Chapter 3

Bacteria and Archaea

Bacterial and Archaea Structure and Function

- **prokaryotes differ from eukaryotes in size and simplicity**
  - **most lack internal membrane systems**
  - **term prokaryotes is becoming blurred**
  - **this text will use Bacteria and Archaea**
- **prokaryotes are divided into two taxa**
  - ***Bacteria* and *Archaea***

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

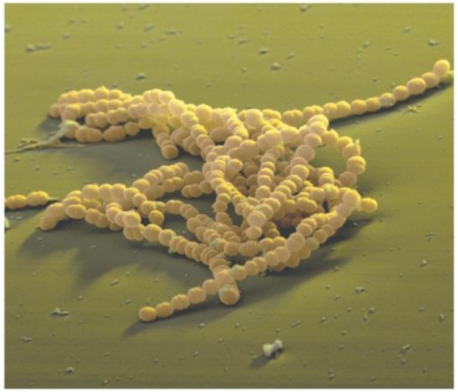
Shape and Arrangement-1

- **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

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

Figure 3.1



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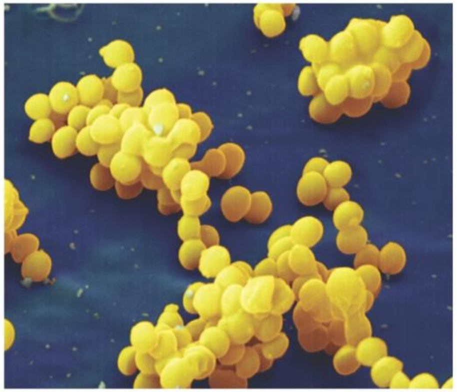

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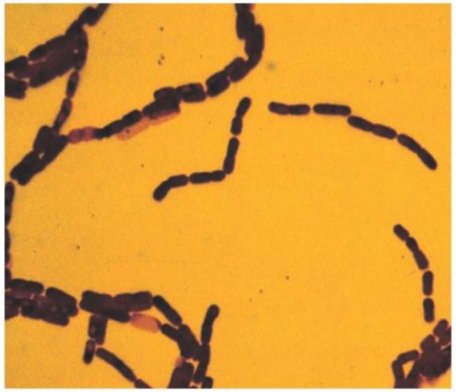

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Shape and Arrangement-3

- **mycelium – network of long, multinucleate filaments**
- **pleomorphic – organisms that are variable in shape**
- ***Archaea***
  - **pleomorphic, branched, flat, square, other unique shapes**

Figure 3.2; e.g v.cholera, Streptomyces, leptospirae etc

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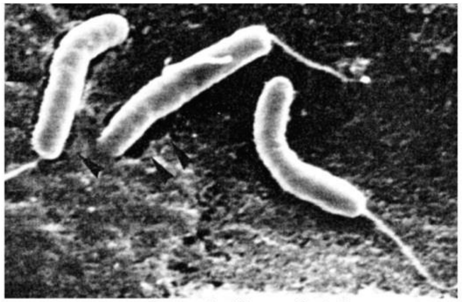

Centers for Disease Control

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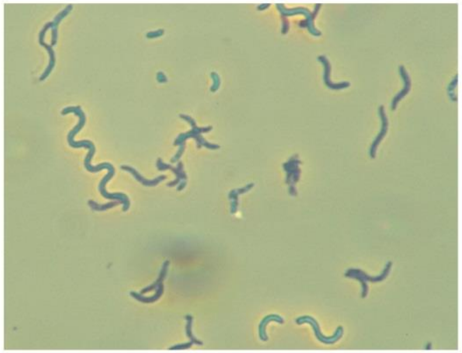

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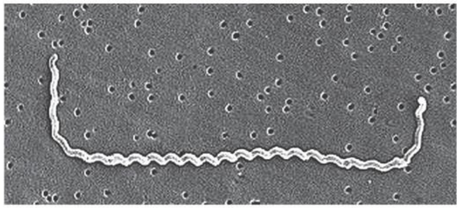

(c) *Leptospira interrogans*—a spirochete

CDC/NCID/HIP/Janice Carr

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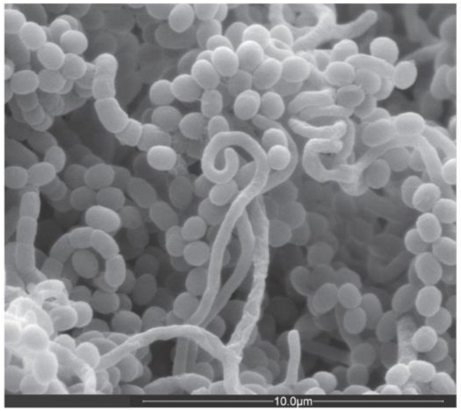

(d) *Streptomyces*—a filamentous bacterium

Dr. Amy Gehring

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From Walther Stoeckenius: Walsby's Square Bacterium Fine Structures of an Orthogonal Procaryote

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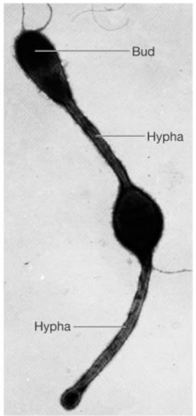

(e) *Hyphomicrobium*

Re-printed from The Shorter Bergey's Manual of Determinative Bacteriology, 8e, John G. Holt, Editor, 1977 © Bergey's Manual Trust. Pub-lished by Williams & Wilkins Baltimore, MD

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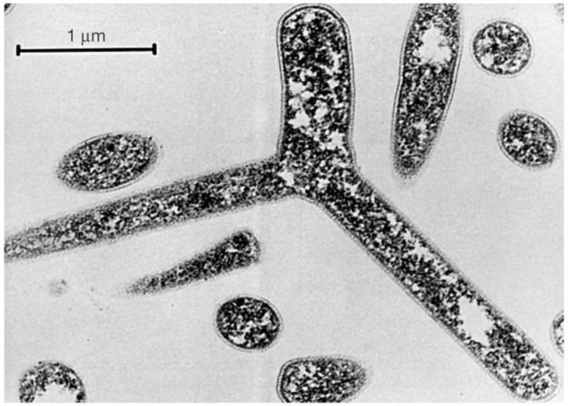

(f) *Thermoproteus tenax*—a branched archaeal cell

From J.T. Staley, M.P. Bryant, N. Pfenning and J.G. Holt (Eds.), Bergey's Manual of System-atic Bacteriology, Vol. 3. © 1989 Williams and Wilkins Co., Baltimore, Robinson, Dept. of Micro, U. of Cal., LA

Size

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

Figure 3.3

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Specimen	Approximate diameter or width × length in nm
Oscillatoria Red blood cell	7,000
E. coli	1,300 × 4,000
Streptococcus	800–1,000
Poxvirus	230 × 320
Influenza virus	85
T2 *E.coli* bacteriophage	65 × 95
Tobacco mosaic virus	15 × 300
Poliomyelitis virus	27

