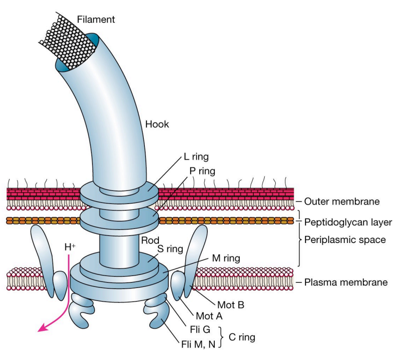
✓ flagellum rotates like a propeller
  ✒ in general, counterclockwise rotation causes forward motion (run)
  ✒ in general, clockwise rotation disrupts run causing a tumble (twiddle)

Bacterial Movement — Rotating Flagellum



Run vs. tumble





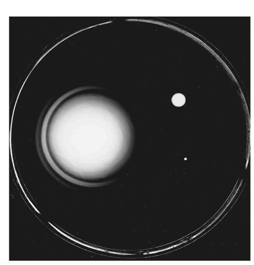
Other types of motility

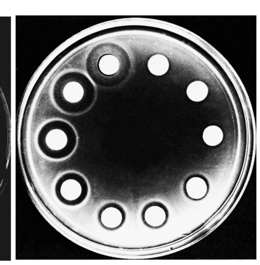
- ✓ spirochetes
  - ✑axial filaments cause flexing and spinning movement
- ✓ gliding motility
  - ✑cells coast along solid surfaces
  - ✑no visible motility structure has been identified

Chemotaxis

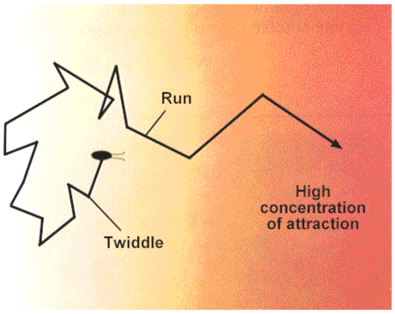
- ✓ movement towards a chemical attractant or away from a chemical repellant
- ✓ concentrations of chemoattractants and chemorepellants detected by chemoreceptors on surfaces of cells

Positive and negative Chemotaxis


Serine and aspartate

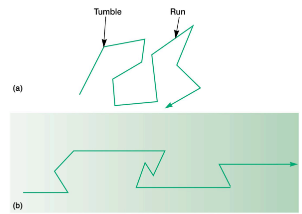

Acetate concentrations

Chemotaxis



Travel towards attractant

- ✓ caused by lowering the frequency of tumbles
- ✓ biased random walk



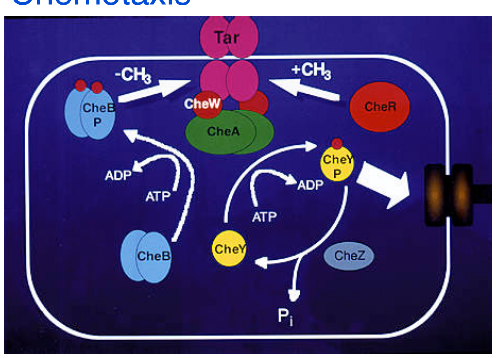
Travel away from repellant

- ✓ involves similar but opposite responses

Mechanism of chemotaxis

- ✓ complex but rapid
  - ✑responses occur in less than 20 milliseconds
- ✓ involves conformational changes in proteins
- ✓ also involves methylation or phosphorylation of proteins

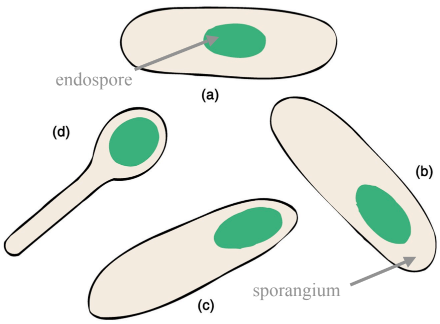
Chemotaxis



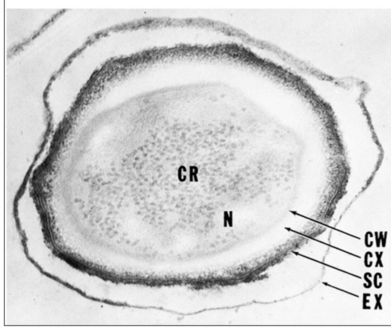
The Bacterial Endospore

- ✓ formed by some bacteria
  - ✑*Bacillus*, *Clostridium*, *Sporosarcina*, etc.
- ✓ dormant
- ✓ resistant to numerous environmental conditions
  - ✑heat
  - ✑radiation
  - ✑chemicals
  - ✑desiccation

Spore position helps identify the Genus



Endospore structure

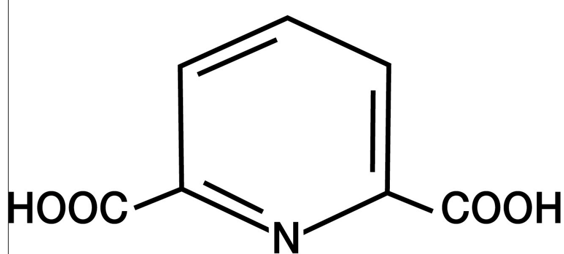


EX= exoporium
thin covering
SC= spore coat
protein layers
CX= cortex
peptidoglycan
CW= core wall
dpiconlinic
acid with Ca^{2+}
CR= core
ribosomes, N,
and enzymes
N= nucleoid

What makes an endospore so resistant?

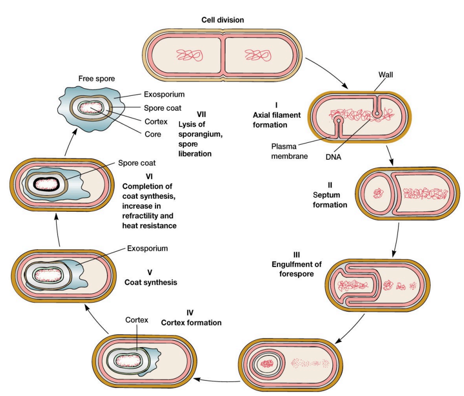
- ✓ calcium (complexed with dipicolinic acid) - heat resistance
- ✓ acid-soluble, DNA-binding proteins
- ✓ dehydrated core
- ✓ spore coat
- ✓ DNA repair enzymes

Dipicolinic acid



Sporogenesis/Sporulation

- ✓ normally commences when growth ceases because of lack of nutrients
- ✓ complex multistage process



Germination

- ✓ trans-formation of endospore into active vegetative cell
- ✓ complex, multistage process