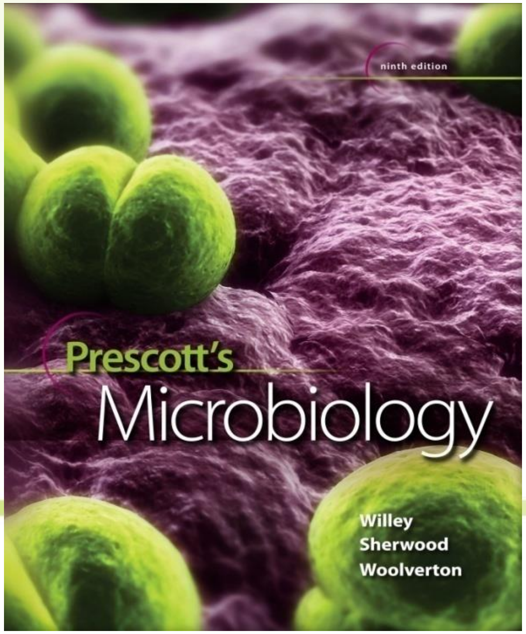
3

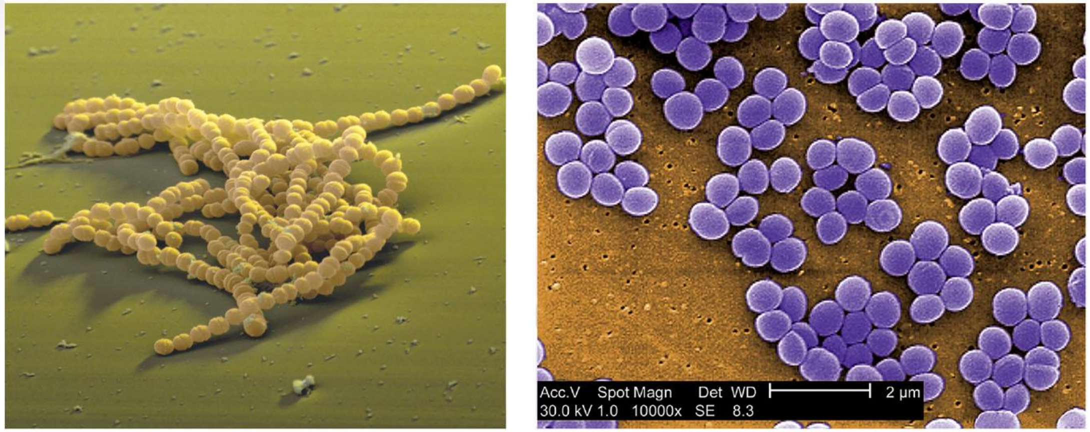


Bacterial Cell Structure

Size, Shape, and Arrangement

- Shape
  - cocci and rods most common
  - various others
- Arrangement
  - determined by plane of division
  - determined by separation or not
- Size - varies

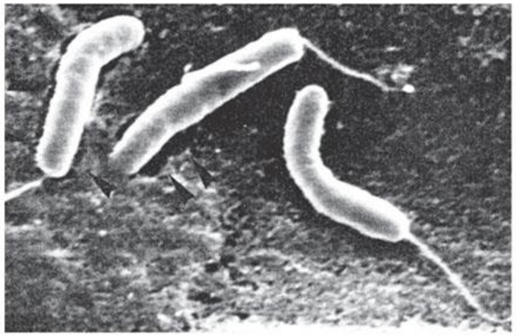
Shape and Arrangement-1



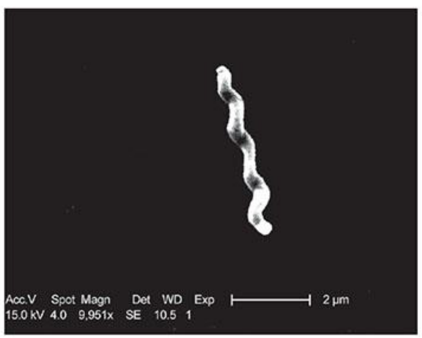
(a) *S. agalactiae*—cocci in chains **(b)** *S. aureus*—cocci in clusters

- 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

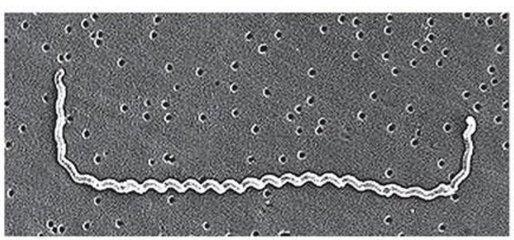
Shape and Arrangement-2



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

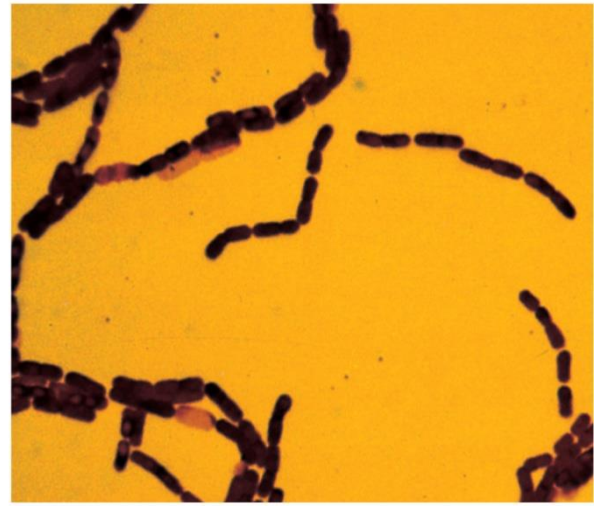


(b) *C. jejuni*—Spiral-shaped spirillum



(c) *Leptospira interrogans*—a spirochete

a: CDC; b: CDC/Janice Haney Carr;
c: CDC/NCID/HIP/Janice Carr



(c) *B. megaterium*—rods in chains

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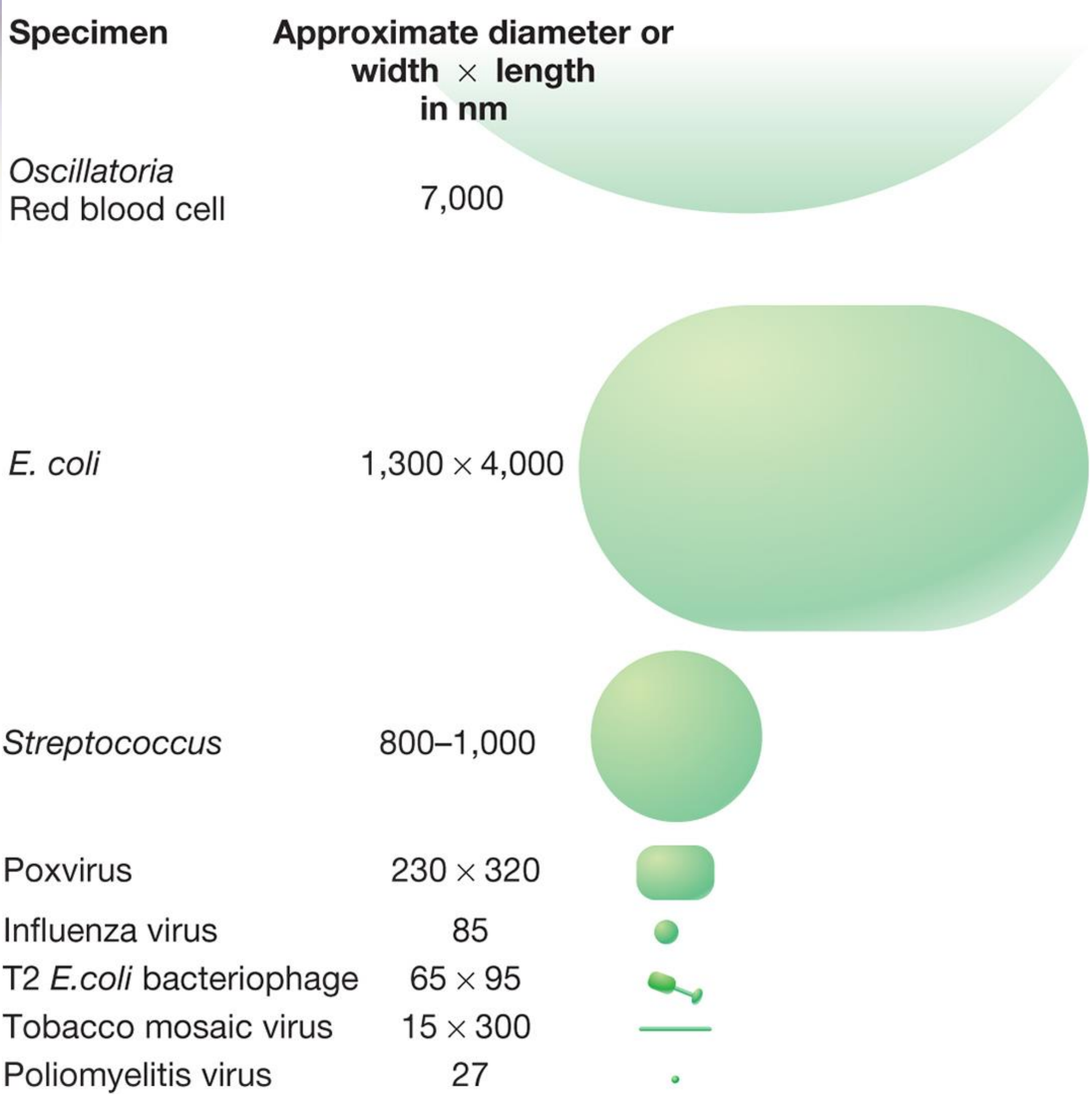
- bacilli (s., bacillus) – rods
  - coccobacilli – very short rods
- vibrios – resemble rods, comma shaped
- spirilla (s., spirillum) – rigid helices
- spirochetes – flexible helices