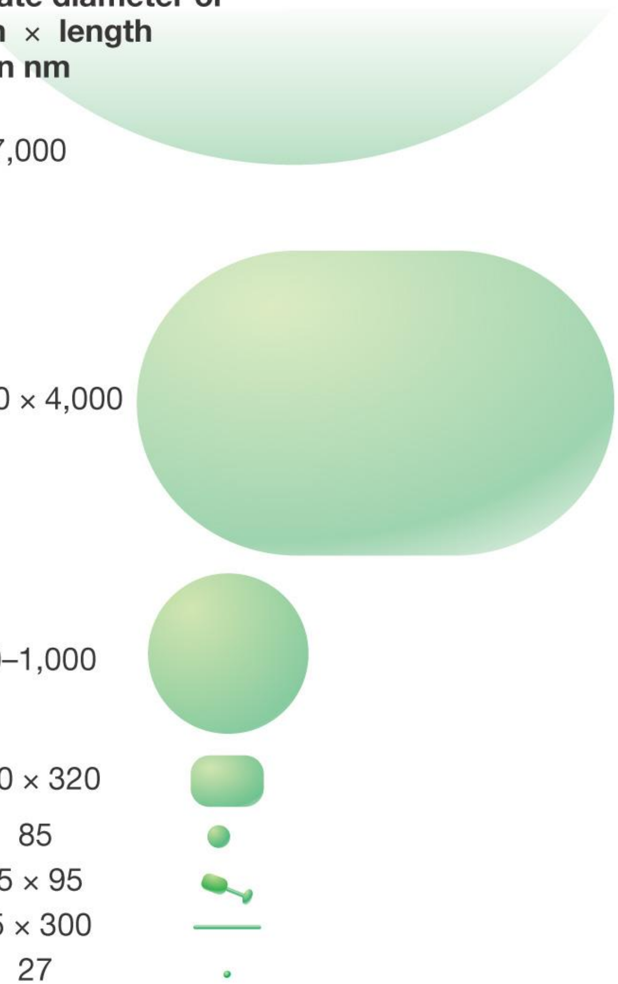

Figure 3.4; *Epulopiscium fishelsoni*

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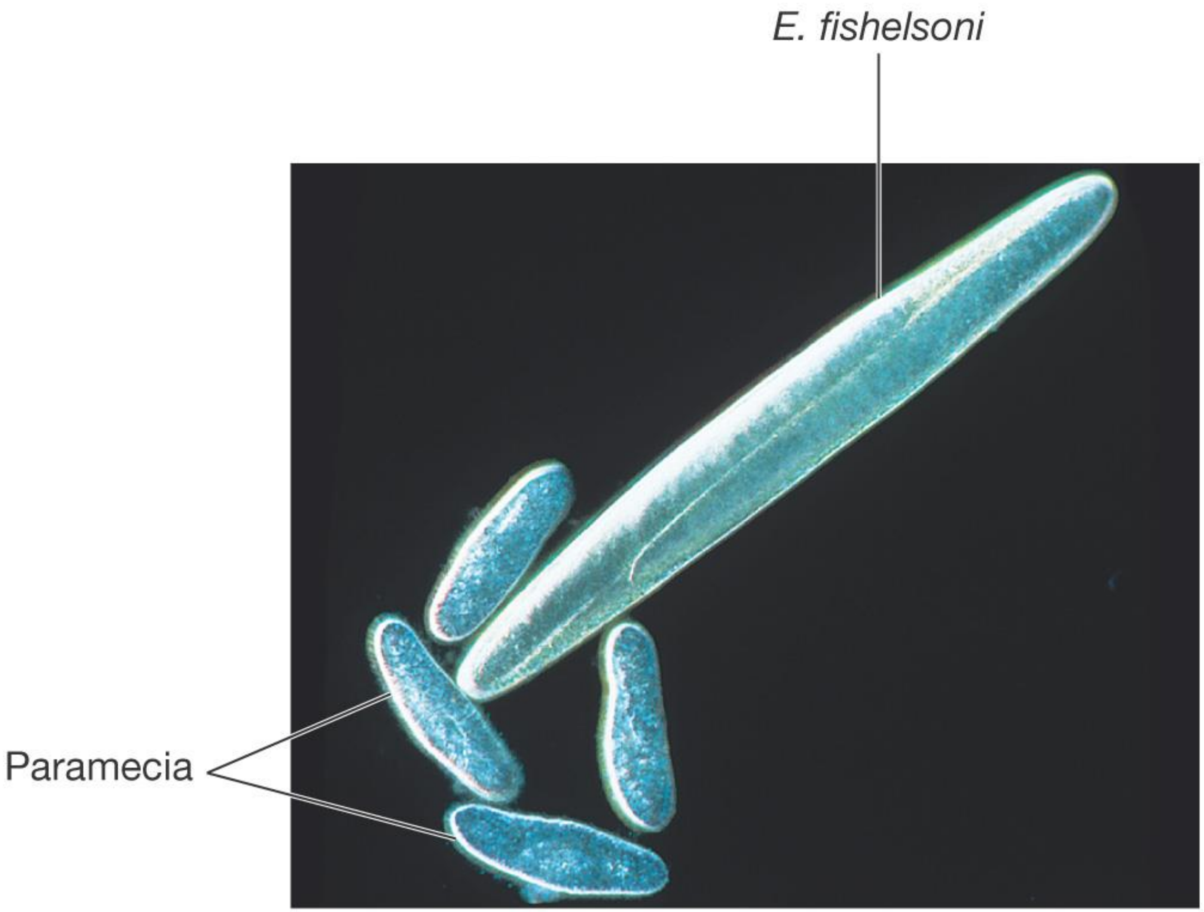

Dr. Leon J. LeBeau

Size – Shape Relationship

- **important for nutrient uptake**
- **Small have higer surface to volume ratio (S/V)**
- **small size may be protective mechanism from predation**

Figure 3.5

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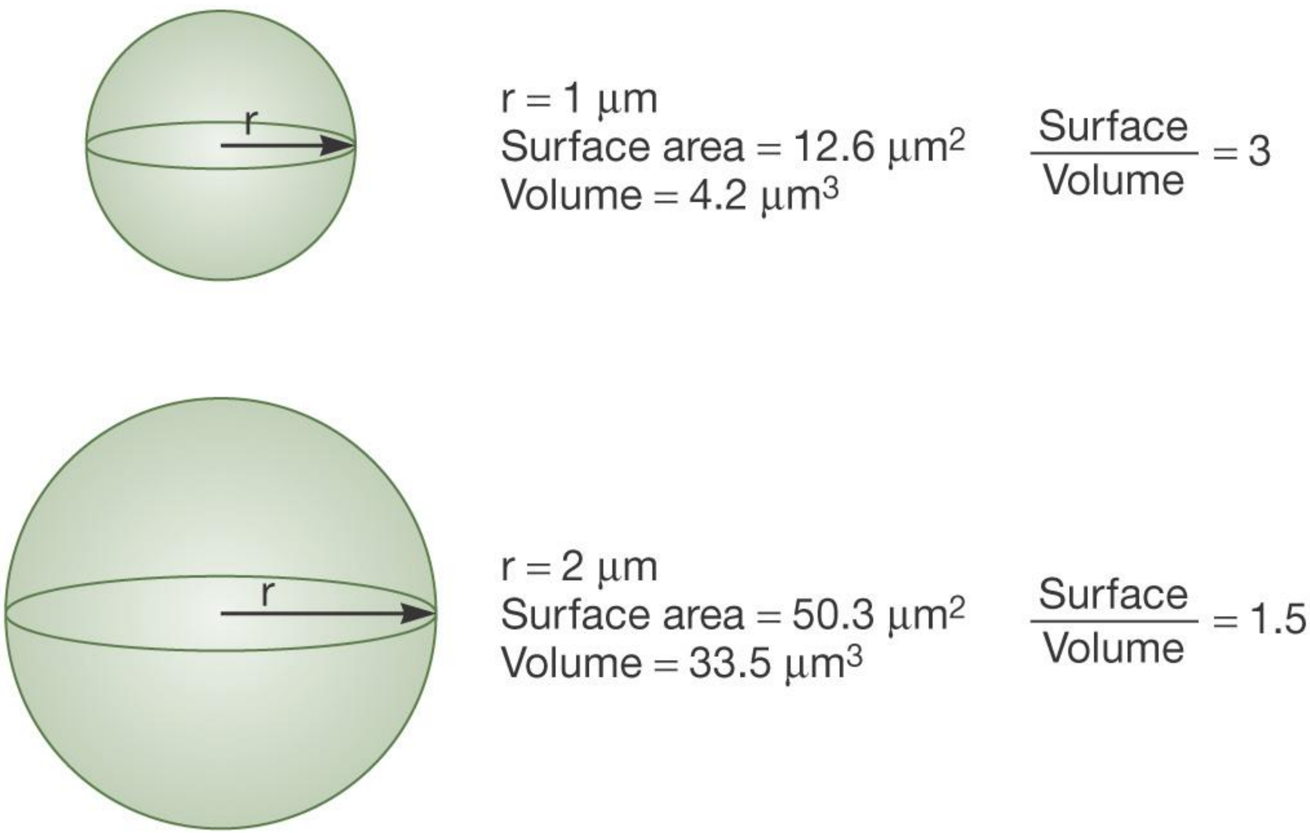

Cell Organization
Archaea and Bacteria
Common Features

Cell envelope – 3 layers

Cytoplasm

External structures

Table 3.1

Figure 3.6

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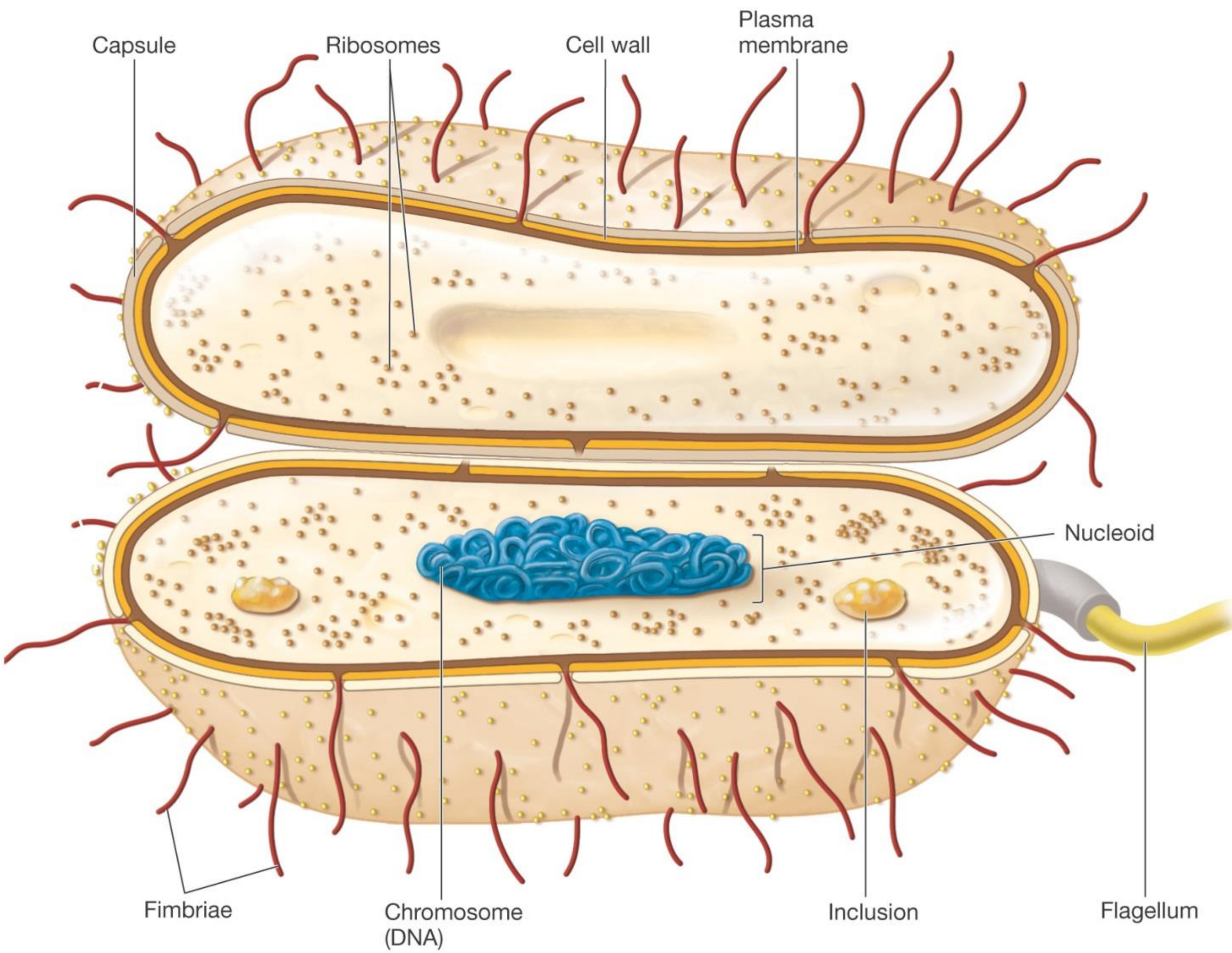

