#Microbiology

Prescott's MICROBIOLOGY

ELEVENTH EDITION

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Chapter 3

Bacterial Cell Structure

Shape, Arrangement, and Size

Shape.

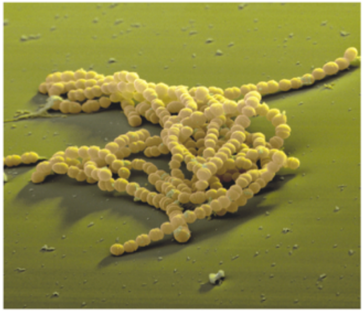
- Cocci and rods most common.
- Various others.

Arrangement.

- Determined by plane of division.
- Determined by separation or not.

Size—varies.

Cocci Shape and Arrangement



(a) *S. agalactiae*—cocci in chains

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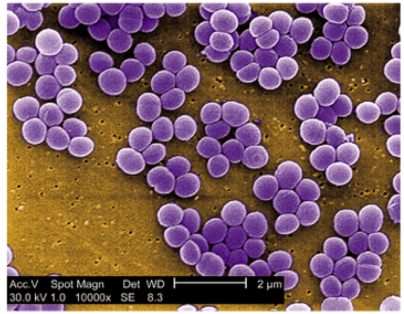

(b) *S. aureus*—cocci in clusters

Source: CDC/Janice Haney Carr

(c) *L. pneumophila*—rods in chains

Source: CDC/Janice Haney Carr

Cocci (s., coccus)—spheres.

- √ diplococci (s., diplococcus)—pairs.
- √ streptococci—chains.
- √ staphylococci—grape-like clusters.
- √ tetrads—4 cocci in a square.
- √ sarcinae—cubic configuration of 8 cocci.

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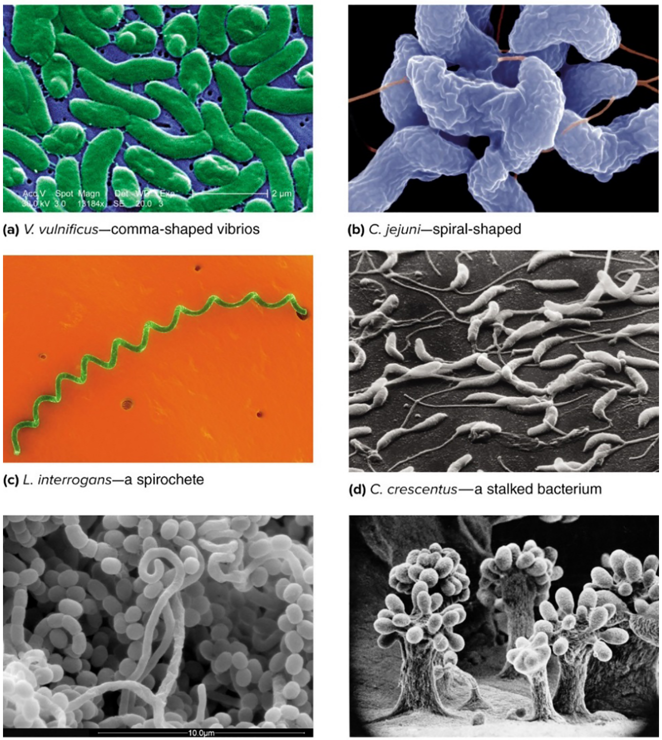
Other Shapes and Aggregations



(a) *V. vulnificus*—comma-shaped vibrios

(b) *C. jejuni*—spiral-shaped

(c) *L. interrogans*—a spirochete

(d) *C. crescentus*—a stalked bacterium

(e) *Streptomyces*—a filamentous bacterium

(f) *C. crocatus* fruiting body

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- Bacilli (s., bacillus)—rods.
- Coccobacilli—very short rods.
- Vibrios—resemble rods, comma shaped.
- Spirilla (s., spirillum)—rigid helices.
- Spirochetes—flexible helices.
- Mycelium—network of long, multinucleate filaments.
- Pleomorphic—organisms that are variable in shape.

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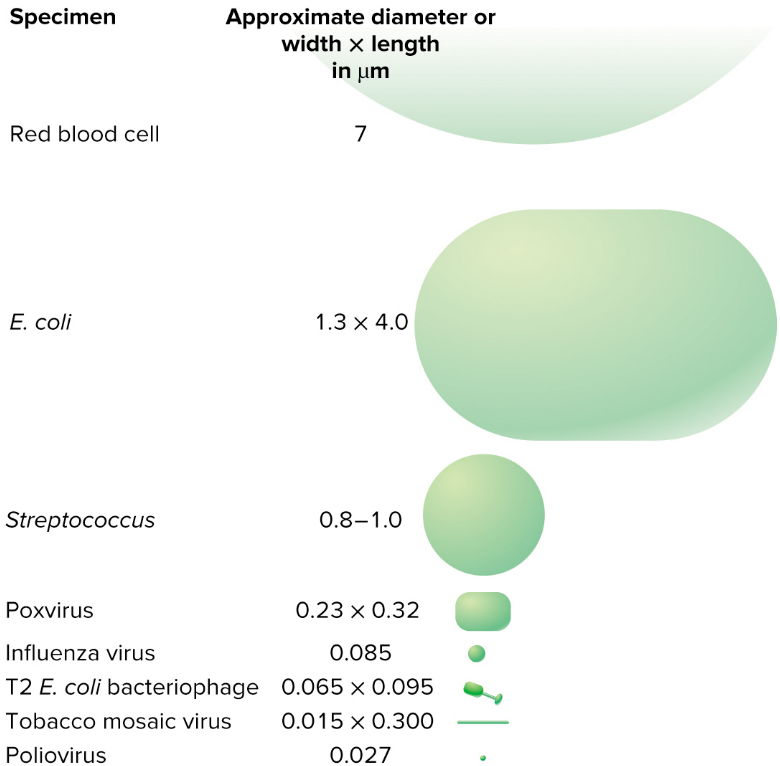
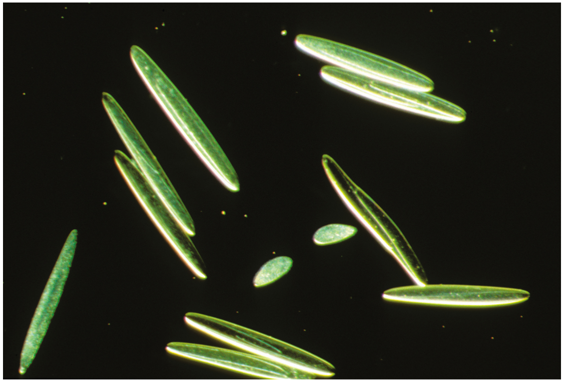
Size



Smallest—0.3 µm (*Mycoplasma*).

Average rod—1.1 to 1.5 by 2 to 6 µm (*E. coli*).

Very large—600 by 80 µm (*Epulopiscium fishelsoni*).



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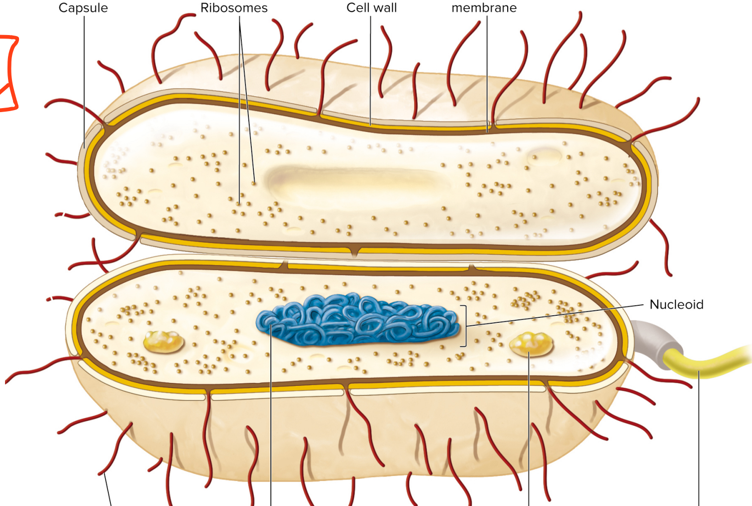
Bacterial Cell Organization–Common Features

Cell envelope—3 layers.

Cytoplasm.

External structures.



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Common Bacterial Structures and Their Functions

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	An inclusion that provides buoyancy for floating in aquatic environments
Ribosomes	Protein synthesis
Inclusions	Storage of carbon, phosphate, and other substances; site of chemical reactions (microcompartments); movement
Nucleoid	Localization of genetic material (DNA)
Periplasmic space	In typical Gram-negative bacteria, contains hydrolytic enzymes and binding proteins for nutrient processing and uptake; in typical Gram-positive bacteria, may be smaller or absent
Cell wall	Protection from osmotic stress, helps maintain cell shape
Capsules and slime layers	Resistance to phagocytosis, adherence to surfaces
Fimbriae and pili	Attachment to surfaces, bacterial conjugation and transformation, twitching
Flagella	Swimming and swarming motility
Endospore	Survival under harsh environmental conditions

Bacterial Cell Envelope

① Plasma membrane.

② Cell wall.

③ Layers outside the cell wall.

- ⓐ Capsule.
- ⓑ Slime layer.

↳ S layer may be Present. ✓

Plasma Membrane Functions

Encompasses the cytoplasm; absolute requirement for all living organisms.

Selectively permeable barrier.

Interacts with external environment.

- Receptors for detection of and response to chemicals in surroundings.
- Transport systems.
- Metabolic processes.