Size

- smallest – 0.3 μm (*Mycoplasma*)
- average rod – 1.1 - 1.5 x 2 – 6 μm (*E. coli*)
- very large – 600 x 80 μm *Epulopiscium fishelsoni*

Bacterial Cell Organization Common Features

- Cell envelope – 3 layers
- Cytoplasm
- External structures

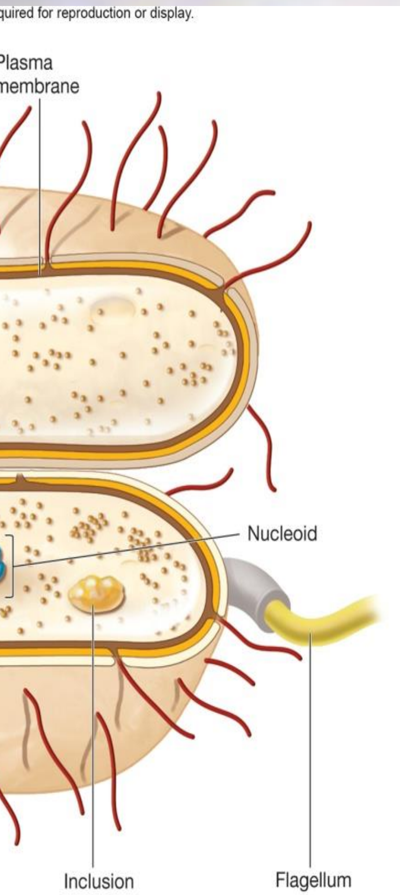


Table 3.1 Common Bacterial Structures and Their Functions

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
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 and gliding motility
Flagella	Swimming and swarming motility
Endospore	Survival under harsh environmental conditions

Bacterial Cell Envelope

- Plasma membrane
- Cell wall
- Layers outside the cell wall

Bacterial Plasma Membrane

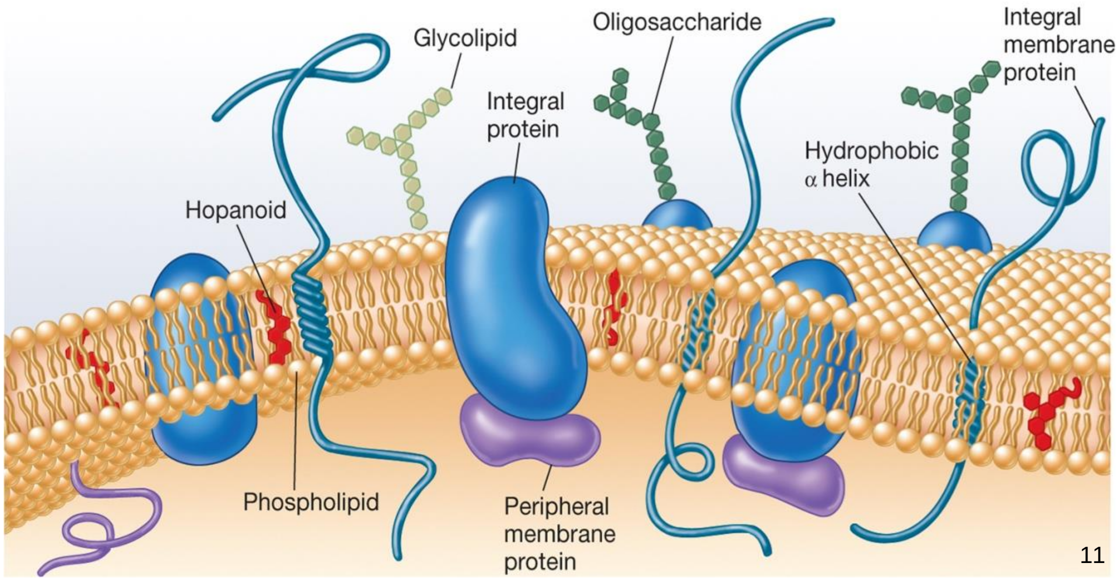
- Absolute requirement for all living organisms
- Some bacteria also have internal membrane systems

Plasma Membrane Functions

- Encompasses the cytoplasm
- Selectively permeable barrier
- Interacts with external environment
  - receptors for detection of and response to chemicals in surroundings
  - transport systems
  - metabolic processes

Fluid Mosaic Model of Membrane Structure

- lipid bilayers with floating proteins
  - amphipathic lipids
    - polar ends (hydrophilic – interact with water)
    - non-polar tails (hydrophobic – insoluble in water)
  - membrane proteins



Bacterial Cell Wall

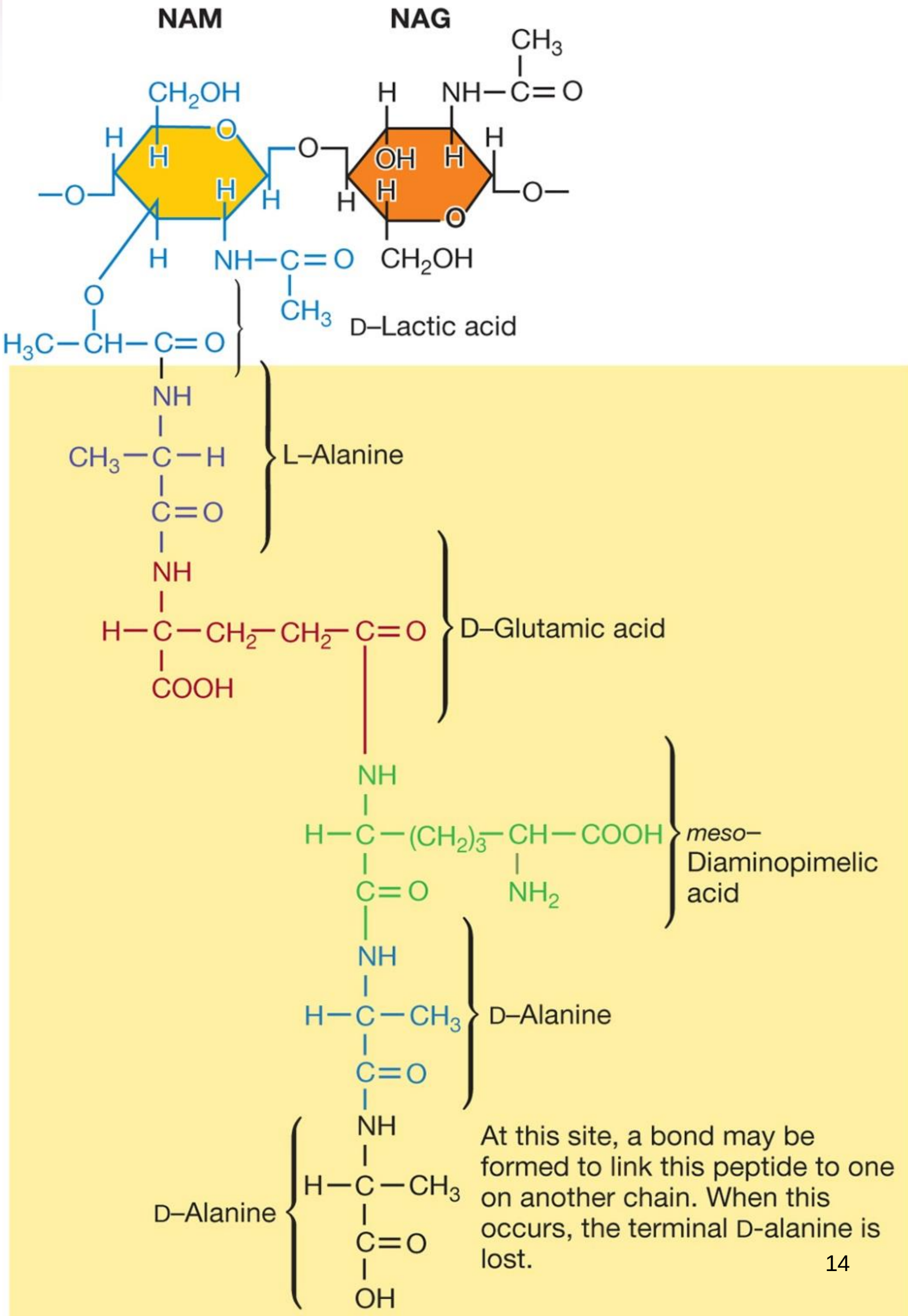
- Peptidoglycan (murein)
  - – rigid structure that lies just outside the cell plasma membrane
  - – two types based on Gram stain
    - Gram-positive: stain purple; thick peptidoglycan
    - Gram-negative: stain pink or red; thin peptidoglycan and outer membrane