Bacterial Cell Envelope

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**

Fluid Mosaic Model of Membrane Structure

Figure 3.7

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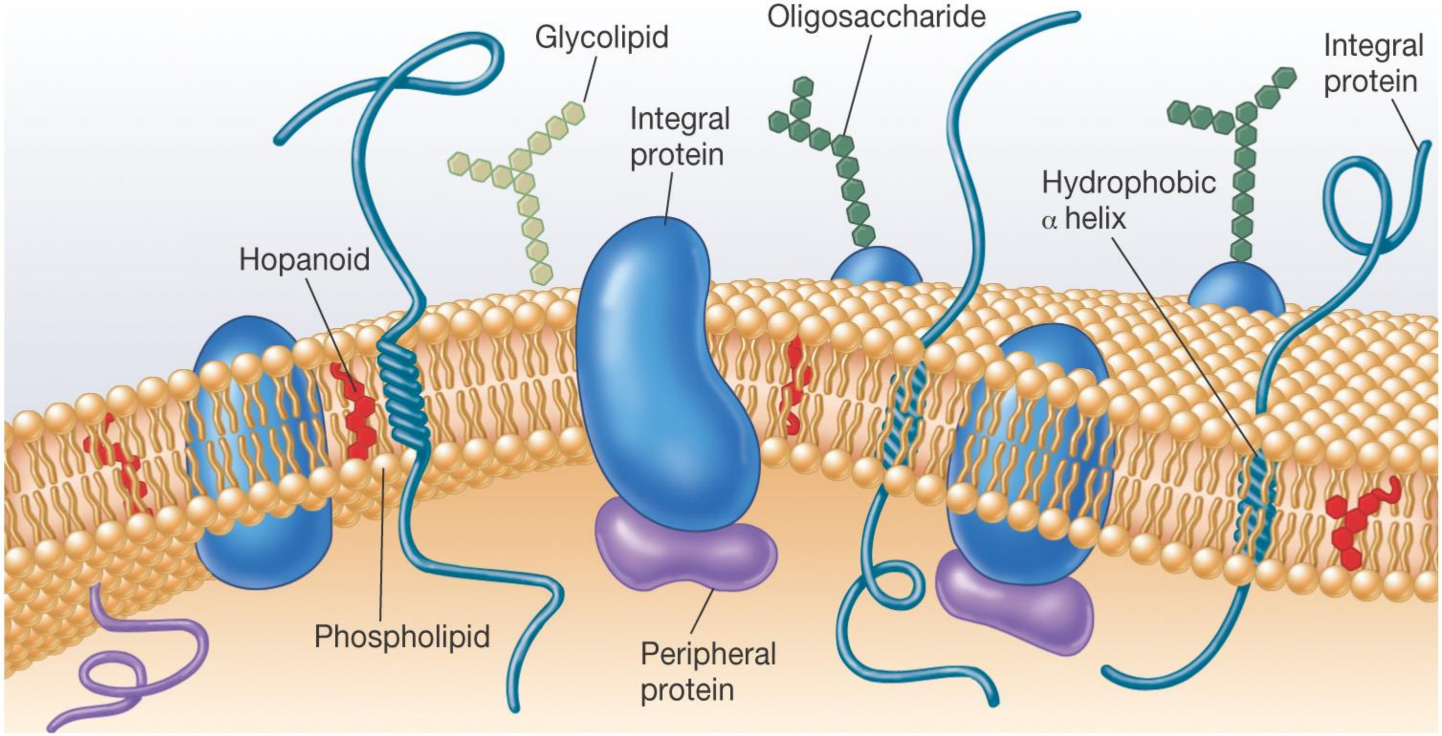

The Asymmetry of Most Membrane Lipids

Figure 3.8

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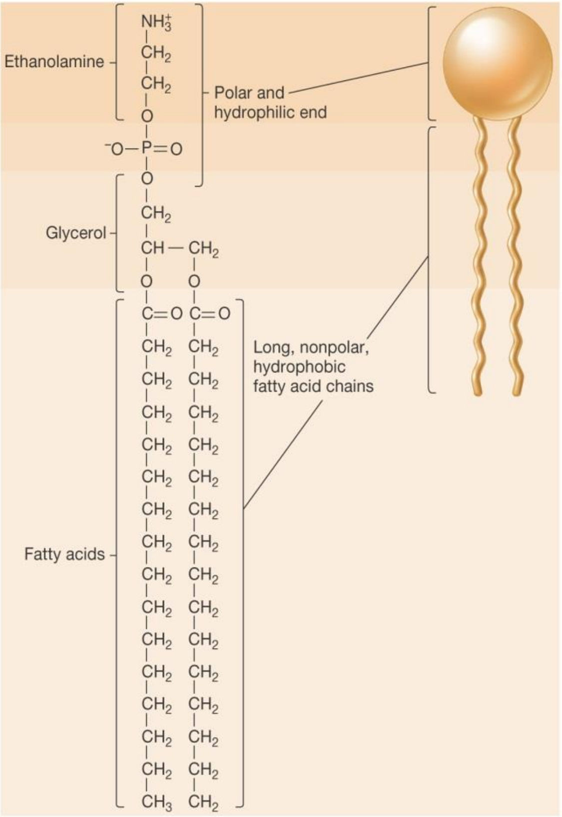

Membrane Proteins

- **peripheral**
  - **loosely connected to membrane**
  - **easily removed**
- **integral**
  - **amphipathic – embedded within membrane**
  - **carry out important functions**
  - **may exist as microdomains**

Bacterial Lipids

- **saturation levels of membrane lipids reflect the environmental conditions such as temperature**
- **bacterial membranes lack sterols but do contain sterol-like molecules, hopanoids**
  - **stabilize membrane**
  - **found in petroleum**

Figure 3.9 Membrane Steroids and Hopanoids

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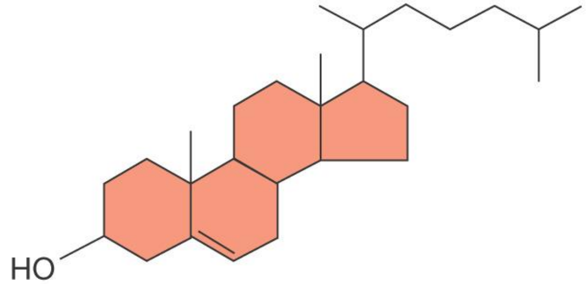
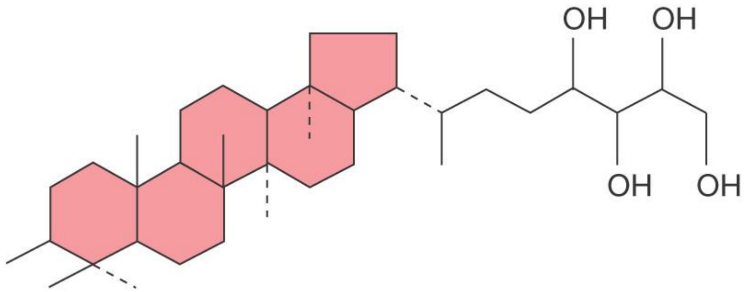


(a) Cholesterol (a steroid) is found in eucaryotes

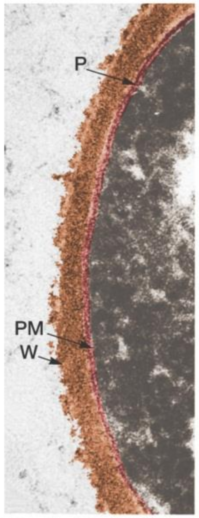


(b) A bacteriohopanetetrol (a hopanoid) is found in bacteria

Bacterial Cell Wall

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

Figure 3.10



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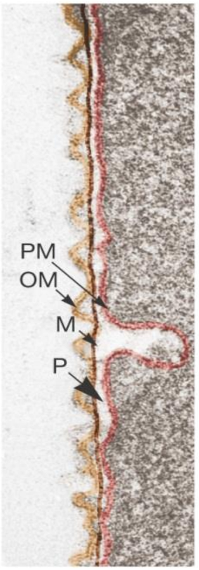

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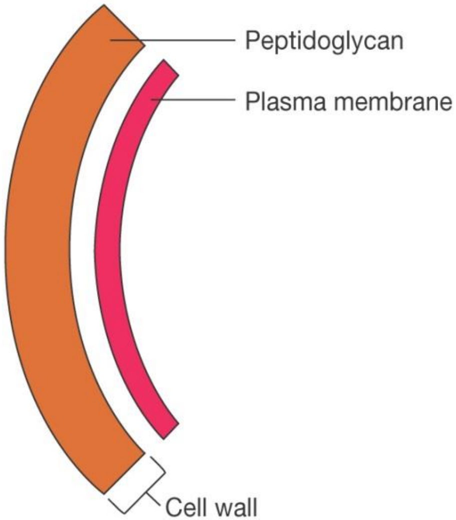
The gram-positive cell wall