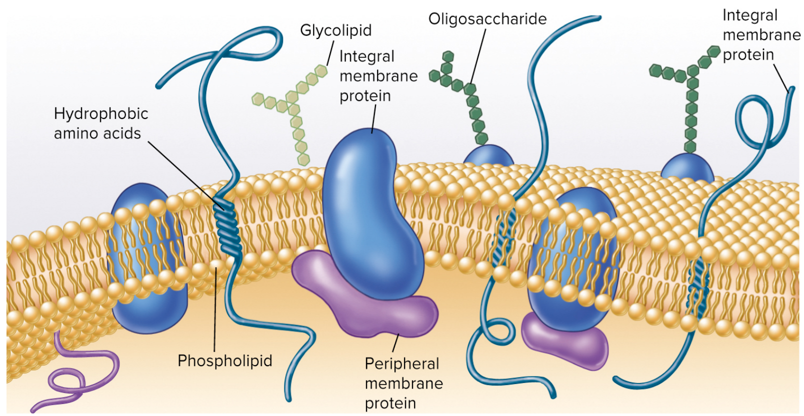
Membranes Are Lipid Bilayers With Floating Proteins

Amphipathic lipids.

- Polar ends (hydrophilic—interact with water).
- Non-polar tails (hydrophobic—insoluble in water).

Membrane proteins.

- Peripheral—Loosely connected to membrane; easily removed.
- Integral—Amphipathic (embedded within membrane); carry out important functions.



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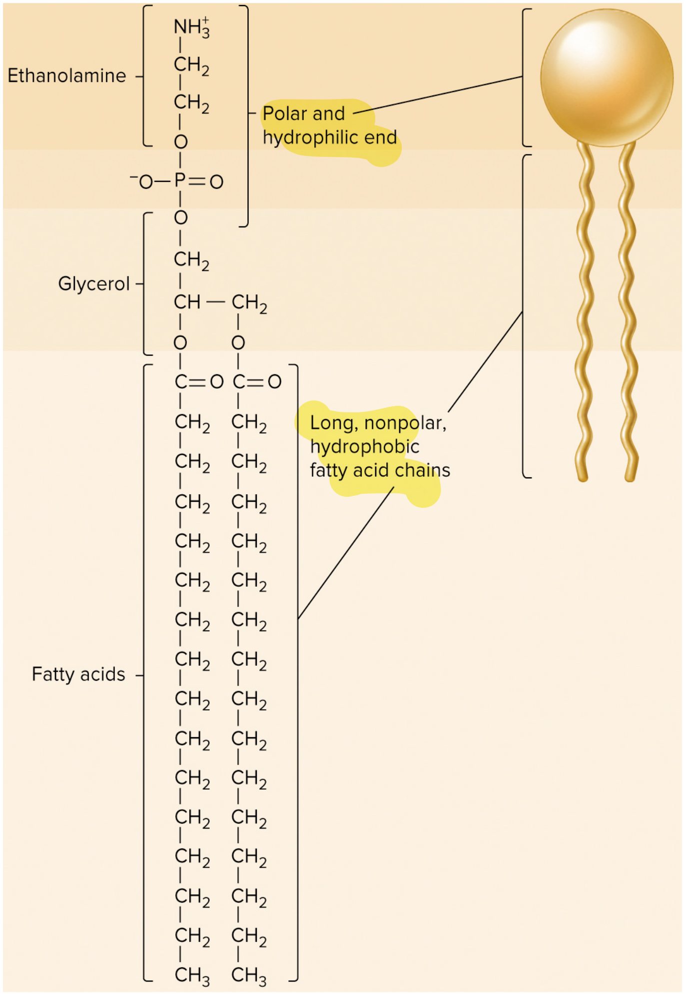
Structure of a Phospholipid



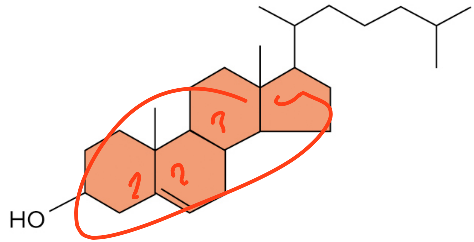
Bacterial Lipids

Saturation levels of membrane lipids reflect environmental conditions such as temperature.

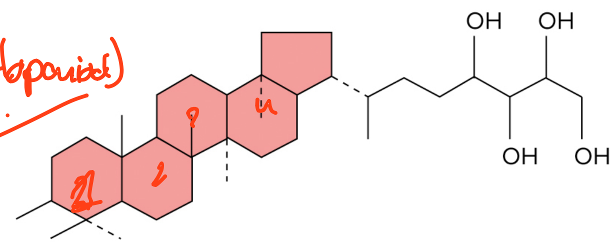
Bacterial membranes lack sterols but do contain sterol-like molecules, hopanoids. (No Sterols/Steroids => (Hopanoids)

- Stabilize membrane.
- Mark microdomain boundaries.

Areas that are Responsible for Cellular Signals. → Regions with ↑ Microdomains => High levels of Hopanoids



(a) Cholesterol (a steroid) is found in the membranes of eukaryotes.



(b) Bacteriohopanetetrol (a hopanoid) is found in many bacterial membranes.

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Nutrients

Macroelements (macronutrients)—required in relatively large amounts.

- C, O, H, N, S, and P—found in organic molecules (proteins, lipids, carbohydrates, and nucleic acids).
- K, Ca, Mg, and Fe—cations; serve in variety of roles including assisting enzymes and biosynthesis.

Micronutrients (trace elements)—required in trace amounts.

small amounts

- Mn, Zn, Co, Mo, Ni, and Cu.
- Often supplied in water/media components; ubiquitous
- Work to assist enzymes (cofactors).

Some unique substances may be required.

Growth Factors

cannot be synthesised by the cell

Organic compounds.

Essential cell components (or their precursors) that the cell cannot synthesize.

Must be supplied by environment if cell is to survive and reproduce.

Classes include:

- Amino acids—needed for protein synthesis.
- Purines and pyrimidines—needed for nucleic acid synthesis.
- Vitamins—function as enzyme cofactors.

assisting enzyme

Methods for Uptake of Nutrients

Microbes can only take in dissolved particles across a selectively permeable membrane.

Some nutrients enter by passive diffusion.

Microorganisms use transport mechanisms.

- Passive diffusion.
- Facilitated diffusion.
- Primary and secondary active transport.
- Group translocation.

↑Conc. → ↓Conc

Passive Diffusion

Not energy dependent

Molecules move from region of higher concentration to one of lower concentration between the cell’s interior and the exterior.

H_2O, O_2, and CO_2 often move across membranes this way.

Facilitated Diffusion

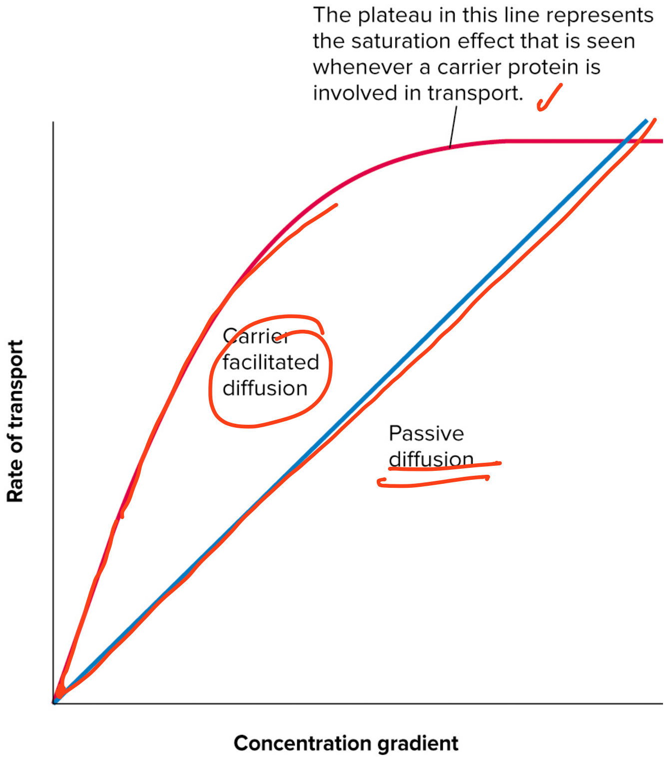
Similar to passive diffusion.

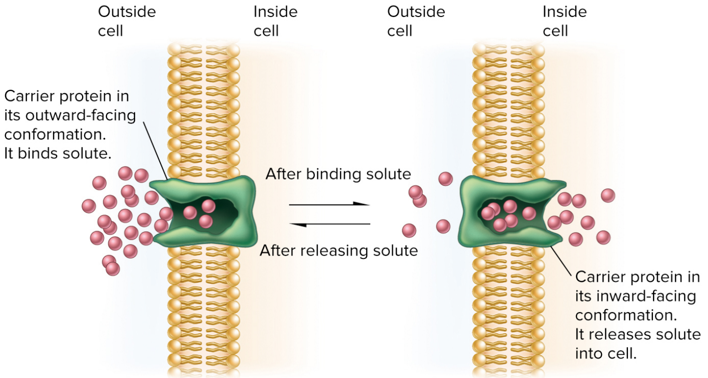
- Movement of molecules is not energy dependent.
- Direction of movement is from high concentration to low concentration.
- Size of concentration gradient impacts rate of uptake.

Differs from passive diffusion.

- Uses membrane bound carrier molecules (permeases).
- Rate increases with the concentration gradient.
- Effectively transports glycerol, sugars, and amino acids.

Facilitated versus Passive Diffusion





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③ Active Transport

Energy-dependent process.

- ✓ATP or proton motive force used.

Move molecules against the gradient.

Concentrates molecules inside cell.

Involves carrier proteins (permeases).

- Carrier saturation effect is observed at high solute concentrations.

Carrier Protien at High Saturation → High Solute concentration.