Cell Wall Functions

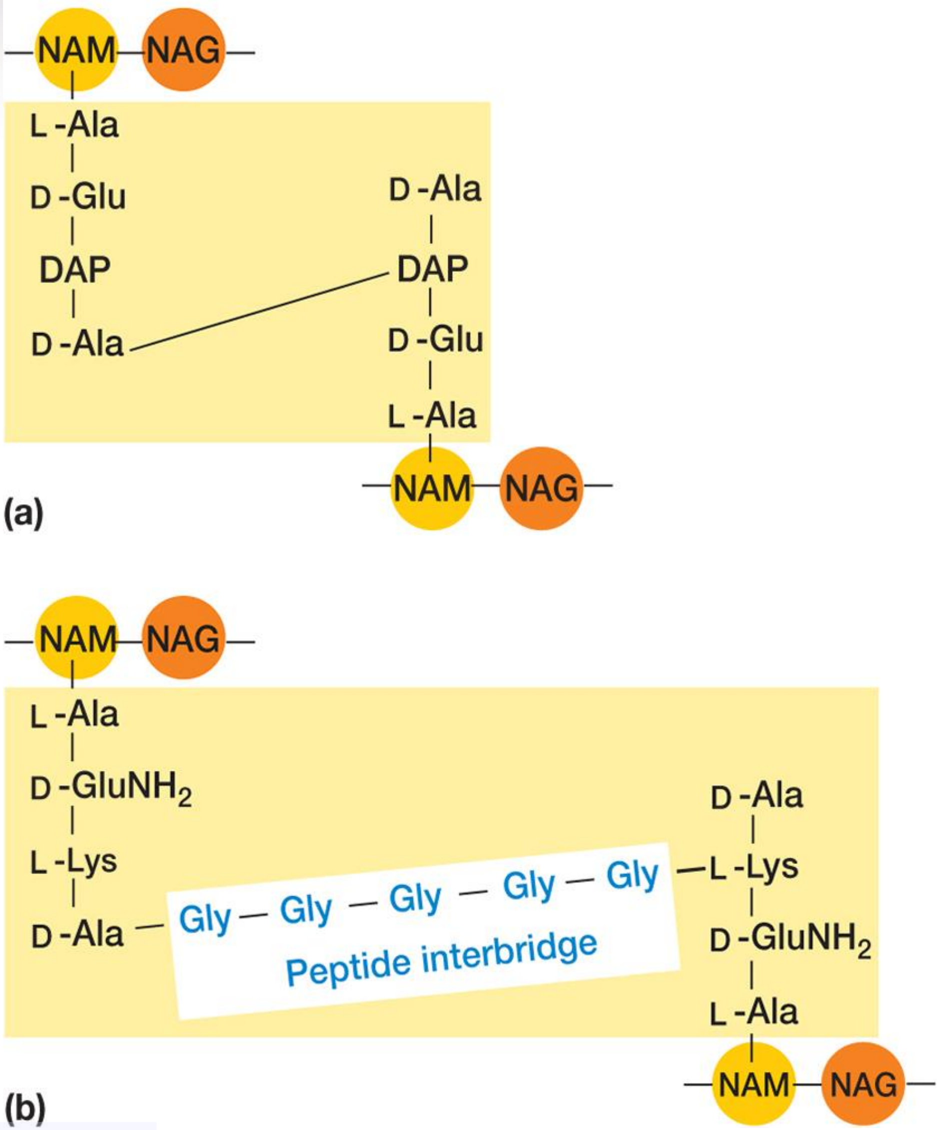
- Maintains shape of the bacterium
  - almost all bacteria have one
- Helps protect cell from osmotic lysis
- Helps protect from toxic materials
- May contribute to pathogenicity

Peptidoglycan Structure

- Meshlike polymer of identical subunits forming long strands
  - two alternating sugars
    - *N*-acetylglucosamine (NAG)
    - *N*- acetylmuramic acid
  - alternating D- and L- amino acids

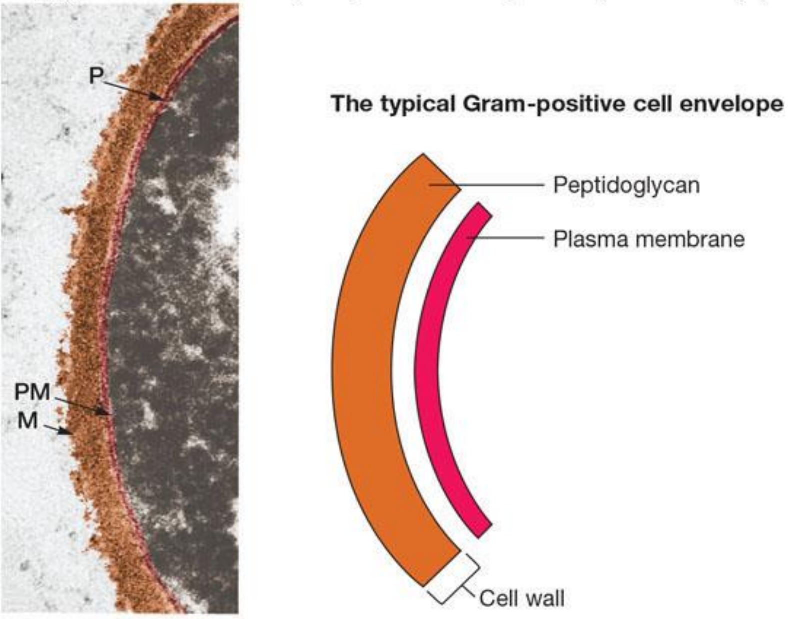


Strands Are Crosslinked متشابكة



- Peptidoglycan strands have a helical shape
- Peptidoglycan chains are crosslinked by peptides for strength
  - interbridges may form
  - peptidoglycan sacs – interconnected networks
  - various structures occur