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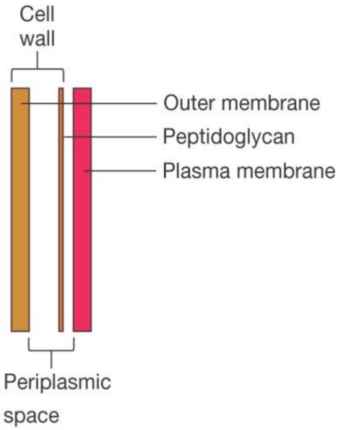
The gram-negative cell wall



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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**

Figure 3.11

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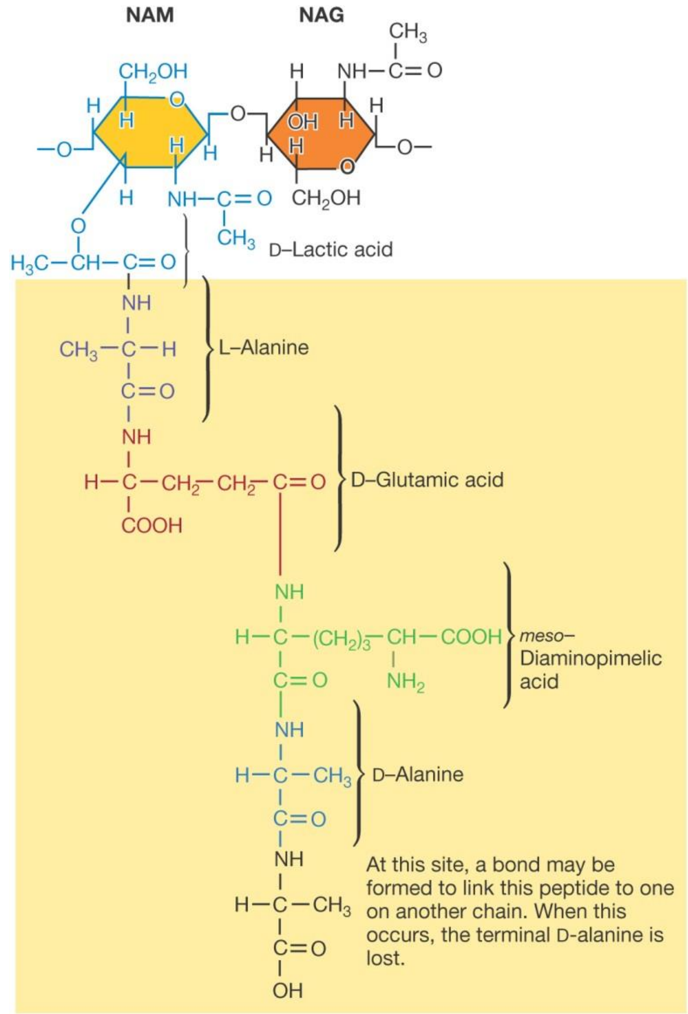

Strands Are Crosslinked

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

Figure 3.12

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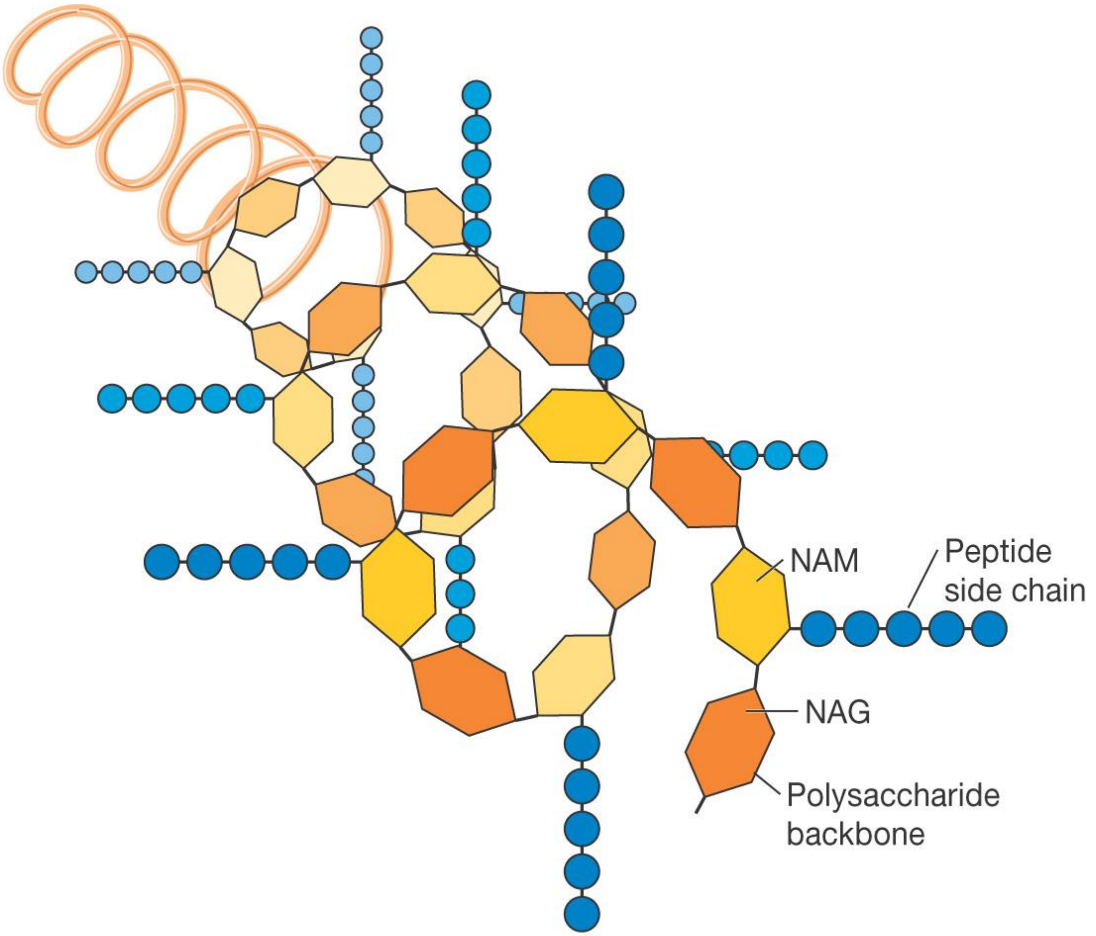

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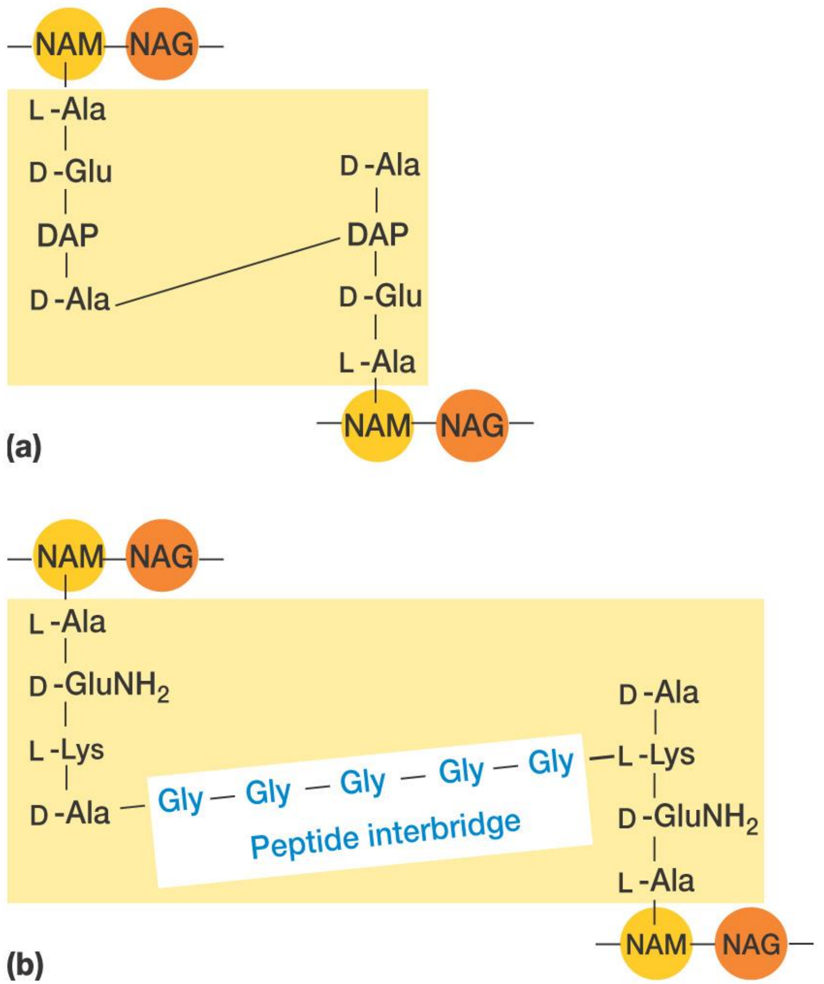