Primary Active Trasporters,

ABC Transporters

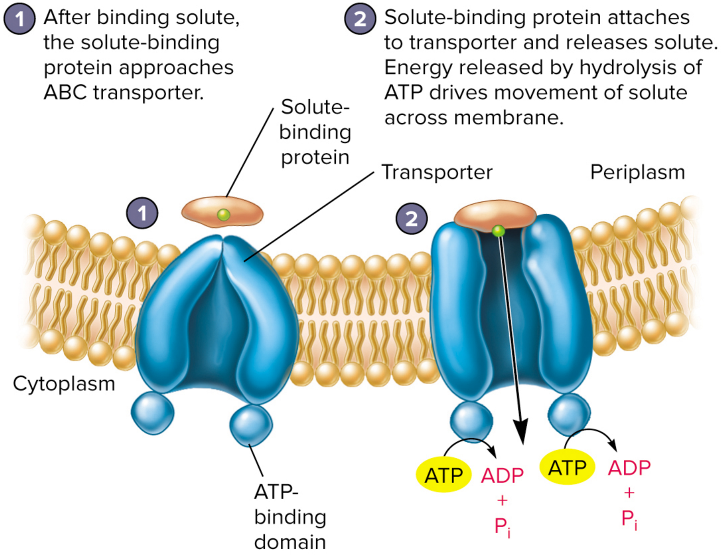
Primary active transporters use ATP.

ATP-binding cassette (ABC) transporters.

Observed in *Bacteria*, *Archaea*, and eukaryotes

Consist of:

- 2 hydrophobic membrane spanning domains.
- 2 cytoplasmic associated ATP-binding domains.
- Substrate binding domains.



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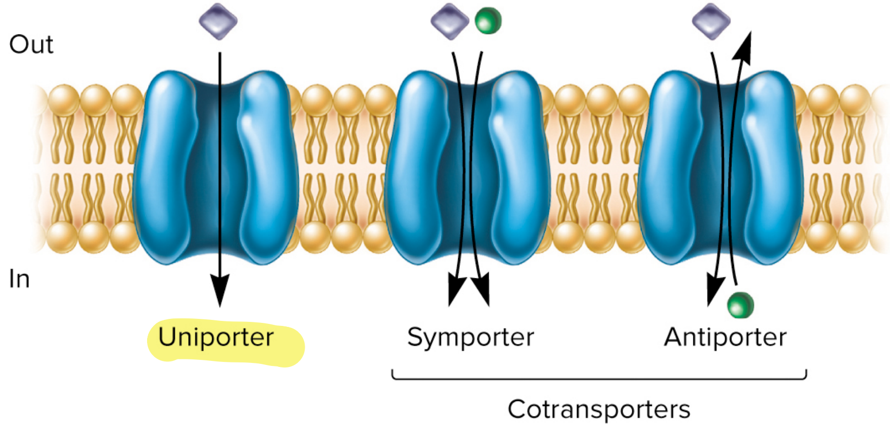
Secondary Active Transport

Use ion gradients to cotransport substances.

- Protons.
- Symport—two substances both move in the same direction.
- Antiport—two substances move in opposite directions.



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Require more than 1 enzyme.

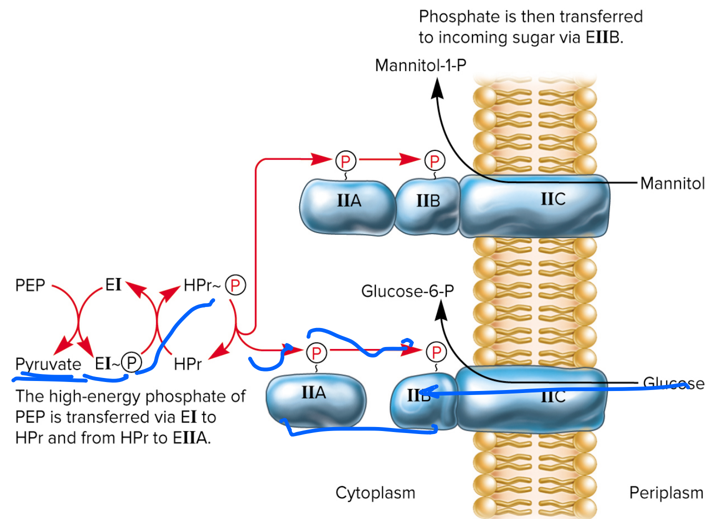
For the phosphate group with the use of an enzyme.

Group Translocation

If we need glucose to get in we need to modify it.

Energy dependent transport that chemically modifies molecule as it is brought into cell.

Best known translocation system is phosphoenolpyruvate: sugar phosphotransferase system (PTS).



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Iron Uptake

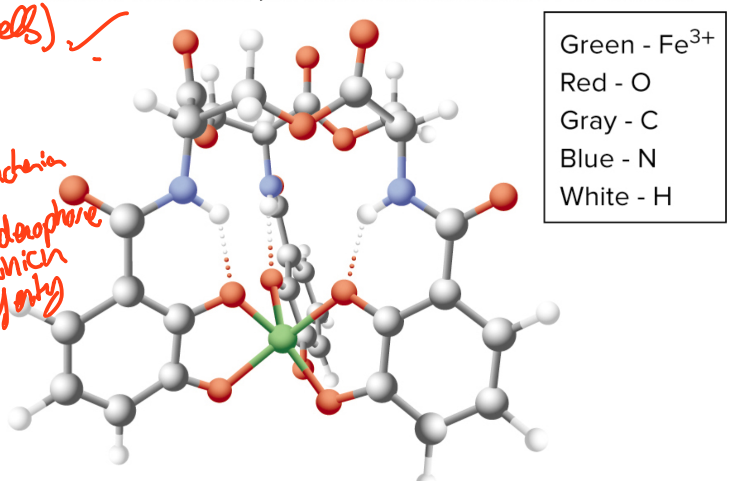
Microorganisms require iron.

- Ferric iron is very insoluble so uptake is difficult.

Microorganisms secrete siderophores to aid uptake.

- Siderophore complexes with ferric ion.

Complex is then transported into cell.



3.4 There Are Two Main Types of Bacterial Cell Walls

a. Describe peptidoglycan structure.

b. Compare and contrast the cell walls of typical Gram-positive and Gram-negative bacteria.

c. Relate bacterial cell wall structure to the Gram-staining reaction.

Bacterial Cell Wall

Cell wall functions.

- Maintains shape of the bacterium.
- Helps protect cell from osmotic lysis and toxic materials.
- May contribute to pathogenicity.

Peptidoglycan (murein). → Cell wall of microorganism is made from Peptidoglycan.

- Rigid structure lying just outside the cell plasma membrane.

Two types of bacteria based on Gram stain.

- Gram-positive: stain purple; thick peptidoglycan.
- Gram-negative: stain pink or red; thin peptidoglycan and outer membrane.

Peptidoglycan Structure

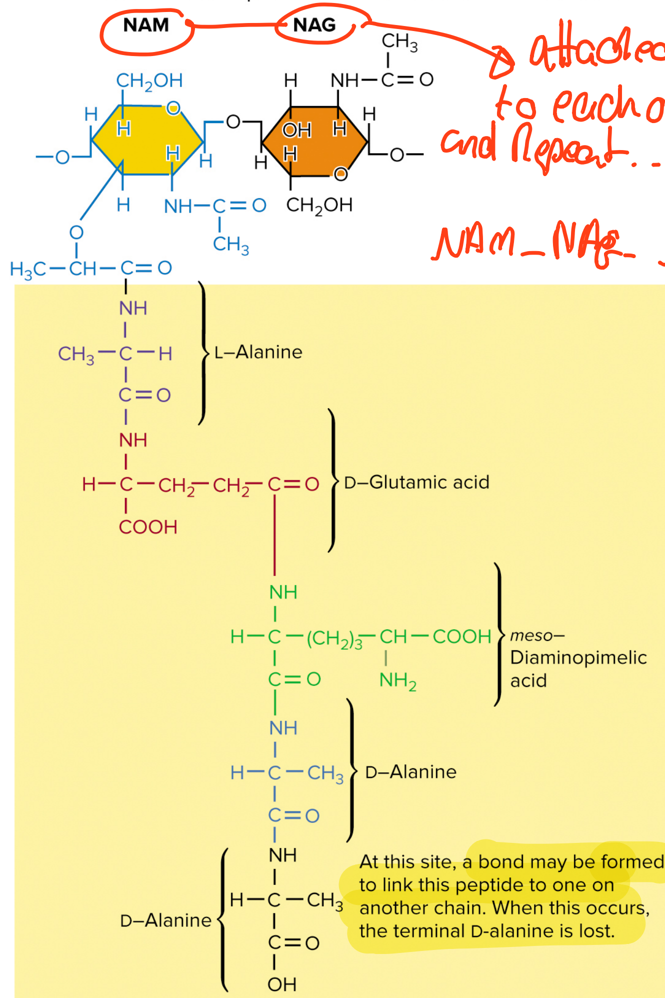
Meshlike polymer of identical subunits forming long strands.

Two alternating sugars.

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

Alternating D- and L- amino acids.

Regulating enzymes that synthesis and modify



attached to each other and repeat...