Gram-Positive Cell Walls



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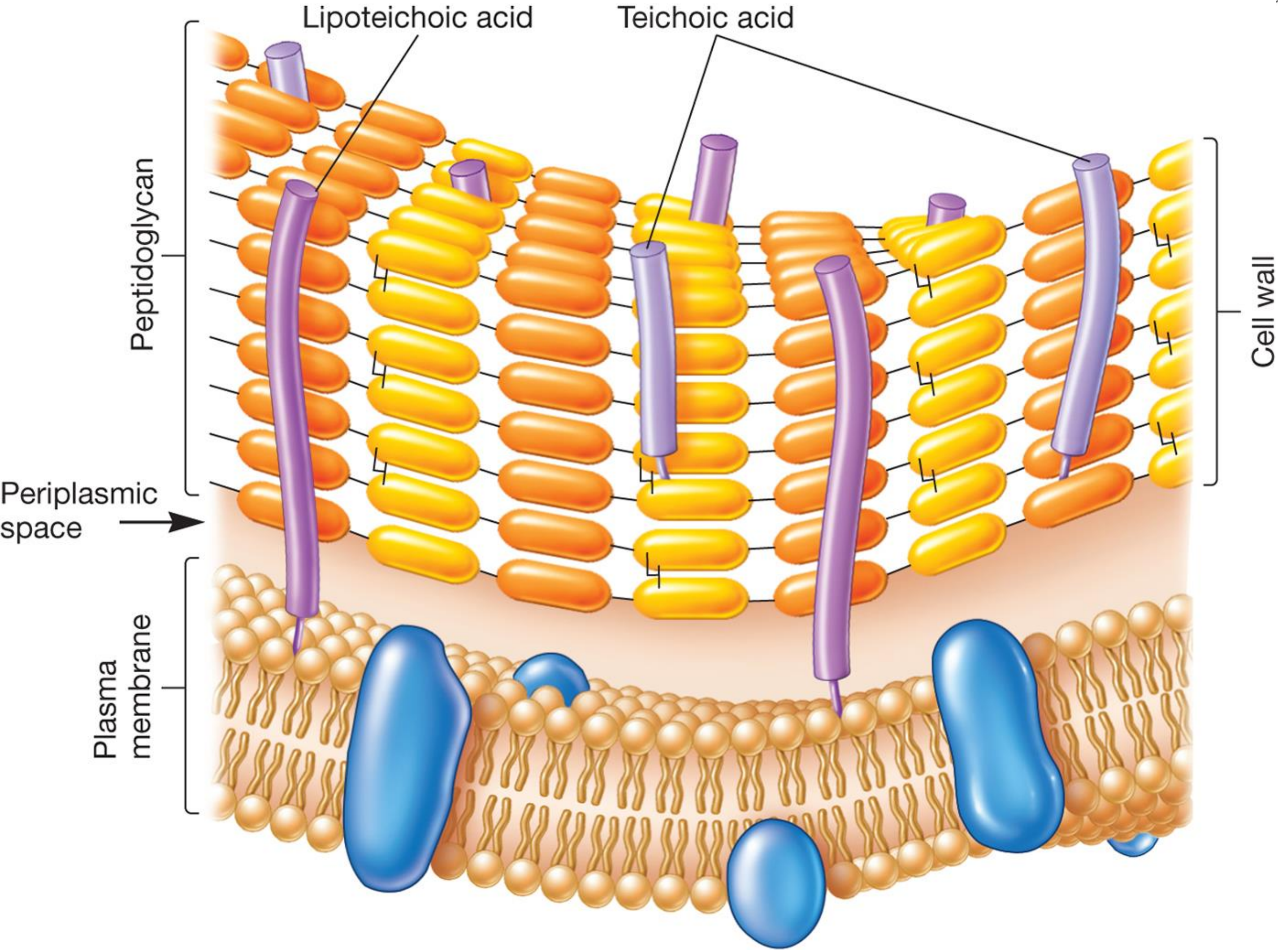
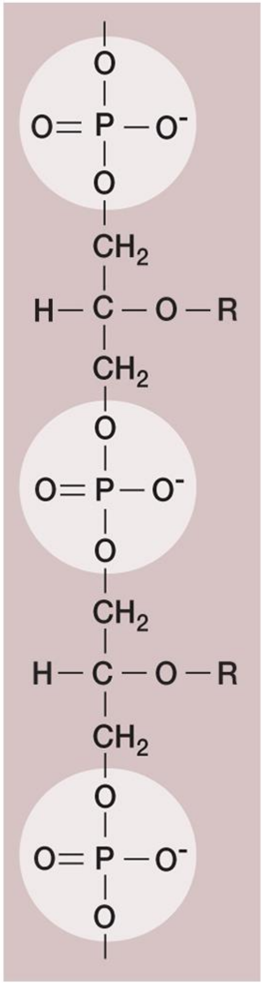
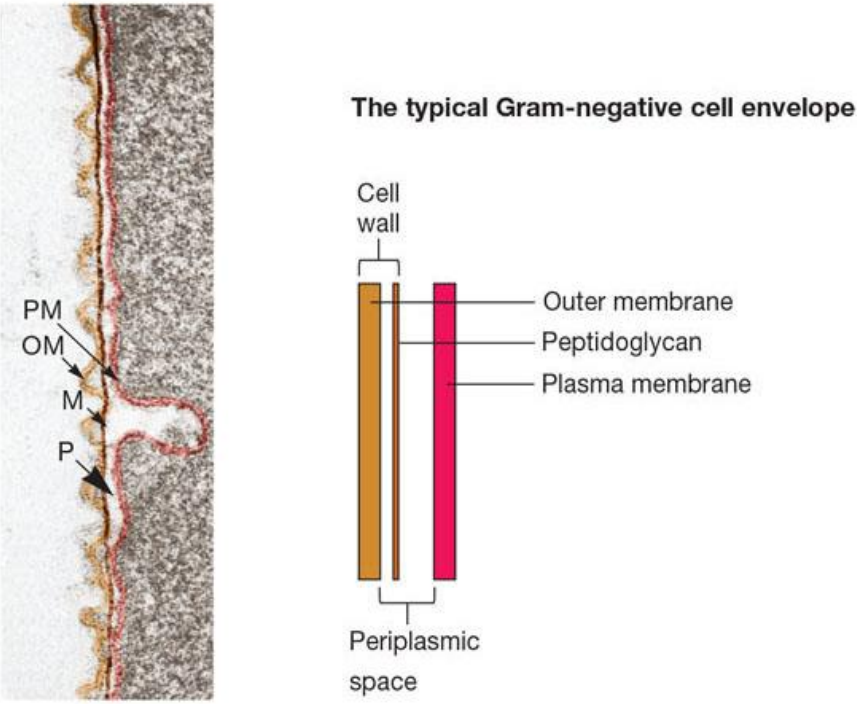
- Composed primarily of peptidoglycan
- May also contain teichoic acids (negatively charged)
  - help maintain cell envelope
  - protect from environmental substances
  - may bind to host cells
- some gram-positive bacteria have layer of proteins on surface of peptidoglycan


Lipoteichoic acid
Teichoic acid
Peptidoglycan
Periplasmic space
Plasma membrane
Cell wall


O
O= P — O⁻
O
CH2
H— C — O — R
CH2
O
O= P — O⁻
O
CH2
H— C — O — R
CH2
O
O= P — O⁻
O

Gram-Negative Cell Walls

- 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 (LPS)
- No teichoic acids



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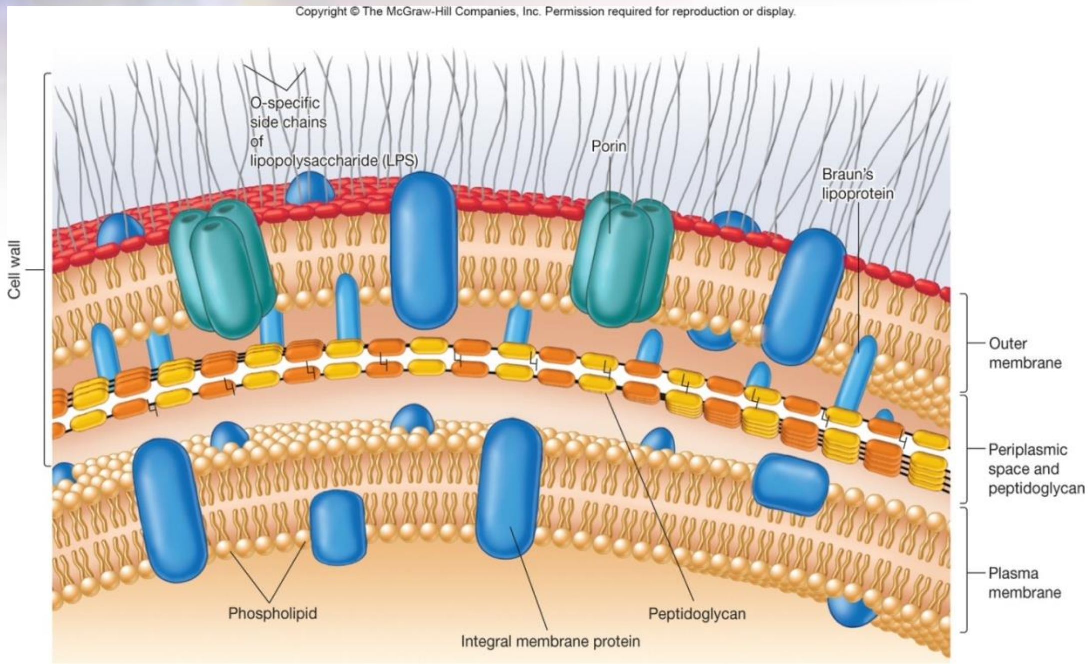
Gram-Negative Cell Walls

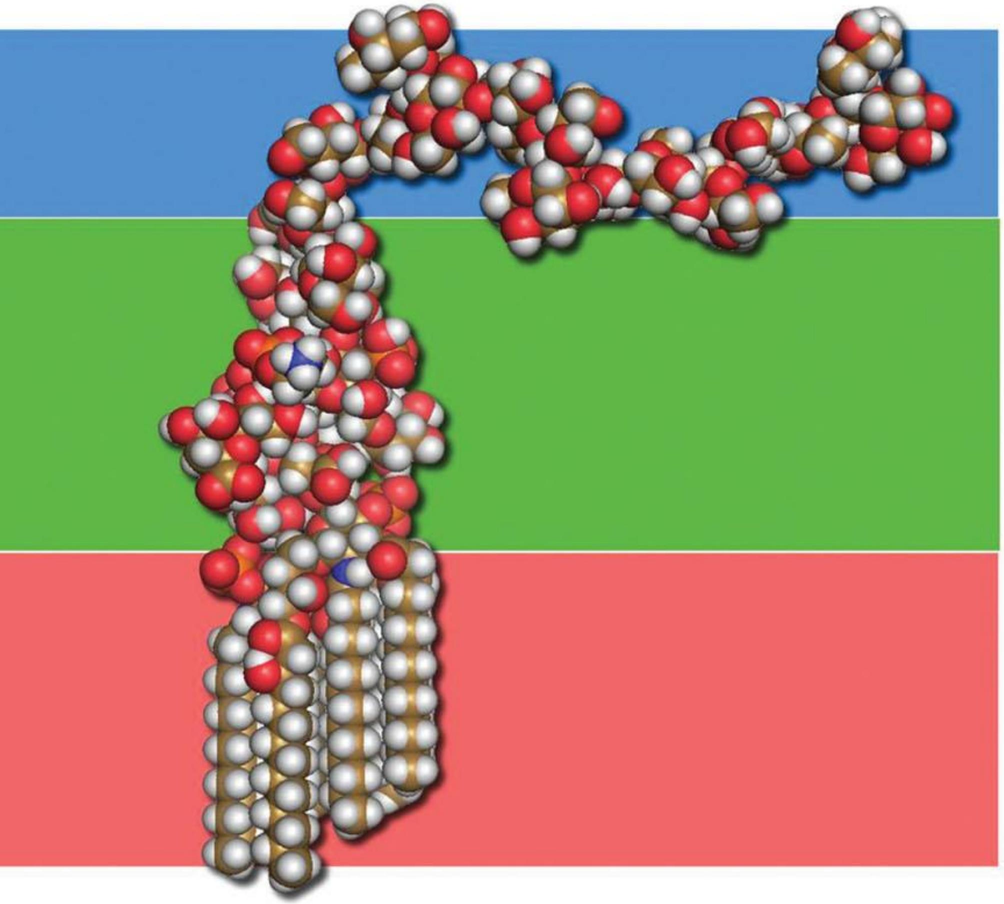
- Peptidoglycan is ~5-10% of cell wall weight
- Periplasmic space differs from that in Gram-positive cells
  - may constitute 20–40% of cell volume
  - many enzymes present in periplasm
    - hydrolytic enzymes, transport proteins and other proteins