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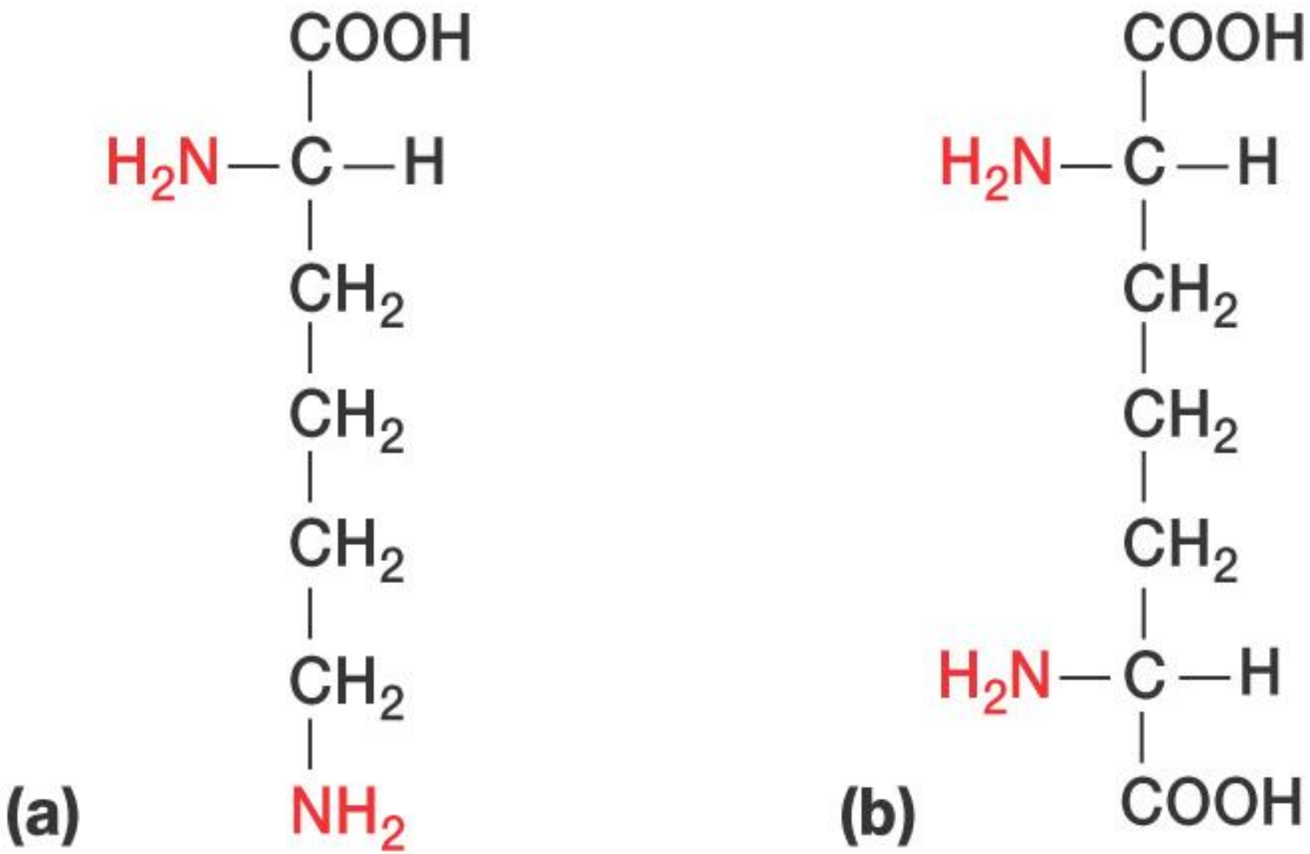

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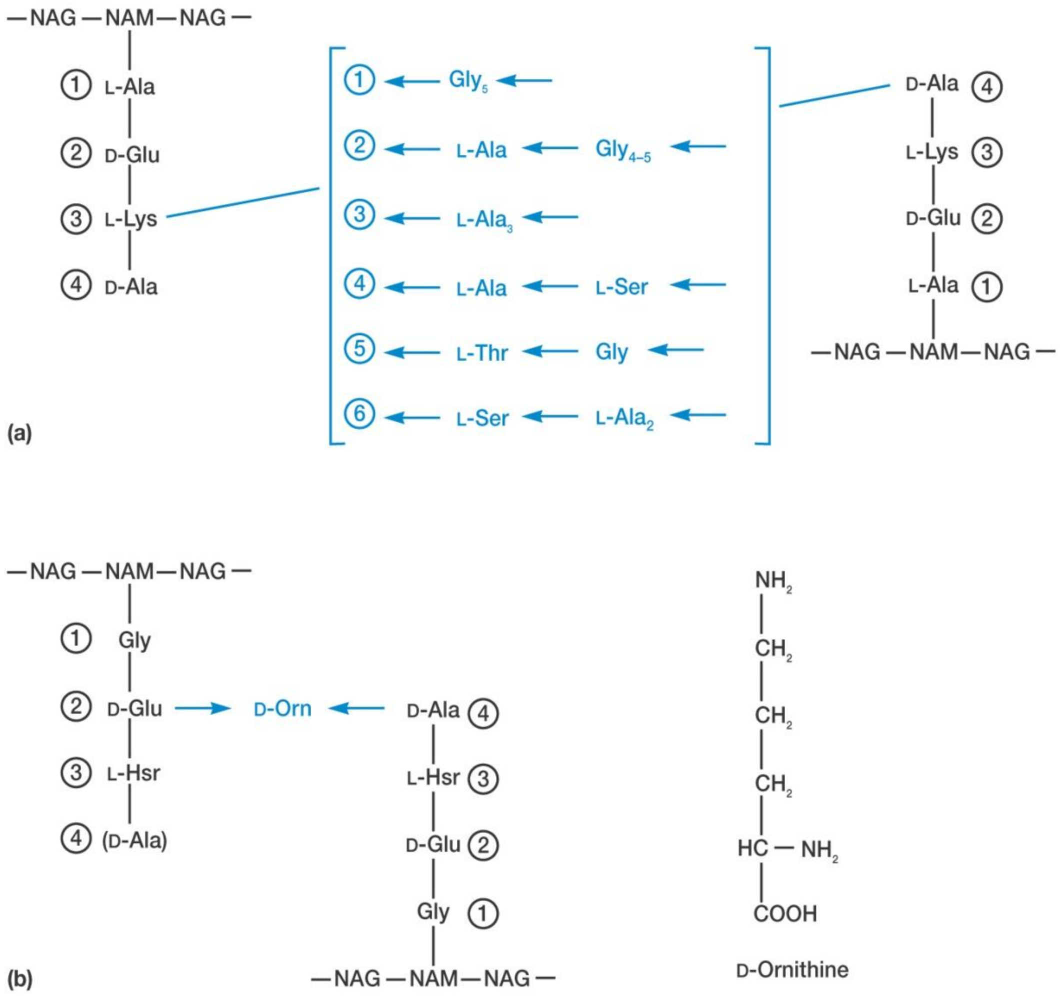

Gram-Positive Cell Walls

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

Periplasmic Space of Gram +ve Bacteria

- lies between plasma membrane and cell wall and is smaller than that of gram-negative bacteria
- periplasm has relatively few proteins
- enzymes secreted by gram-positive bacteria are called exoenzymes
  - aid in degradation of large nutrients

Figure 3.17; gm+ cell wall

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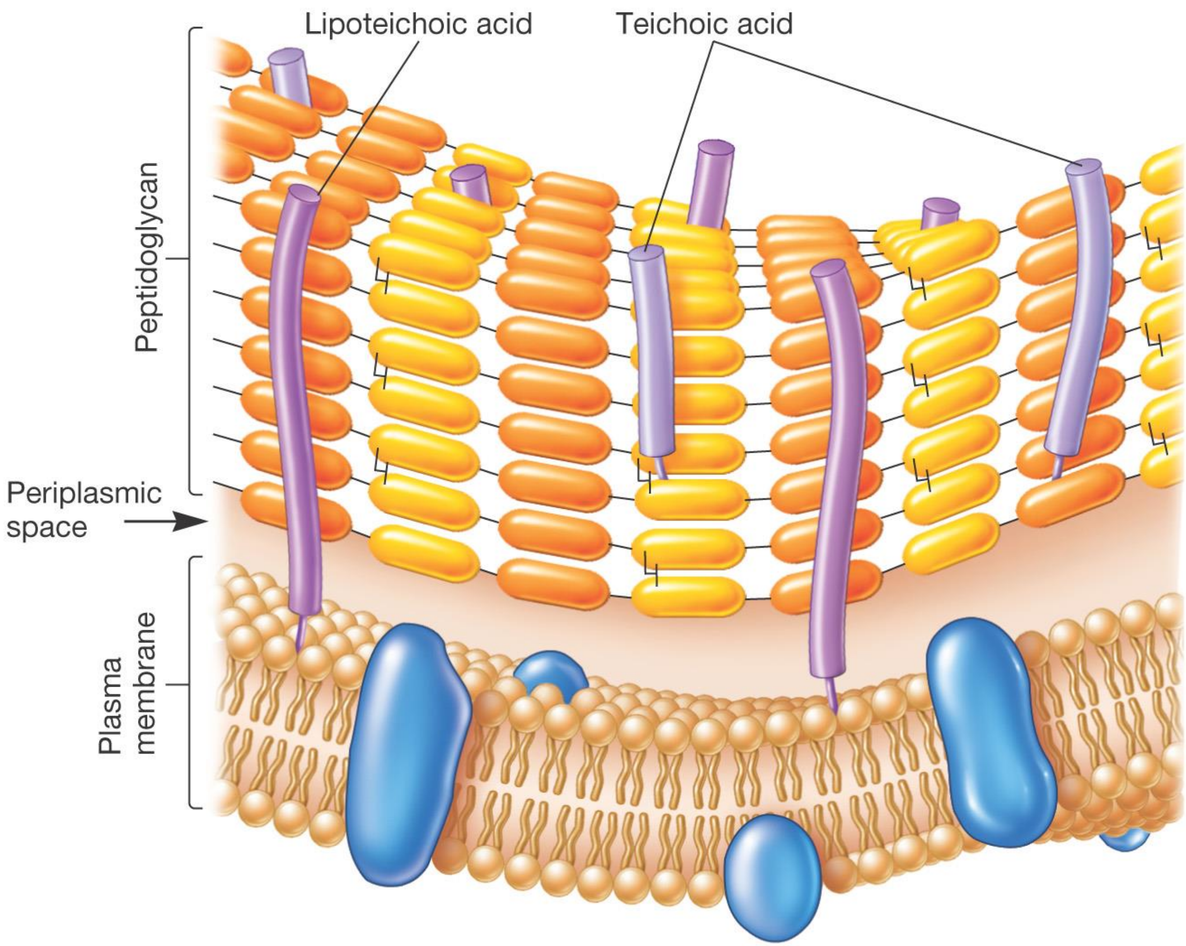