NAM_NAG_NAM

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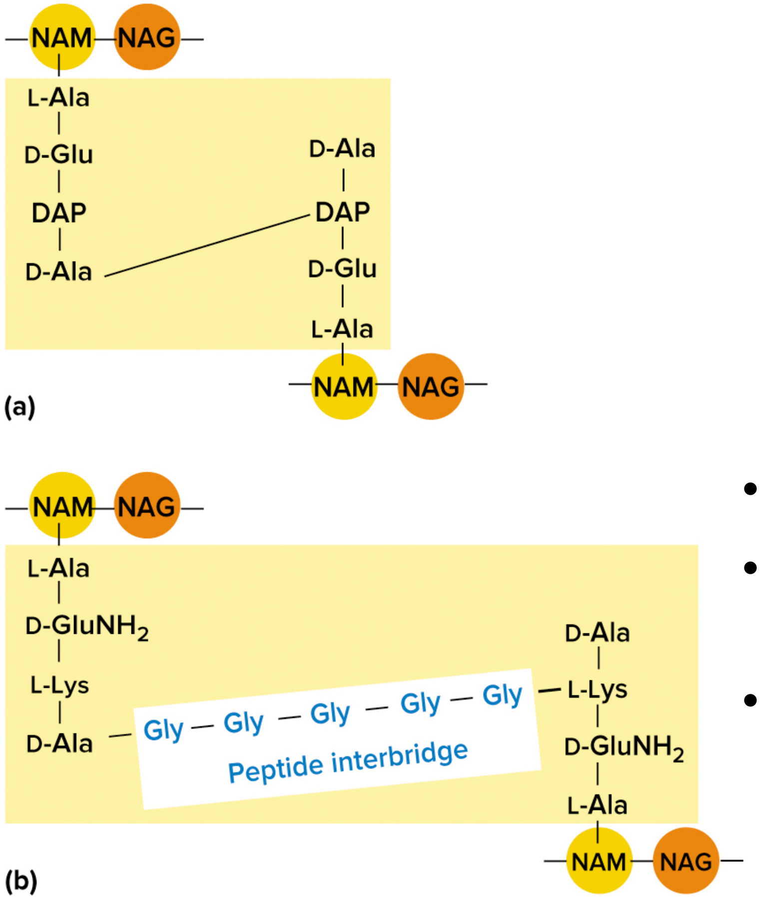
Strands Are Crosslinked



Peptidoglycan strands have a helical shape.

Peptidoglycan chains are crosslinked by peptides for strength.

- Interbridges may form.
- Peptidoglycan sacs—interconnected networks.
- Various structures occur.

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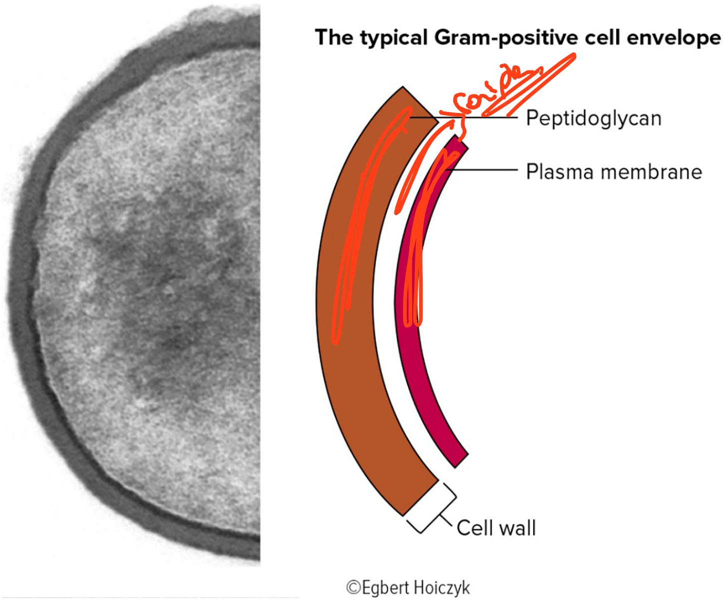
Gram-Positive Cell Walls



Composed primarily of peptidoglycan.

May also contain teichoic acids (negatively charged).

- Help maintain cell envelope.
- Protect from environmental substances.
- May bind to host cells.

Some Gram-positive bacteria have layer of proteins on surface of peptidoglycan.

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Periplasmic Space of Gram-Positive Bacteria

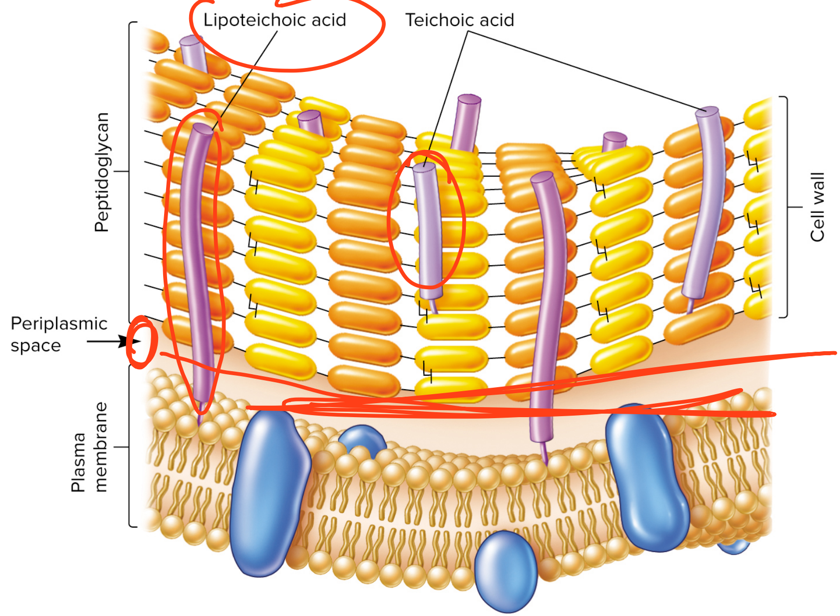
Between plasma membrane and cell wall.

Periplasm has relatively few proteins.

Exoenzymes secreted by Gram-positive bacteria.

- Aid in degradation of large nutrients.

gives the cell wall it's negative charge.



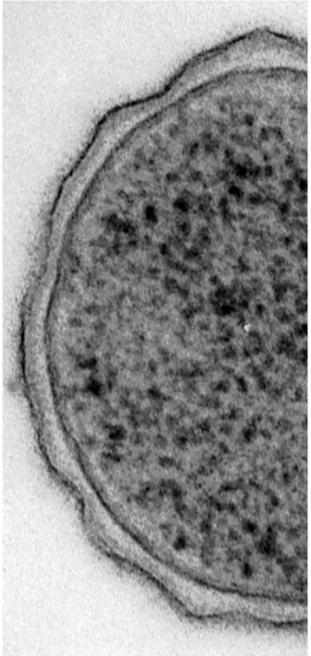
Gram-Negative Cell Wall Basic Structure

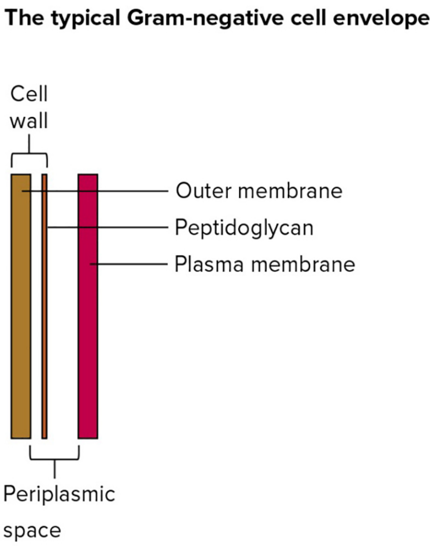
More complex than Gram-positive.

Consist of a thin layer of peptidoglycan surrounded by an outer membrane.

Outer membrane composed of lipids, lipoproteins, and lipopolysaccharide.

No teichoic acids.





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Gram-Negative Cell Walls

Outer membrane (OM) outside thin peptidoglycan layer.

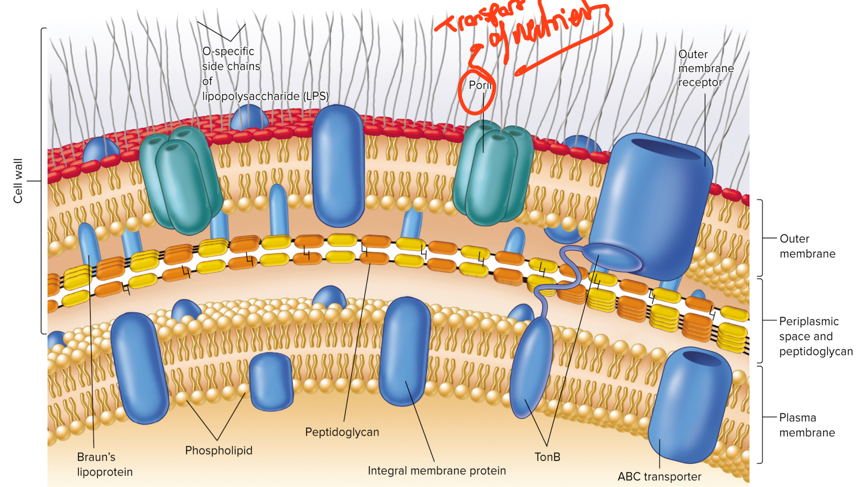
Braun’s lipoproteins connect OM to peptidoglycan.

Other adhesion sites reported.

Peptidoglycan is approximately 5 to 10% of cell wall weight.

Periplasmic space differs from that in Gram-positive cells.

- May constitute 20 to 40% of cell volume.
- Many enzymes present in periplasm.
- Hydrolytic enzymes, transport proteins and other proteins.



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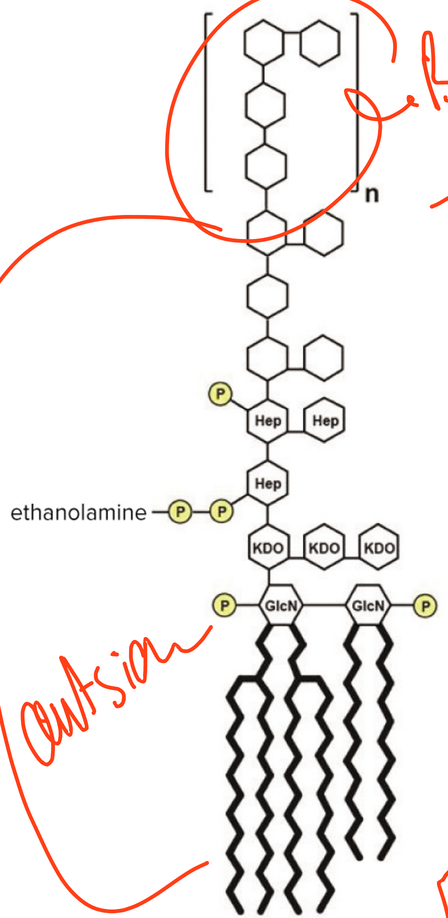
LPS—Lipopolysaccharide

gives the negative charge + helps in protection.