Gram-Negative Cell Walls



- outer membrane lies outside the thin peptidoglycan layer
- Braun's lipoproteins connect outer membrane to peptidoglycan
- other adhesion sites reported

Lipopolysaccharide (LPS)



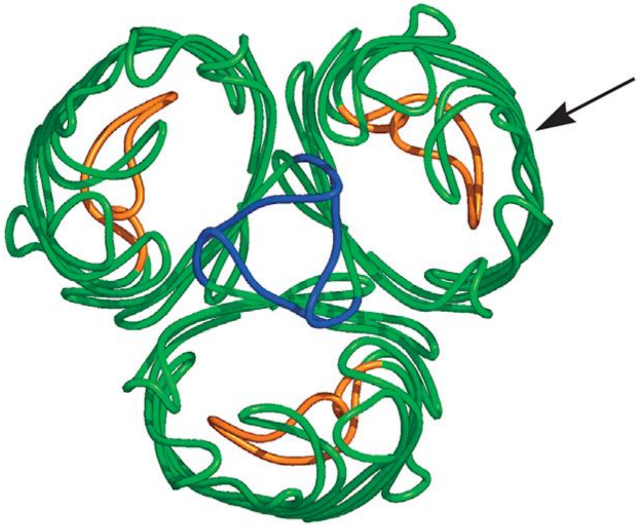
- Consists of three parts
  - lipid A
  - core polysaccharide
  - O side chain (O antigen)
- Lipid A embedded in outer membrane
- Core polysaccharide, O side chain extend out from the cell

Importance of LPS

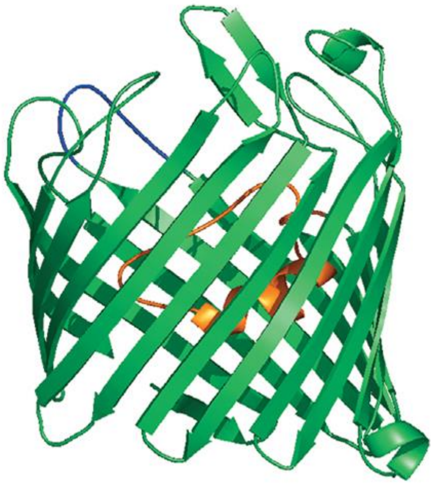
1. contributes to negative charge on cell surface
2. helps stabilize outer membrane structure
3. may contribute to attachment to surfaces and biofilm formation
4. creates a permeability barrier
5. protection from host defenses (O antigen)
6. can act as an endotoxin (lipid A)

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 (600–700 daltons) pass



(a) Porin trimer



(b) OmpF side view

Osmotic Protection

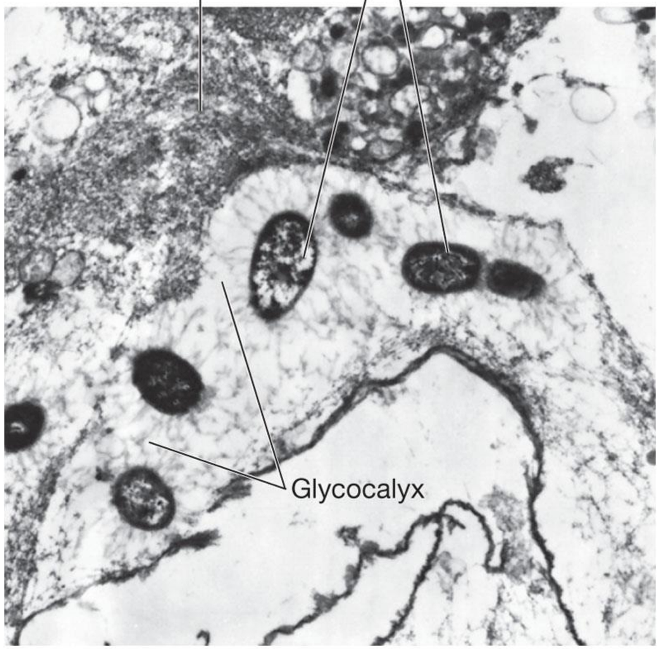
- Hypotonic environments
  - solute concentration outside the cell is less than inside the cell
  - water moves into cell and cell swells
  - cell wall protects from lysis
- Hypertonic environments
  - solute concentration outside the cell is greater than inside
  - water leaves the cell
  - plasmolysis occurs

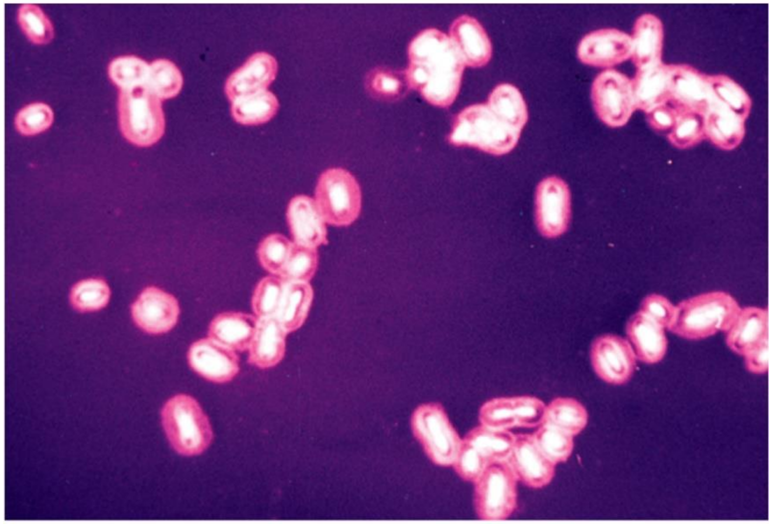
Components Outside of the Cell Wall

- Outermost layer in the cell envelope
- Glycocalyx
  – capsules and slime layers
  – S layers
- Aid in attachment to solid surfaces
  – e.g., biofilms in plants and animals

Capsules

- Usually composed of polysaccharides.
- Well organized and not easily removed from cell
- Visible in light microscope
- Protective advantages
  - resistant to phagocytosis
  - protect from desiccation
  - exclude viruses and detergents





K. pneumoniae

Bacterial Cytoplasmic Structures

1. Cytoskeleton
2. Intracytoplasmic membranes
3. Inclusions
4. Ribosomes
5. Nucleoid and plasmids

The Cytoskeleton

- Homologs of all 3 eukaryotic cytoskeletal elements have been identified in bacteria
- Functions are similar as in eukaryotes

	Comments
	Widely observed in bacteria and archaea
	Observed only in *Prosthecobacter* spp.; thought to be encoded by eukaryotic tubulin genes obtained by horizontal gene transfer
	Encoded by large plasmids observed in members of the genus *Bacillus*
	Observed in magnetotactic species
involved in proteins	Most rod-shaped bacteria
	Plasmid encoded
	Caulobacter crescentus