Figure 3.18; teichoic acid structure

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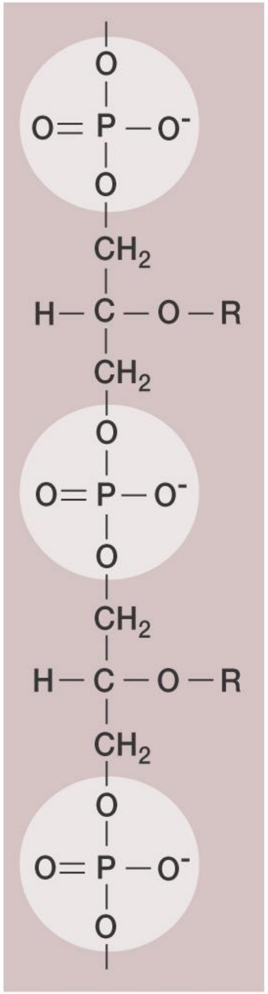

Gram-Negative Cell Walls

- 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

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 connects outer membrane to peptidoglycan**
- **other adhesion sites were also reported to be present in the Gm –ve cell wall**

Figure 3.19; typical Gram negative cell wall

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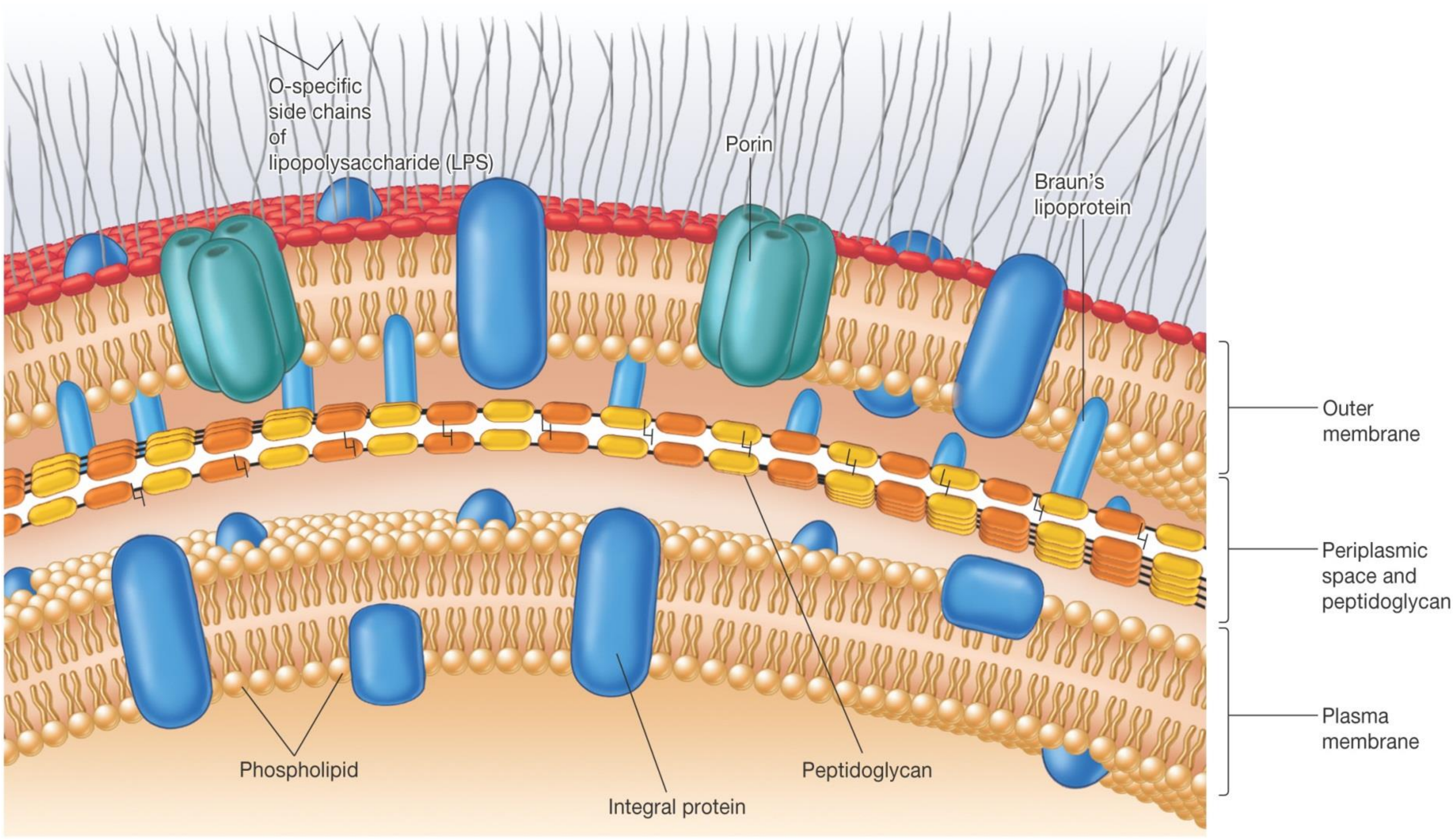

Lipopolysaccharides (LPSs)

- consists of three parts
  - lipid A (toxic)
  - core polysaccharide
  - O side chain (O antigen); used in bacterial classification and identification
- lipid A embedded in outer membrane
- core polysaccharide, O side chain extend out from the cell

Figure 3.20; LPS

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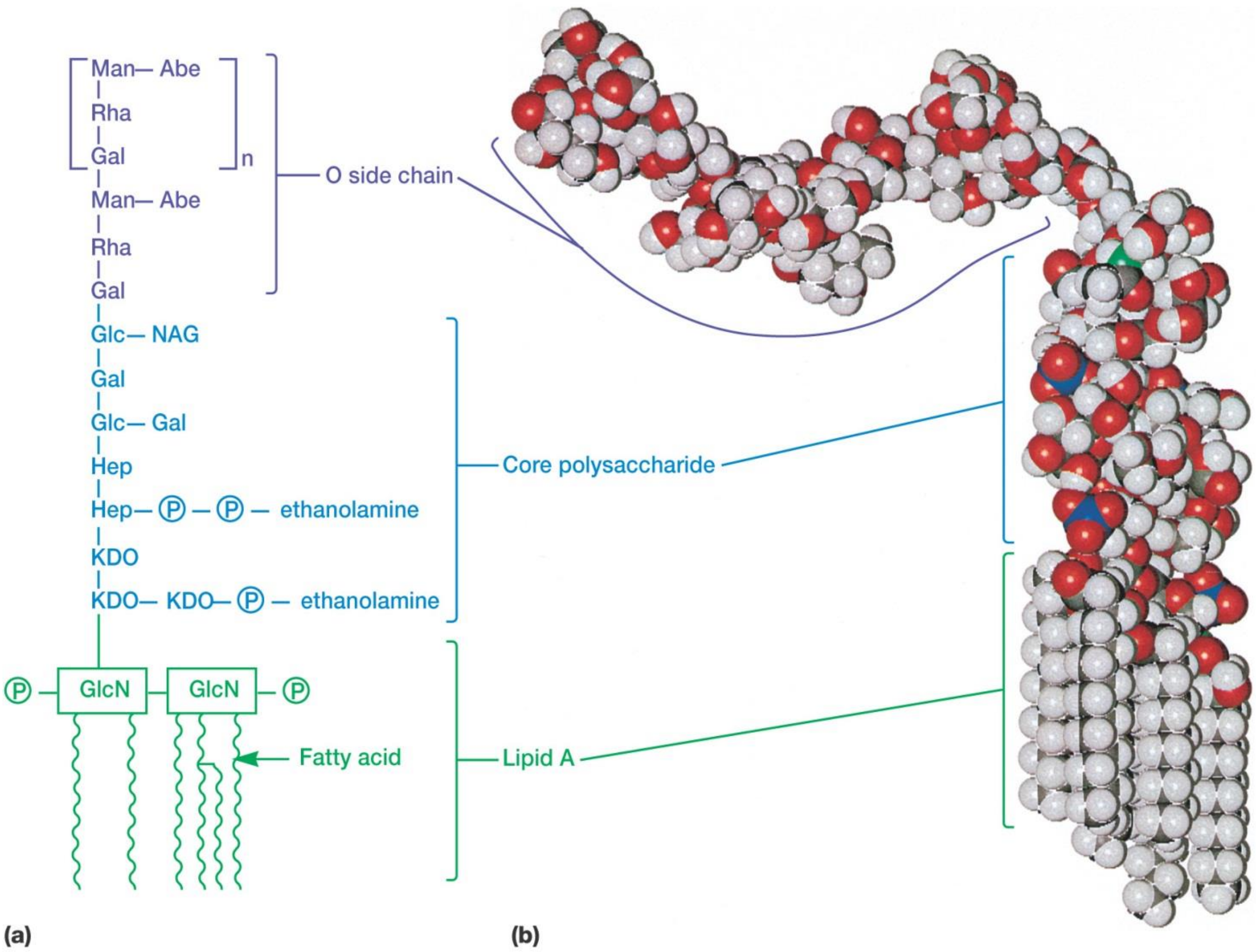