(a)

Consists of three parts.

- Lipid A. ✓
- Core polysaccharide. ✓
- O side chain (O antigen). ✓

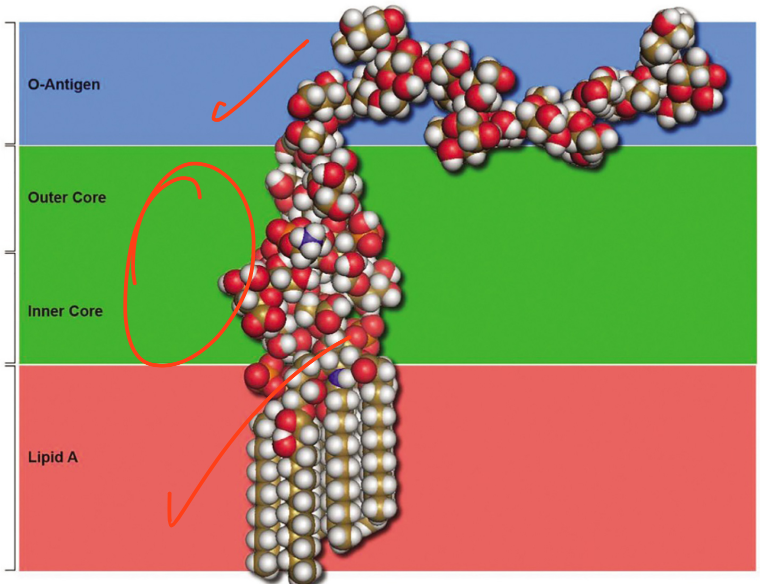
Antibody that stimulates the Receptor.

Lipid A buried in outer membrane.

Core polysaccharide, O side chain extend out from the cell.

Liposaccaride

Importance of LPS



(b)

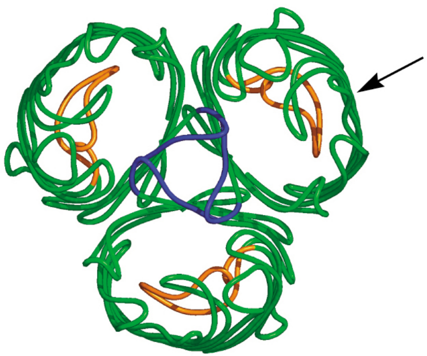
O antigen → بتغير → So immune system won't Recognize it.

- Contributes to negative charge on cell surface.
- Helps stabilize outer membrane structure.
- Creates a permeability barrier.
- Host defense protection (O antigen).
- Acts as an endotoxin (lipid A). (toxic substance

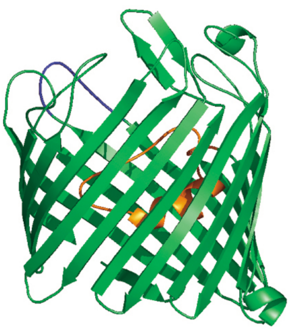
Gram-Negative Outer Membrane Permeability

More permeable than plasma membrane due to presence of porin proteins and transporter proteins.

- Porin proteins form channels to let small molecules (600 to 700 daltons) pass.



(a) Porin trimer



(b) OmpF side view

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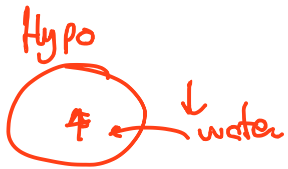
Cell Walls and Osmotic Protection



Hypotonic environments.

- Solute concentration outside cell less than inside cell.
- Water moves into cell and cell swells.
- Cell wall protects from lysis.

Hypertonic environments.

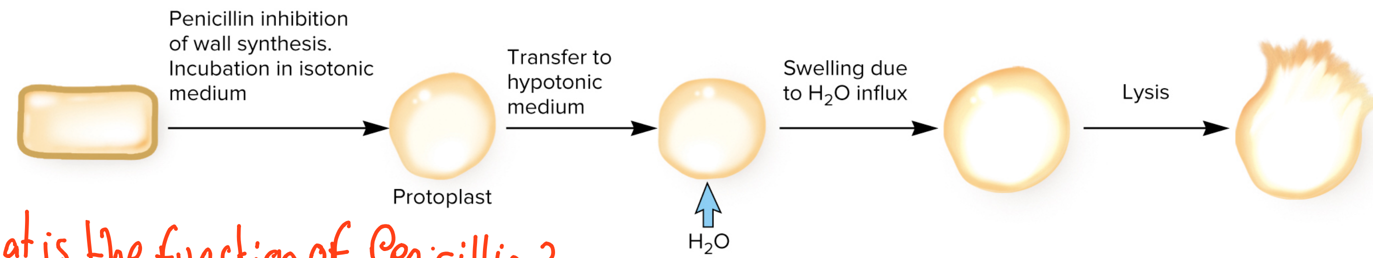
- Solute concentration outside cell is greater than inside.
- Water leaves cell.
- Plasmolysis occurs.

Evidence for Protection of Cell Wall

Lysozyme breaks bond between NAG and NAM.

Penicillin inhibits peptidoglycan synthesis.

If cells are treated with either of the above, they lyse in a hypotonic solution.



what is the function of Penicillin?
↳ Bursting the cell wall of the Bacteria.

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Cells That Lose a Cell Wall May Survive in Isotonic Environments

Protoplasts.

Spheroplasts.

Mycoplasma.

- Never produce a cell wall.
- Plasma membrane more resistant to osmotic pressure.

3.5 The Cell Envelope Often Includes Layers Outside the Cell Wall

a. List the structures found in all the layers of bacterial cell envelopes.

b. Identify the functions and the major component molecules in cell envelope structures.

Components Outside of the Cell Wall

Outermost layer in the cell envelope.

- Capsules and slime layers.

Glycocalyx—aids in attachment to solid surfaces.

- For example, biofilms in plants and animals.

S-layers.

Components Outside of Cell Wall—Capsules

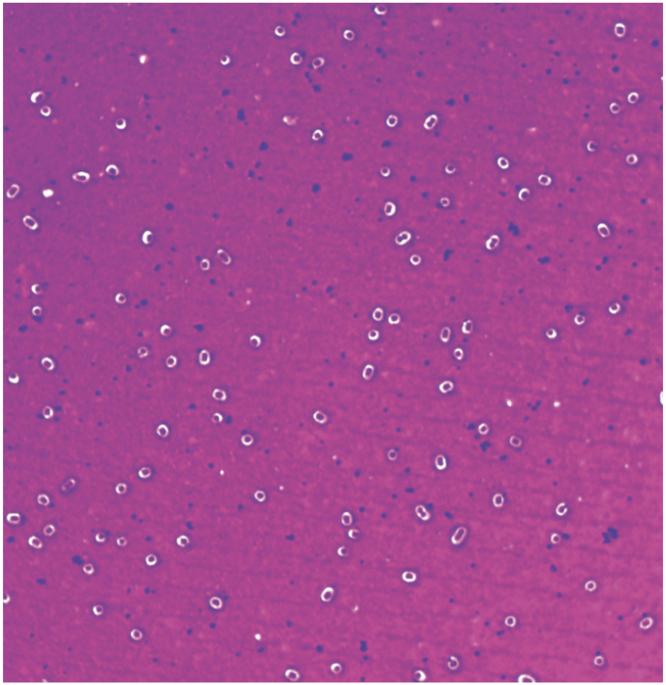
Well organized and not easily removed from cell.

Usually composed of polysaccharides.

Visible in light microscope.

Protective advantages.

- Resistant to phagocytosis.
- Protect from desiccation.
- Exclude viruses and detergents.



K. pneumoniae

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Components Outside of Cell Wall—Slime Layers

Similar to capsules except diffuse, unorganized, and easily removed.

Slime may facilitate motility.

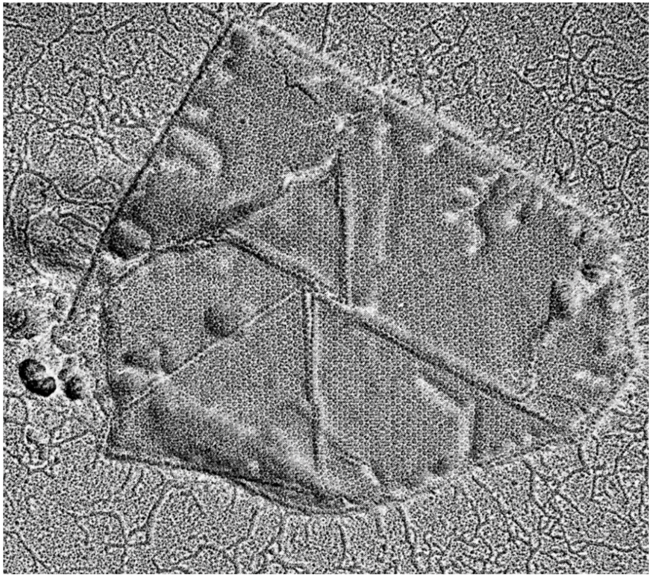
Components Outside of Cell Wall—S Layers

Regularly structured self-assembling layers of protein or glycoprotein.

- In Gram-negative bacteria, S layer adheres to outer membrane.
- In Gram-positive bacteria, associated with peptidoglycan.

S Layer functions.

- Protect from ion and pH fluctuations, osmotic stress, enzymes, and predation.
- Maintains shape and rigidity.
- Promotes adhesion to surfaces.
- Protects from host defenses.
- Potential use in nanotechnology.