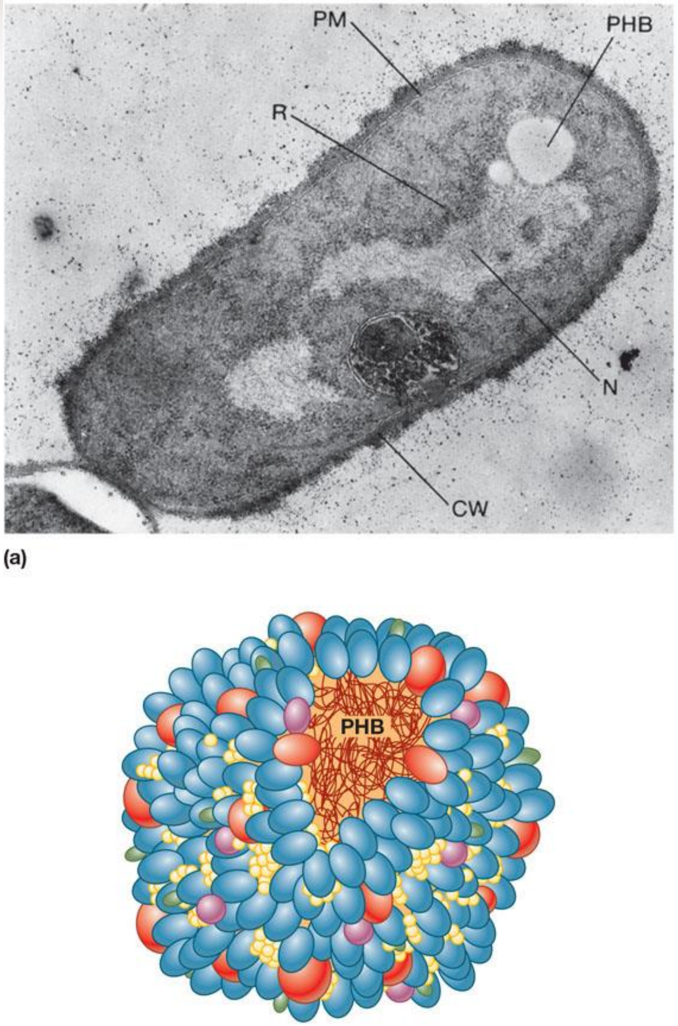
Inclusions

- Granules 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*

Storage Inclusions

- Storage of nutrients, metabolic end products, energy, building blocks
- Glycogen storage
- Carbon storage
  - poly-β-hydroxybutyrate (PHB)
- Phosphate - Polyphosphate (Volutin)
- Amino acids - cyanophycin granules

Storage Inclusions



(a)

(b)

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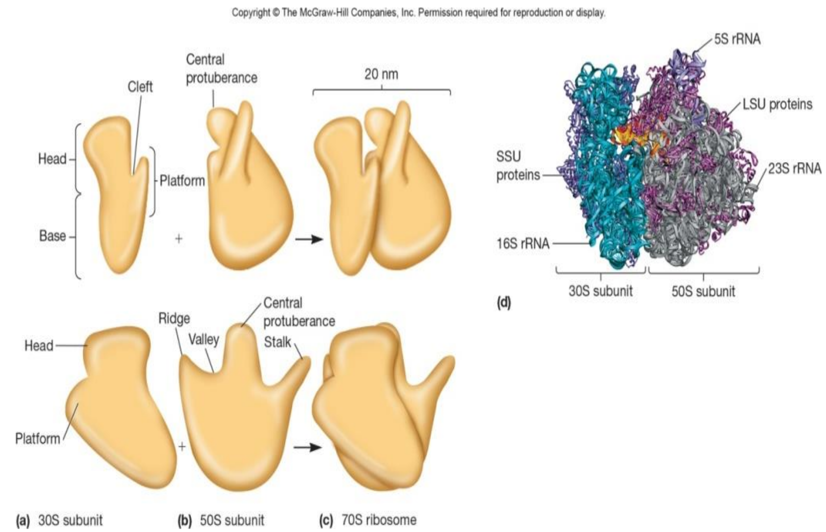
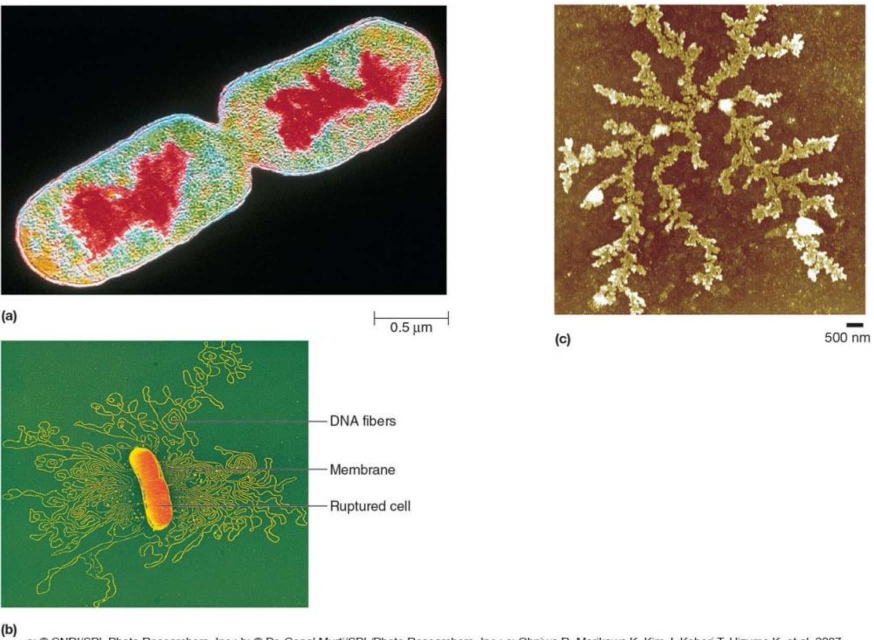
Reprinted from *The Shorter Bergey's Manual of Determinative Bacteriology*, 8e, John G. Holt, Editor, 1977 © Bergey's Manual Trust. Published by Williams & Wilkins Baltimore, MD

Ribosomes



- Complex protein/RNA structures
  - sites of protein synthesis
  - bacterial and archaea ribosome = 70S
  - eukaryotic (80S) S = Svedburg unit
- Bacterial ribosomal RNA
  - 16S small subunit
  - 23S and 5S in large subunit

The Nucleoid



- 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

Plasmids

- Extrachromosomal DNA
  - found in bacteria, archaea, some fungi
  - usually small, closed circular DNA molecules
- Exist and replicate independently of chromosome
  - episomes – may integrate into chromosome
  - inherited during cell division
- Contain few genes that are non-essential
  - confer selective advantage to host (e.g., drug resistance)
- Classification based on mode of existence, spread, and function

Table 3.3 Major Types of Bacterial Plasmids

Type	Function	Example	Size (kbp)	Hosts	Phenotypic Features[1]
Conjugative Plasmids[2]	Transfer of DNA from one cell to another	F factor	95–100	*E. coli, Salmonella, Citrobacter*	Sex pilus, conjugation
R Plasmids	Carry antibiotic-resistance genes	RP4	54	*Pseudomonas* and many other Gram-negative bacteria	Sex pilus, conjugation, resistance to Amp, Km, Nm, Tet
Col Plasmids	Produce bacteriocins, substances that destroy closely related species	ColE1	9	*E. coli*	Colicin E1 production
Virulence Plasmids	Carry virulence genes	Ti	200	*Agrobacterium tumefaciens*	Tumor induction in plants
Metabolic Plasmids	Carry genes for enzymes	CAM	230	*Pseudomonas*	Camphor degradation

1 Abbreviations used for resistance to antibiotics: Amp, ampicillin; Gm, gentamycin; Km, kanamycin; Nm, neomycin; Tet, tetracycline.
2 Many R plasmids, metabolic plasmids, and others are also conjugative.

External Structures

-Extend beyond the cell envelope in bacteria

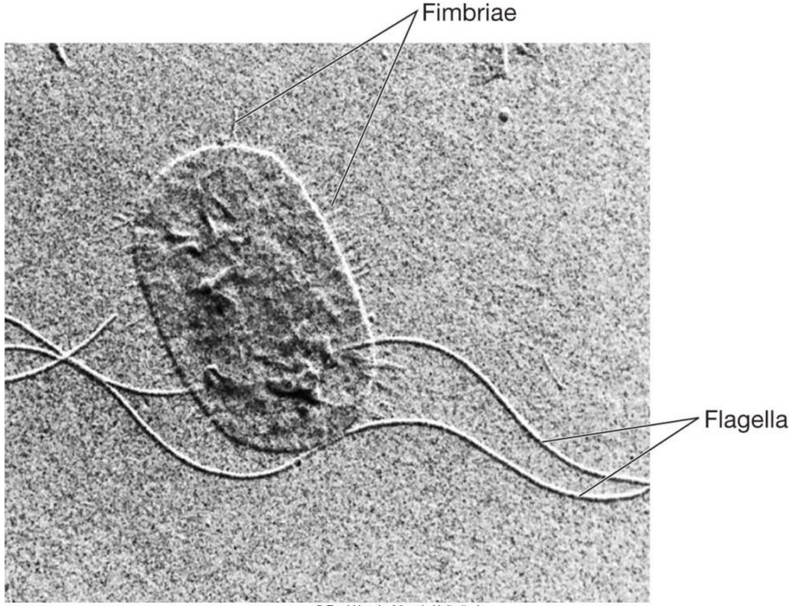
1. Function in protection
2. attachment to surfaces
3. horizontal gene transfer
4. cell movement

e.g.