From M. Kastowsky, T. Gutberlet, and H. Bradaczek, Journal of Bacteriology, 774:4798–4806, 1992

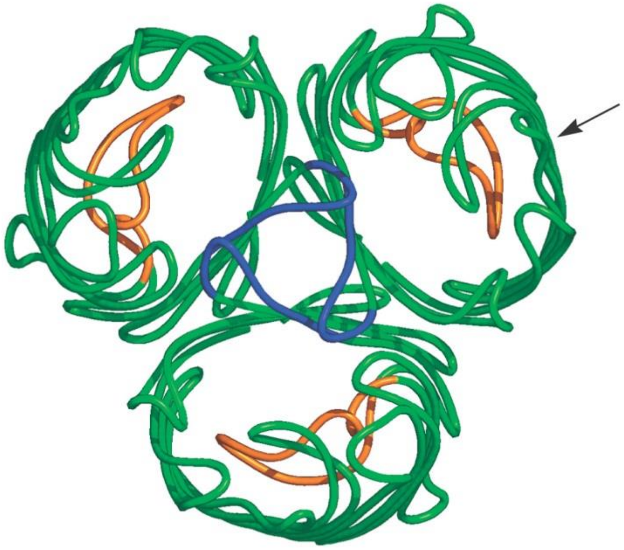
Importance of LPS

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

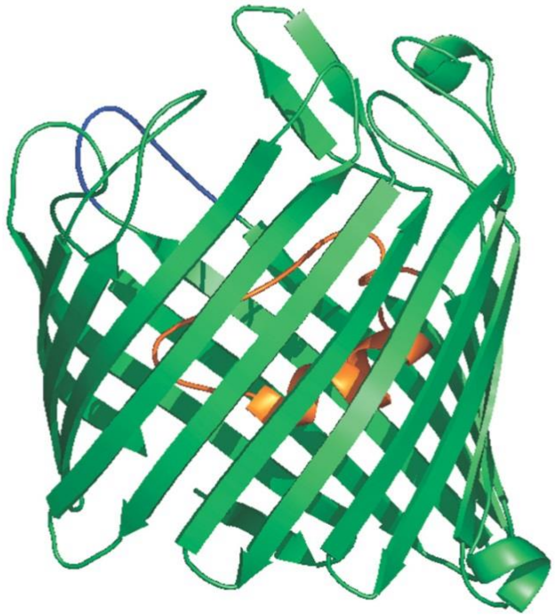
Gram-Negative Outer Membrane Permeability

- **more permeable than plasma membrane due to presence of porin proteins and transporter proteins**
  - **porin proteins form channels through which small molecules (600–700 daltons) can pass**

Figure 3.21; porin proteins



(a) Porin trimer



(b) OmpF side view

Steps of Gram stain

1. fixation of the bacteria on the slide
2. adding gram stain (violet)
3. washing
4. adding the counter stain (red)

Mechanism of Gram Stain Reaction

- **Gram stain reaction due to nature of cell wall**
- **shrinkage of the pores of peptidoglycan layer of gram-positive cells**
  - **constriction prevents loss of crystal violet during decolorization step**
- **thinner peptidoglycan layer and larger pores of gram-negative bacteria does not prevent loss of crystal violet**

Cell walls and 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**

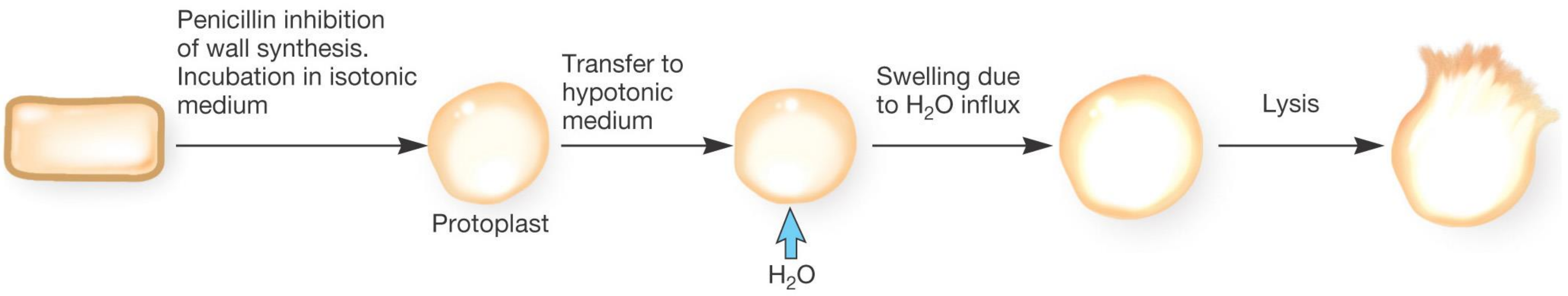
Evidence of Protective Nature of the Cell Wall

- **lysozyme breaks the bond between N-acetyl glucosamine and N-acetylmuramic acid**
- **penicillin inhibits peptidoglycan synthesis**
- **if cells are treated with either of the above they will lyse if they are in a hypotonic solution**

Loss of Cell Wall May Survive in Isotonic Environments

- **protoplasts**
- **spheroplasts**
- ***Mycoplasma***
  - **does not produce a cell wall**
  - **Sensitive to osmotic pressure and if placed in hypotonic solution they burs and get destroyed**

Figure 3.22; protoplast formation and lysis



Components Outside of the Cell Wall

- **outermost layer in the cell envelope**
- **Glycocalyx (polysaccharides) including;**
  - **capsules and slime layers (fuzzy)**
  - **S layers (structured)**
- **aid in attachment to solid surfaces**
  - **e.g., biofilms in plants and animals**

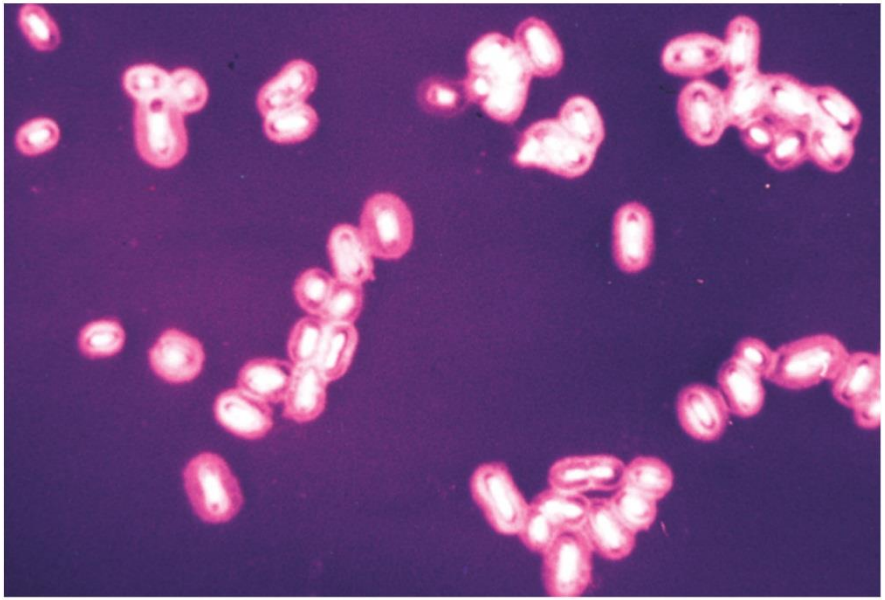
Capsules

- **usually composed of polysaccharides**
- **well organized and not easily removed from cell**
- **visible in light microscope**
- **protective advantages**
  - **resistant to phagocytosis**
  - **protect from dessication**
  - **exclude viruses and detergents**

Slime Layers

- similar to capsules except diffuse, unorganized and easily removed
- slime may aid in motility

Figure 3.23; bacterial capsules; *K. pneumoniae*



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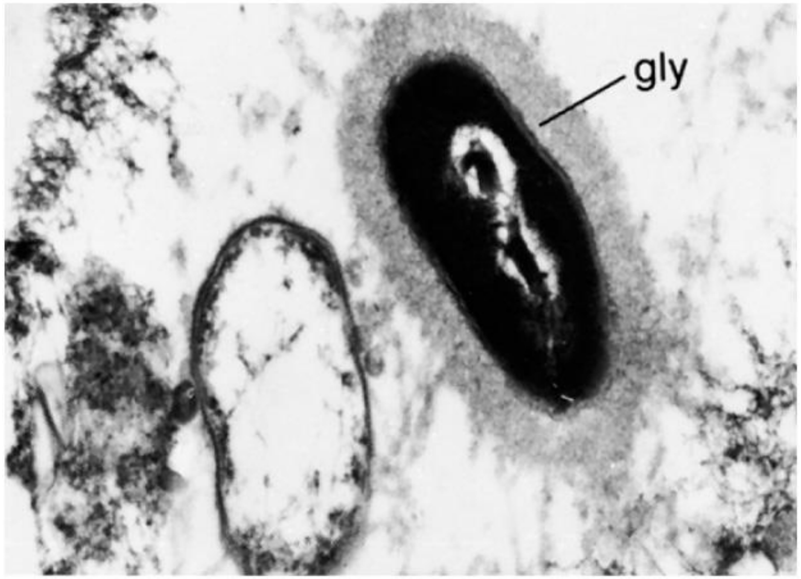

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Figure 3.24; bacterial glycocalyx