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3.6 The Bacterial Cytoplasm Is More Complex Than Once Thought

a. Describe the function of three types of bacterial cytoskeletal proteins and compare their structure with those of eukaryotes.

b. Compare and contrast storage inclusions and microcompartments, citing specific examples.

c. List the composition of bacterial ribosomes and their spatial organization within the cell.

d. Differentiate the structure and function of bacterial chromosomes and plasmids.

Bacterial Cytoplasmic Structures

Cytoskeleton.

Intracytoplasmic membranes.

Inclusions.

Ribosomes.

Nucleoid.

Plasmids.

Bacterial Cytoskeleton

Homologs of all 3 eukaryotic cytoskeletal elements have been identified in bacteria.

- Actin filaments.
- Microtubules.
- Intermediate filaments.

Functions are similar as in eukaryotes.

- Participate in cell division.
- Localize proteins.
- Determine cell shape.

Best Studied Examples of Bacterial Cytoskeleton Molecules

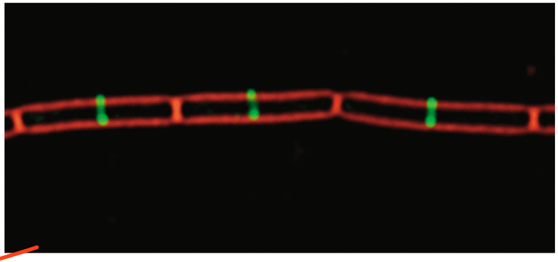
FtsZ—many bacteria.

- Forms ring during septum formation in cell division.

MreB—many rods.

- Maintains shape by positioning peptidoglycan synthesis machinery.

CreS—rare, maintains curve shape.



(a) FtsZ

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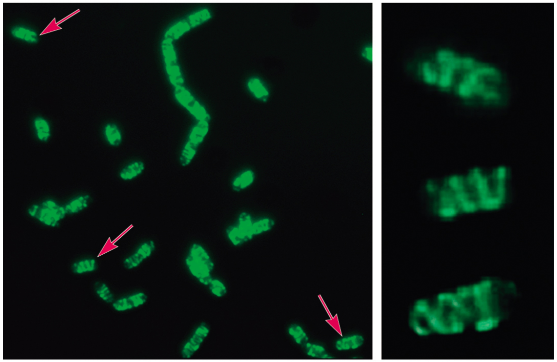

(b) Mbl **(c)** Mbl

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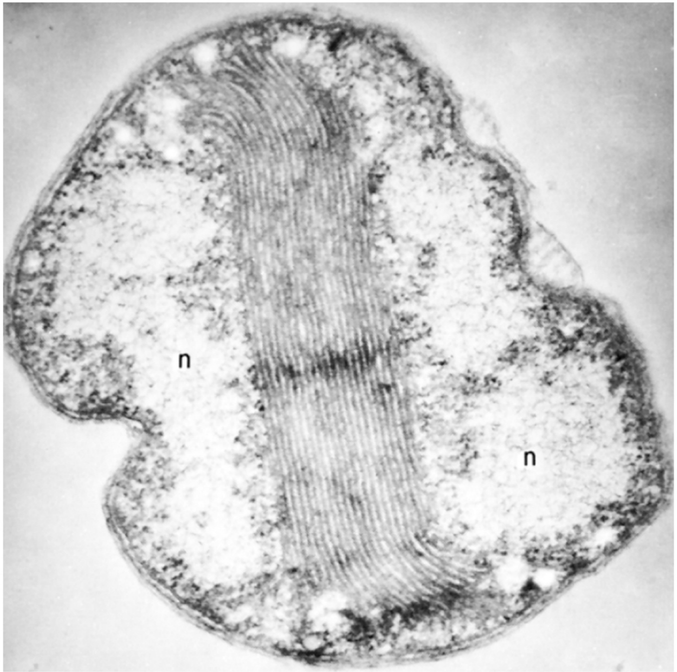
Intracytoplasmic Membranes

Plasma membrane infoldings.

- Observed in many photosynthetic bacteria.
- Observed in many bacteria with high respiratory activity.



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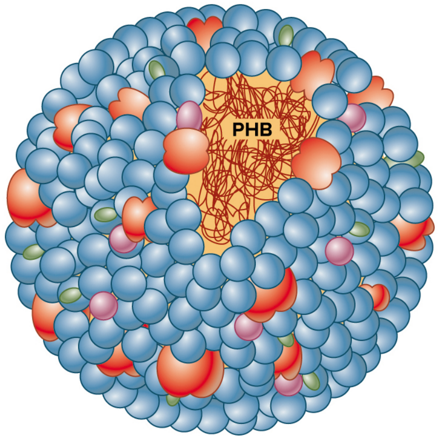
Inclusions

Granules, crystals, or globules of organic or inorganic material that are stockpiled by the cell for future use.

Some are enclosed by a single-layered membrane.

- Membranes vary in composition.
- Some made of proteins; others contain lipids.
- May be referred to as *microcompartments*.



(a) Sulfur globules

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Storage Inclusions

Storage of nutrients, metabolic end products, energy, building blocks.

Glycogen storage.

Carbon storage .

- poly-β-hydroxybutyrate (PHB).

ATP_ Respiration

Phosphate—polyphosphate.

Amino acids—cyanophycin granules.

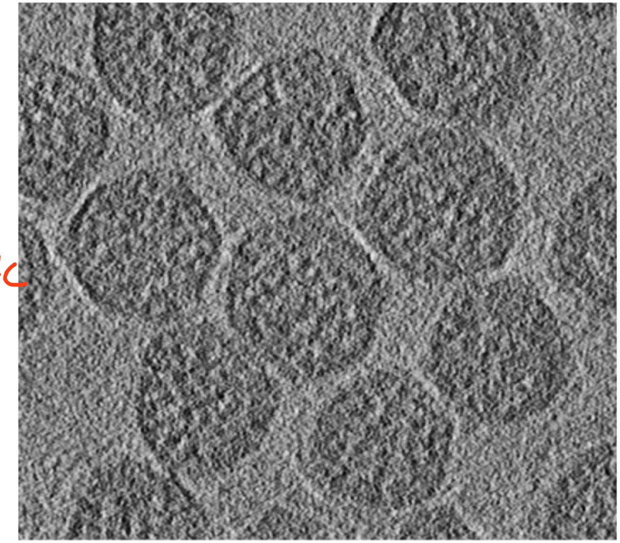
Protien synthesis

Microcompartments

Not bound by membranes but compartments for specific functions.

Carboxysomes—CO_2 fixing bacteria. (in photosynthetic bacteria).

- Contain the enzyme RubisCO for CO_2 fixation.



(b) Carboxysomes

Gas Vacuoles

(c) Gas vacuoles

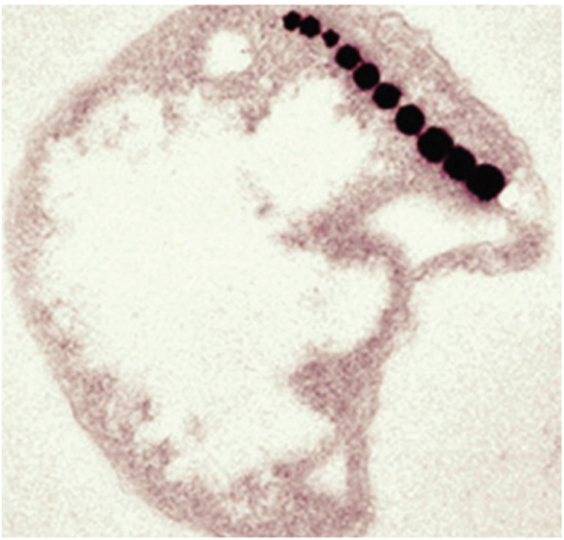
Found in aquatic, photosynthetic bacteria and archaea.

Provide buoyancy in gas vesicles.

floting

Repping microorganisms away form unprefered source

Magnetosomes



(d) Magnetosomes

Found in aquatic bacteria.

Magnetite particles for orientation in Earth's magnetic field.

Cytoskeletal protein MamK.

- Helps form magnetosome chain.

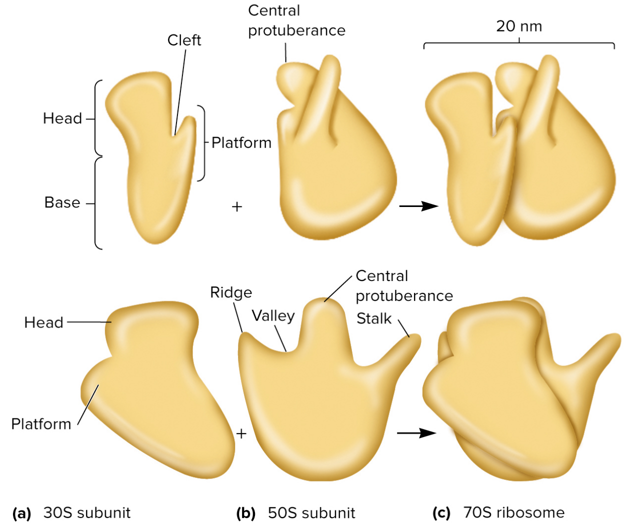
Ribosomes

Complex protein/RNA structures.

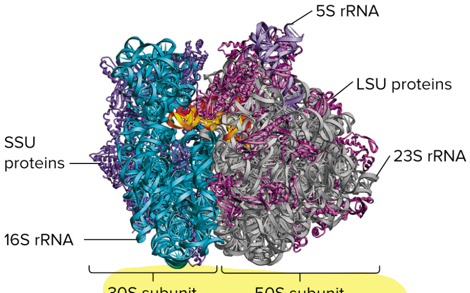
- Sites of protein synthesis.
- Bacterial and archaea ribosome = 70S.

Bacterial ribosomal RNA.

- 16S small subunit.
- 23S and 5S in large subunit.