- pili and fimbriae
- flagella

Pili and Fimbriae

- Fimbriae (s., fimbria); pili (s., pilus)
  - short, thin, hairlike, proteinaceous appendages (up to 1,000/cell)
  - can mediate attachment to surfaces, motility, DNA uptake
- Sex pili (s., pilus)
  - longer, thicker, and less numerous (1-10/cell)
  - genes for formation found on plasmids
  - required for conjugation



Flagella

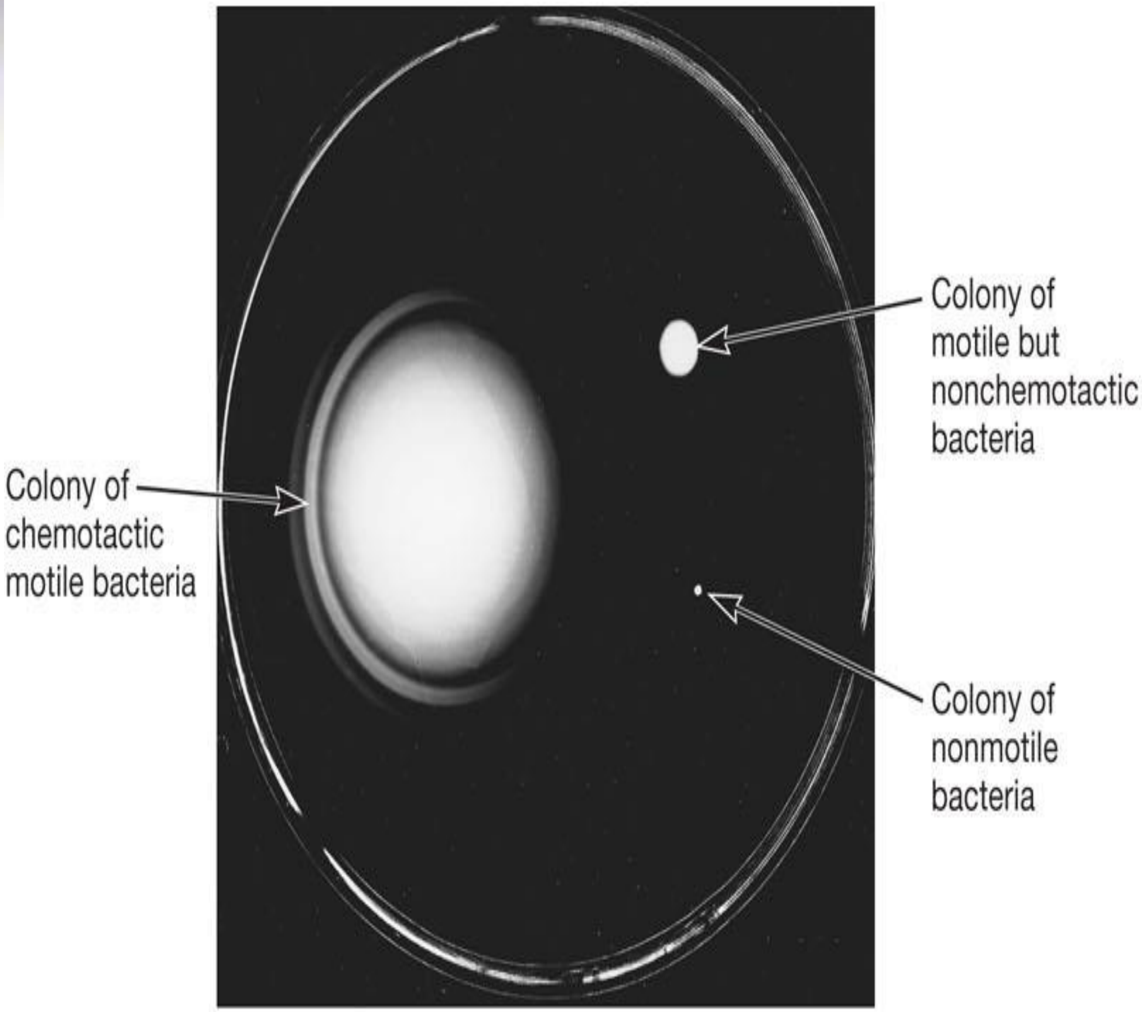
- Threadlike, locomotor appendages extending outward from plasma membrane and cell wall
- Functions
  - motility and swarming behavior
  - attachment to surfaces
  - may be virulence factors

Motility

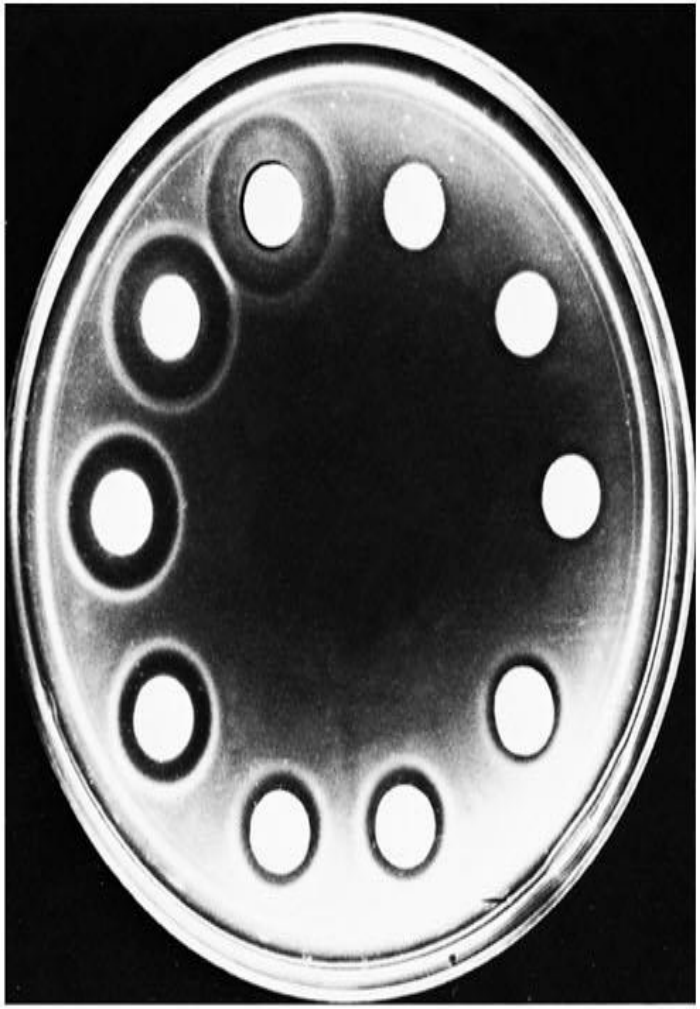
- *Bacteria* and *Archaea* have directed movement
- Chemotaxis
  - move toward chemical attractants such as nutrients, away from harmful substances
- Move in response to temperature, light, oxygen, osmotic pressure, and gravity

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



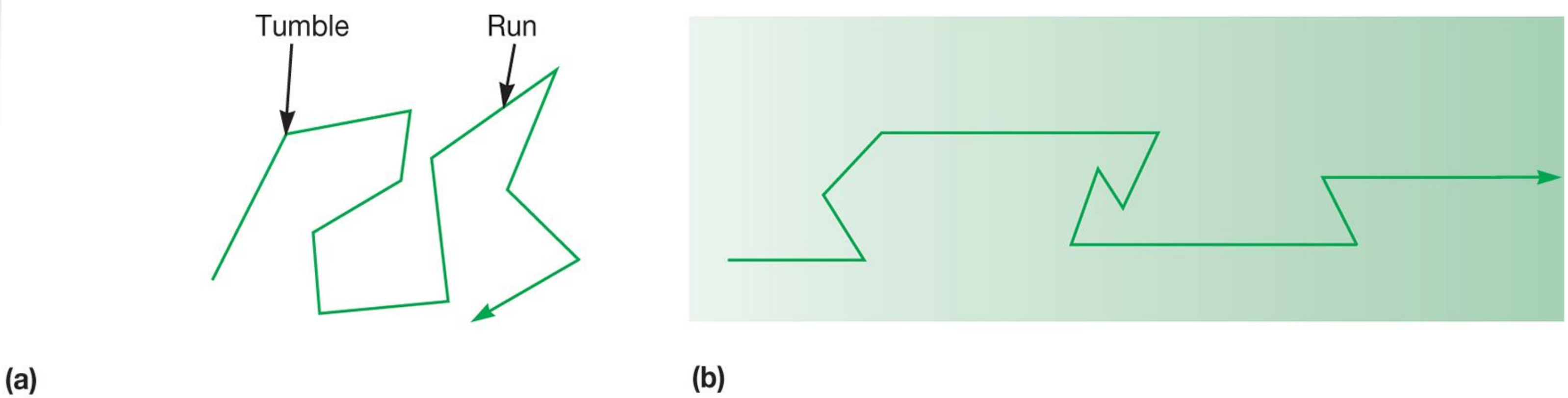
(a) Positive chemotaxis



(b) Negative chemotaxis

Courtesy of Dr. Julius Adler

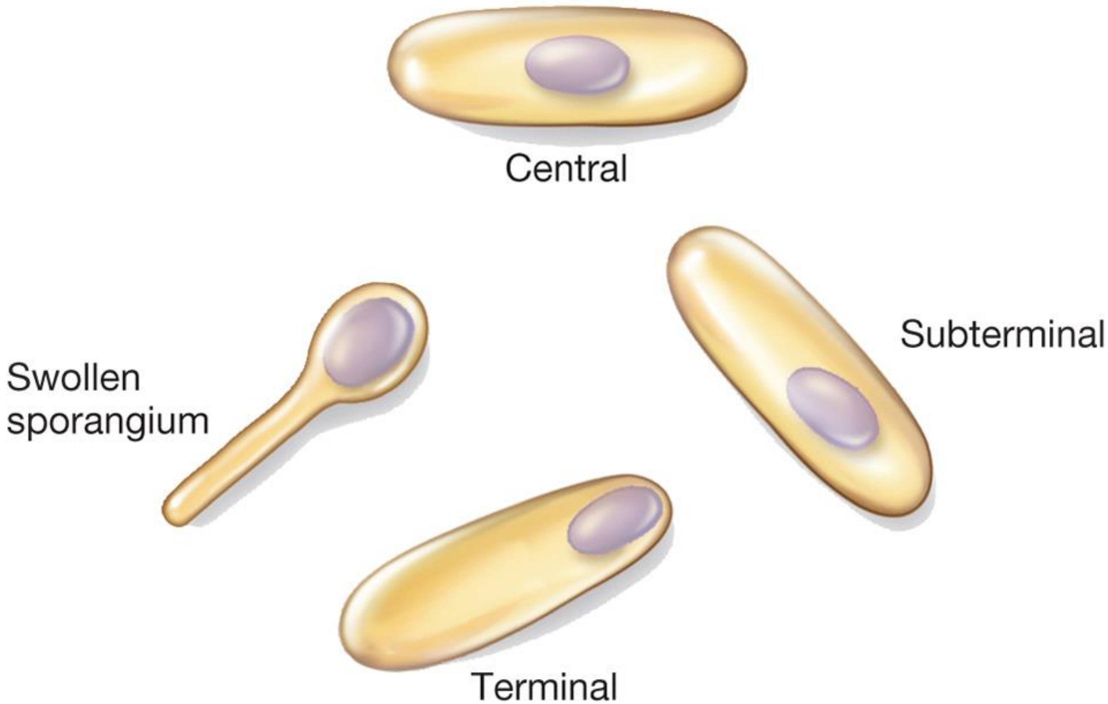
Chemotaxis



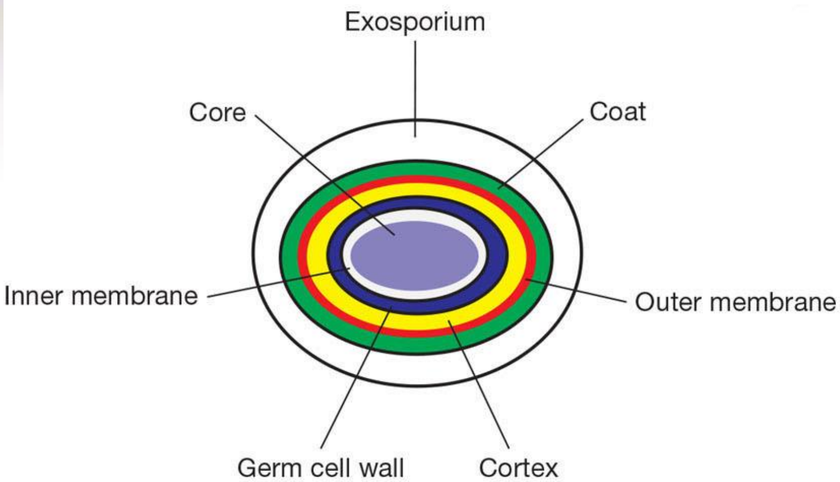
- In presence of attractant (b) tumbling frequency is intermittently reduced and runs in direction of attractant are longer
- Behavior of bacterium is altered by temporal concentration of chemical
- Chemotaxis away from repellent involves similar but opposite responses

The Bacterial Endospore

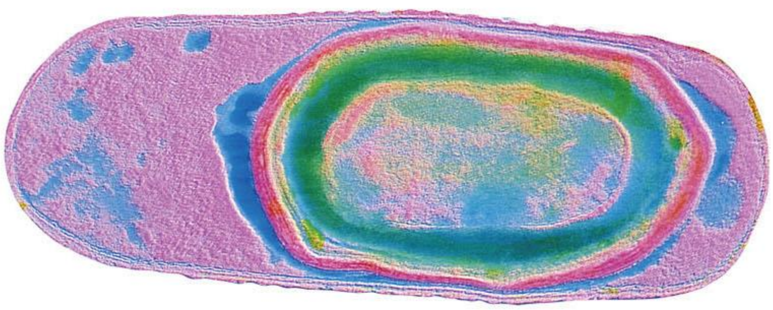
- Complex, dormant structure formed by some bacteria
- Various locations within the cell
- Resistant to numerous environmental conditions
  - heat
  - radiation
  - chemicals
  - desiccation



Endospore Structure



(a)

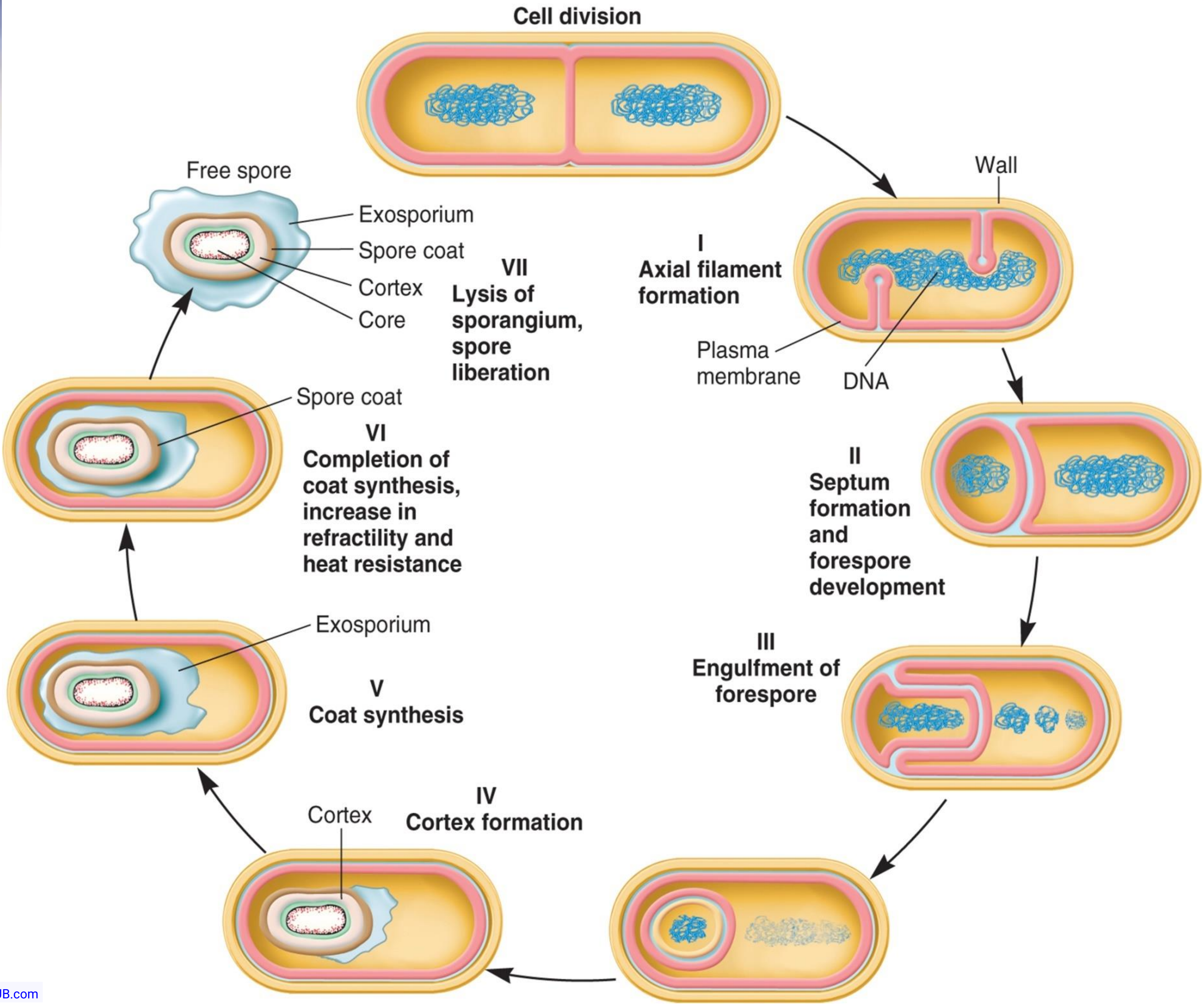


(b)

- 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

Sporulation

- Process of endospore formation
- Takes hours to be completed (up to 10 hours)
- Normally commences when growth ceases because of lack of nutrients
- Complex multistage process


Cell division
Wall
I
Axial filament formation
Plasma membrane
DNA
II
Septum formation and forespore development
III
Engulfment of forespore
IV
Cortex formation
Cortex
V
Coat synthesis
Exosporium
VI
Completion of coat synthesis, increase in refractility and heat resistance
Spore coat
VII
Lysis of sporangium, spore liberation
Free spore
Exosporium
Spore coat
Cortex
Core

Formation of Vegetative Cell

- Activation
  - prepares spores 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