(a) 30S subunit (b) 50S subunit (c) 70S ribosome



(d)

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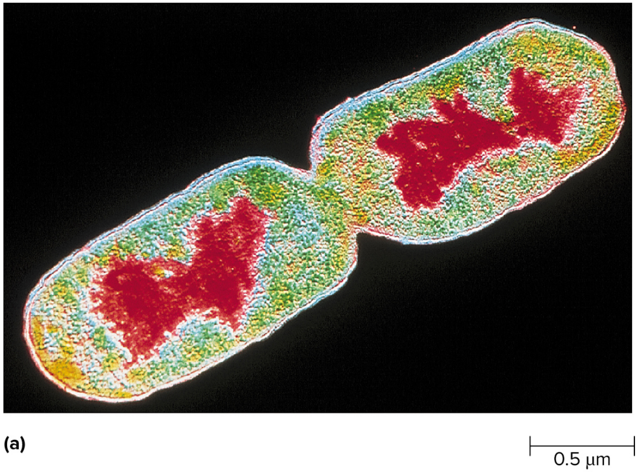
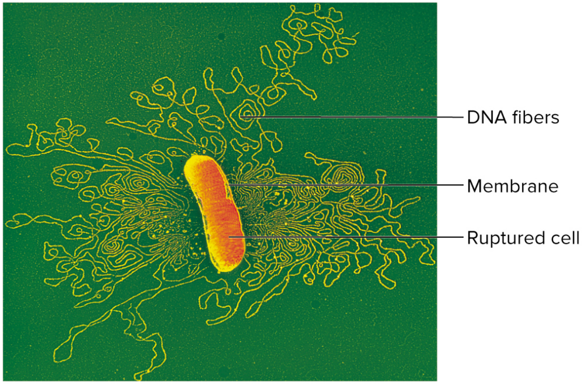
The Nucleoid



(a)



(b)

(a) ©CNRI/SPL/Science Source; (b) ©Dr. Gopal Murti/SPL/Science Source

Usually not membrane bound (few exceptions).

Location of chromosome and associated proteins.

Usually 1 closed circular, double-stranded DNA molecule.

Supercoiling and nucleoid proteins (different from histones) aid in folding.

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(a) ©CNRI/SPL/Science Source; (b) ©Dr. Gopal

Plasmids

Extrachromosomal DNA.

- Usually small, closed circular DNA molecules.

Exist and replicate independently of chromosome.

- Episomes—may integrate into chromosome.
- Inherited during cell division.

Classification via mode of existence, spread, and function.

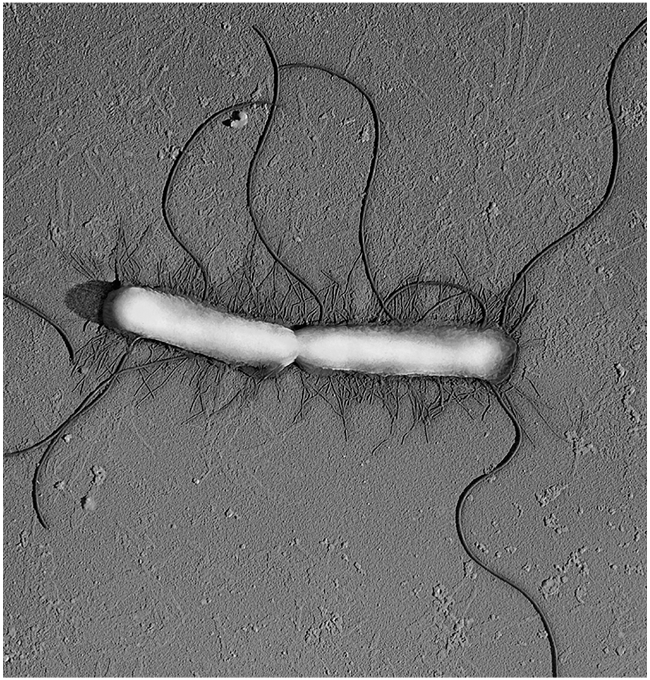
External Structures

Extend beyond the cell envelope in bacteria.

Function in protection, attachment to surfaces, horizontal gene transfer, cell movement.

- Pili and fimbriae.
- Flagella.

Pili and Fimbriae



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Fimbriae (s., fimbria); pili (s., pilus).

- Short, thin, hairlike, protein appendages (up to 1,000/cell).
- Can mediate attachment to surfaces, motility, DNA uptake.

Sex pili (s., pilus).

- Longer, thicker, less numerous (1 to 10/cell).
- Genes for formation on plasmids.
- Required for conjugation.

Flagella

(a) *P. mendocina*—monotrichous polar flagellation
(b) *S. volutans*—lophotrichous flagellation
(c) *B. alvei*—peritrichous flagellation

(a, c) Source: CDC/Dr. William A. Clark; (b) ©McGraw-Hill Education/James Redfearn, photographer

Threadlike, locomotor appendages extending outward from plasma membrane and cell wall.

Functions.

- Motility and swarming behavior.
- Attachment to surfaces.
- May be virulence factors.

Patterns of flagellation.

- 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.

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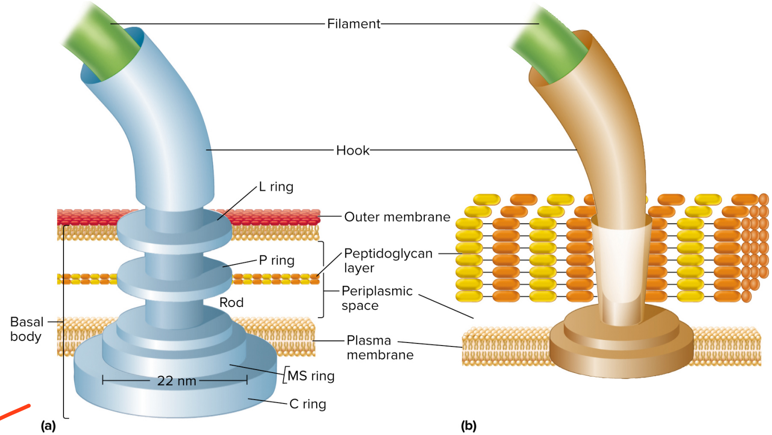
Bacterial Flagella

Thin, rigid protein structures that cannot be observed with bright-field microscope unless specially stained.

Ultrastructure composed of three parts.

- Filament extends from cell surface to the tip.
- Basal body is series of rings that drive flagellar motor.
- Hook links filament to basal body.



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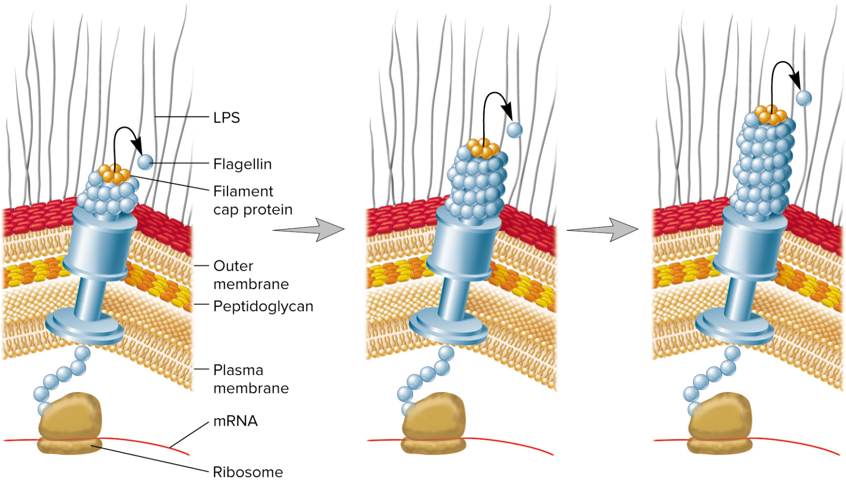
Flagellar Synthesis

Complex process involving many genes/gene products.

New flagellin molecules transported through the hollow filament using Type III-like secretion system.

Filament subunits self-assemble with help of filament cap at tip, not base.



Motility

Flagellar movement.

Swarming.

Spirochete motility.

Twitching and gliding motility.

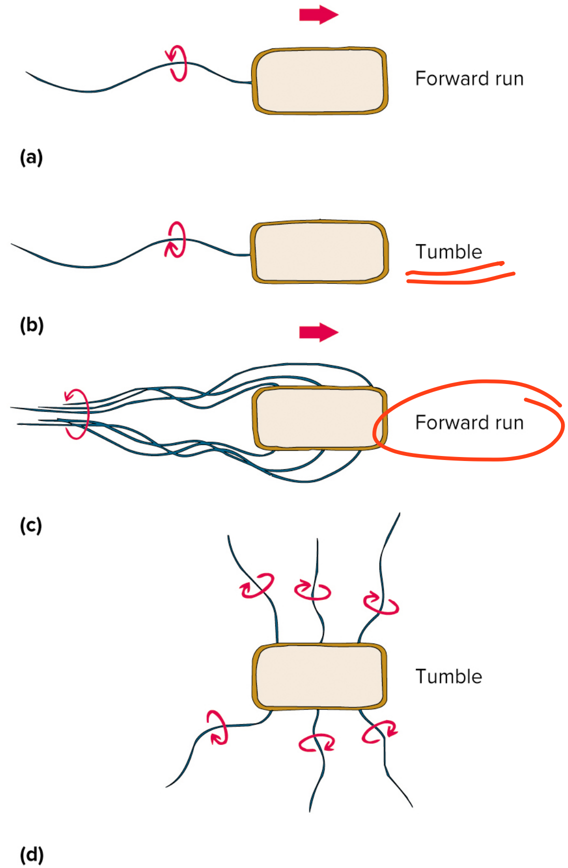
Chemotaxis.

- Move toward chemical attractants such as nutrients, away from harmful substances.
- Move in response to temperature, light, oxygen, osmotic pressure, and gravity.

Flagellar Movement

Flagellum rotates like a propeller.

- Very rapid rotation up to 1100 revolutions/sec.
- In general, counterclockwise (CCW) rotation causes forward motion (run).
- In general, clockwise rotation (CW) disrupts run causing cell to stop and tumble.



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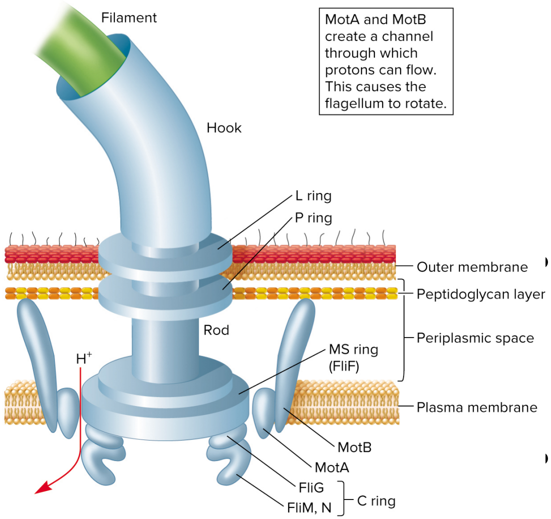
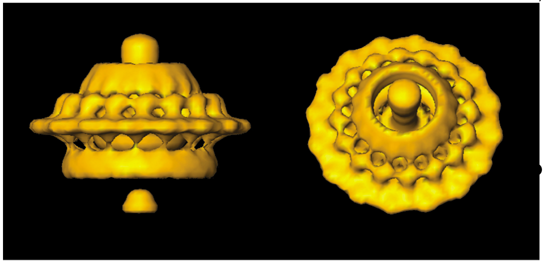
Mechanism of Flagellar Movement



(a)



(b)

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Flagellum is 2 part motor producing torque.

Rotor.

- C (FliG protein) ring and MS ring turn and interact with stator.

Stator—Mot A and Mot B proteins.

- Form channel through plasma membrane.
- Protons move through Mot A and Mot B channels using energy of proton motive force.
- Torque powers rotation of the basal body and filament.

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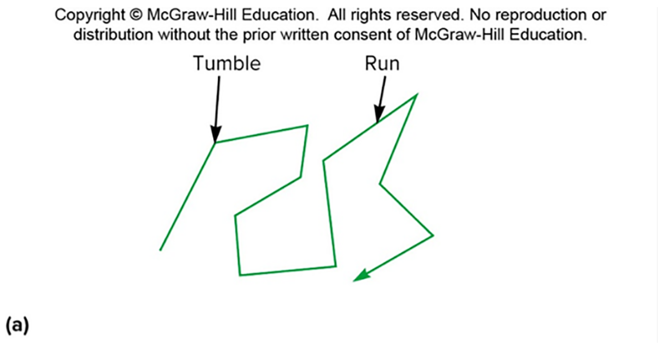
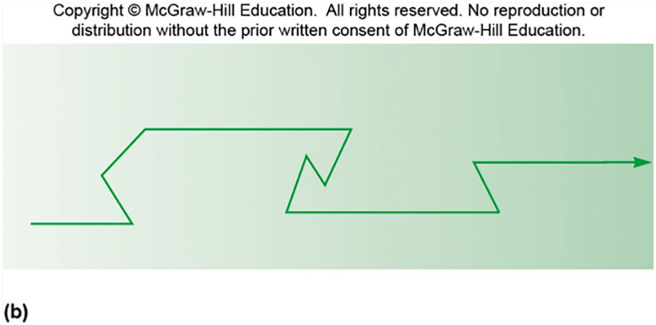
Chemotaxis





Movement toward a chemical attractant or away from a chemical repellent.

Changing concentrations of chemical attractants and chemical repellents bind chemoreceptors of chemosensing system.

In presence of attractant/repellant, tumbling frequency is reduced; runs toward/away from compound are longer.

Behavior of bacterium altered by temporal concentration of chemical.

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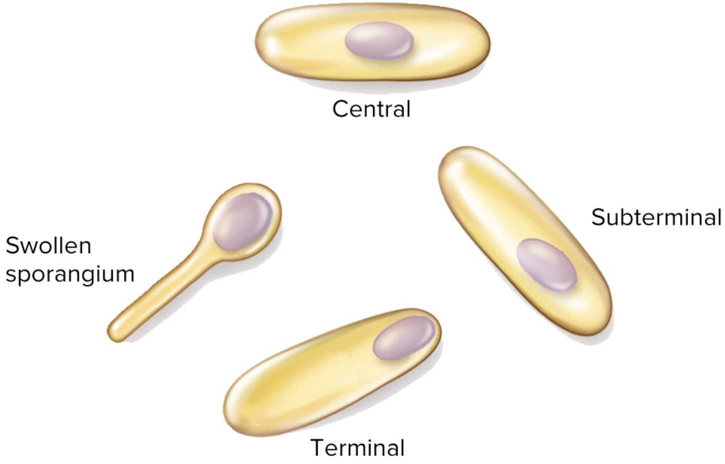
The Bacterial Endospore

Complex, dormant structure formed by some bacteria.

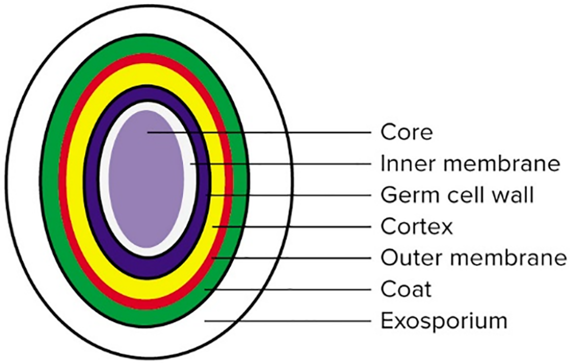
Various locations within the cell.

Resistant to numerous environmental conditions (including heat, radiation, chemicals, desiccation) due to:

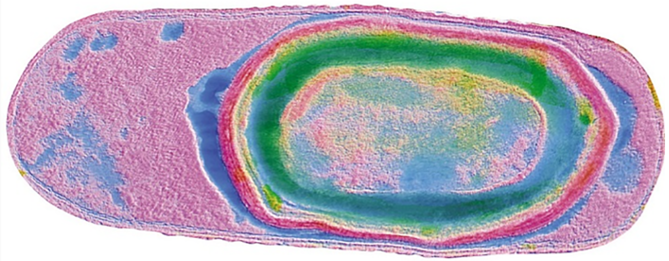
- Calcium (complexed with dipicolinic acid).
- Small, acid-soluble, DNA-binding proteins (SASPs).
- Dehydrated core.
- Spore coat and exosporium protect.



Endospore Structure



(a)



(b)

Spore surrounded by thin covering called exosporium.

Thick layers of protein form the spore coat.

Cortex, beneath the coat, thick peptidoglycan.

Core has nucleoid and ribosomes.

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(b) ©CNRI/Science Source

Sporulation

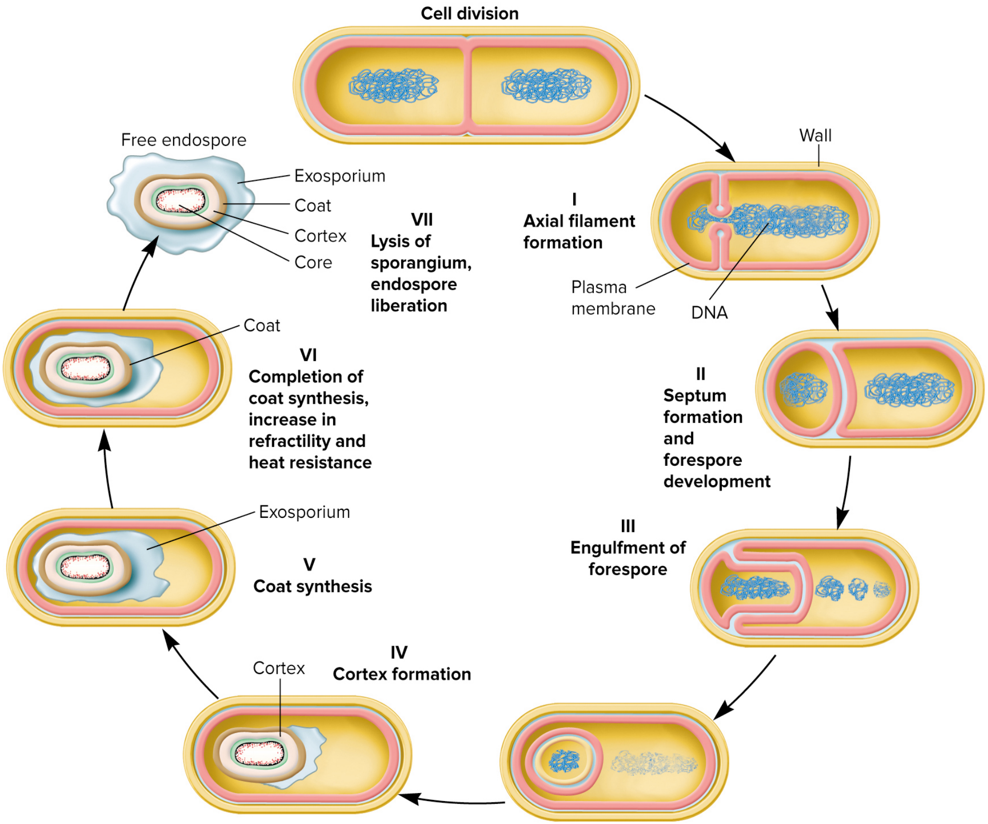
Process of endospore formation.

Occurs over several hours.

Normally commences when growth ceases because of lack of nutrients.

Complex multistage process.

Sporulation Cycle



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Formation of Vegetative Cell

Activation.

- Prepares endospores for germination.
- Often results from treatments like heating.

Germination.

- Environmental nutrients are detected.
- Spore swelling and rupture of absorption of spore coat.
- Increased metabolic activity.

Outgrowth.

- Emergence of vegetative cell.