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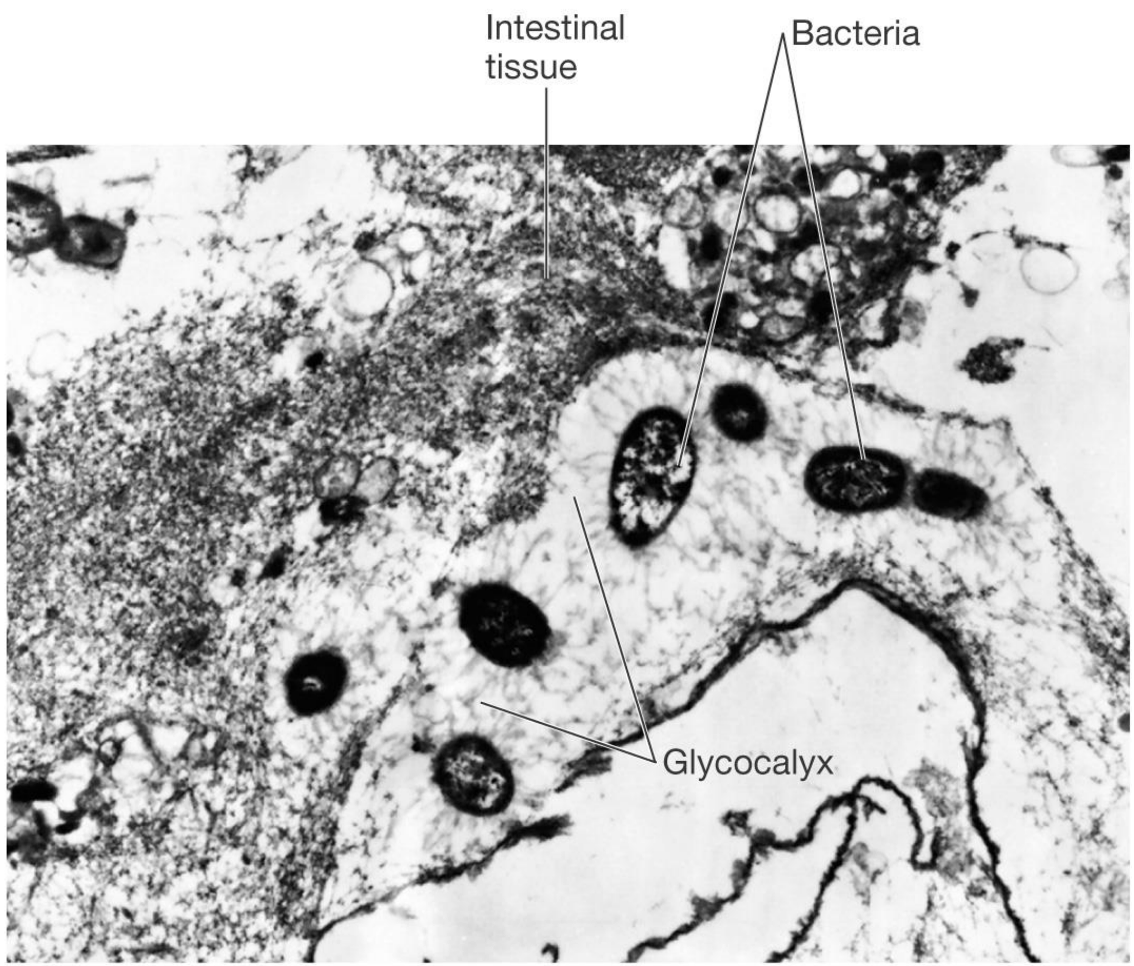

S Layers

- **regularly structured layers of protein or glycoprotein that self-assemble**
  - **in gram-negative bacteria the S layer adheres to outer membrane**
  - **in gram-positive bacteria it is associated with the peptidoglycan surface**

S Layer Functions

- **protect from ions and pH fluctuations, osmotic stress, enzymes, and predation**
- **maintains shape and rigidity**
- **promotes adhesion to surfaces**
- **protects from host defenses**
- **potential use in nanotechnology**
  - **S layer spontaneously associates**

Archaeal Cell Envelopes

- **differ from bacterial envelopes in the molecular makeup and organization**
  - **S layer may be only component outside plasma membrane**
  - **some lack cell wall**
  - **capsules and slime layers are rare**

Archaeal Membranes

- composed of unique lipids
  - isoprene units (five carbon, branched)
  - ether linkages rather than ester linkages to glycerol
- some have a monolayer structure instead of a bilayer structure

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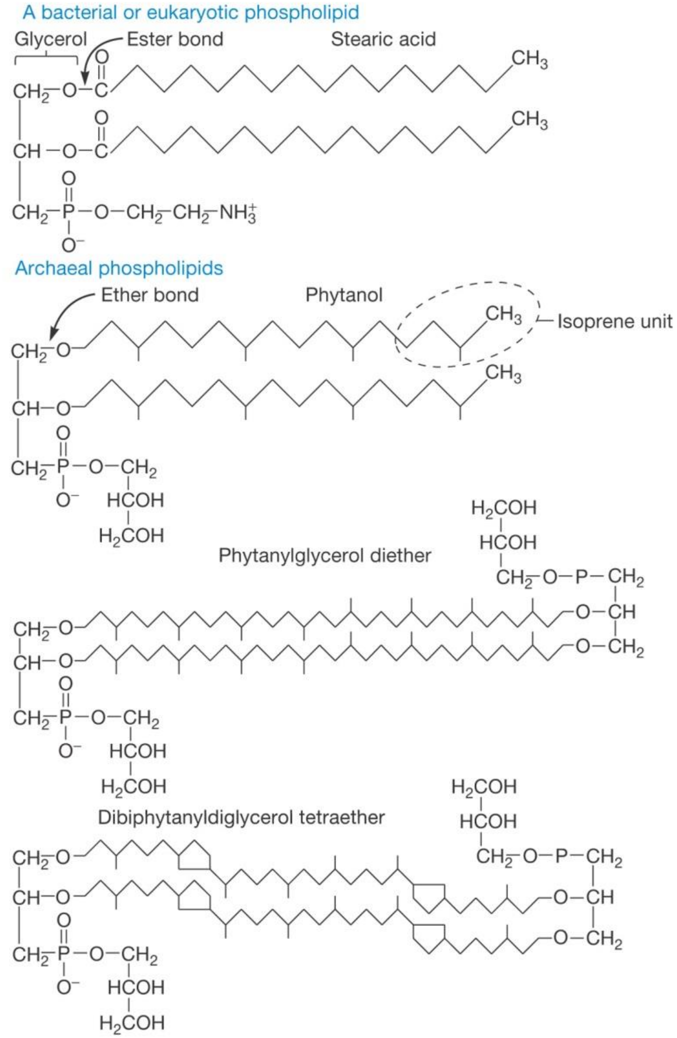

Figure 3.27

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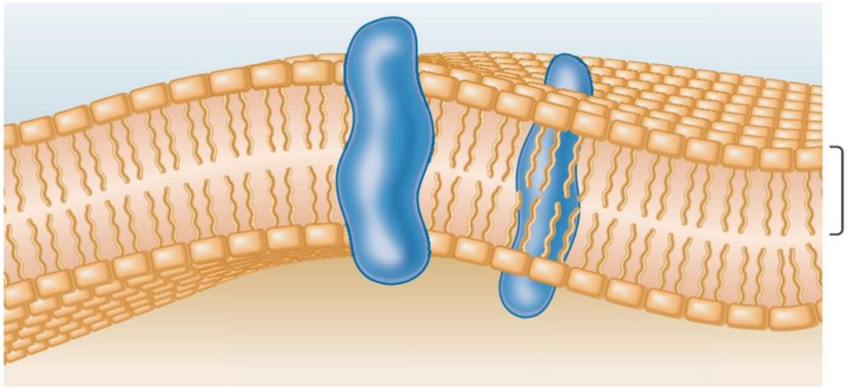
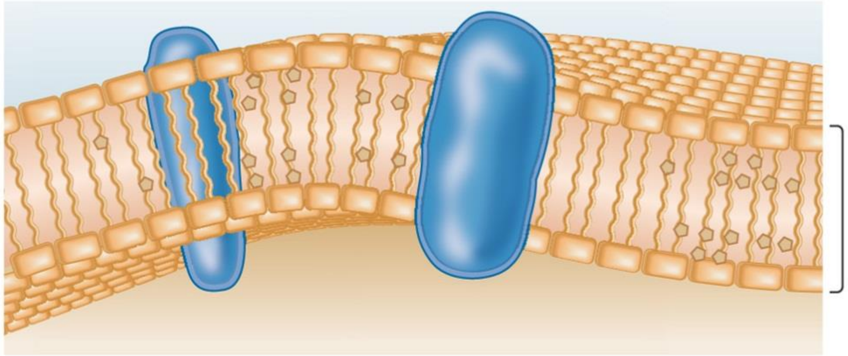


(a) Bilayer of C_{20} diethers

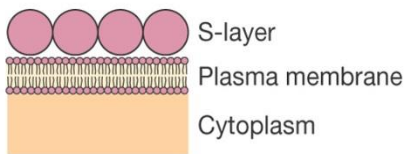


(b) Monolayer of C_{40} tetraethers

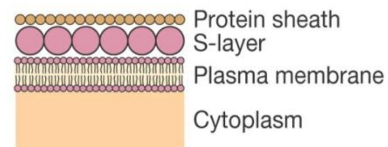
Archaeal Cell Walls Differ from Bacterial Cell Walls

- **lack peptidoglycan**
- **most common cell wall is S layer**
- **may have protein sheath external to S layer**
- **S layer may be outside membrane and separated by pseudomurein**
- **pseudomurein may be outermost layer – similar to gram-positive microorganisms**

Figure 3.28



(a)



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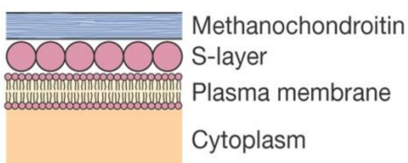

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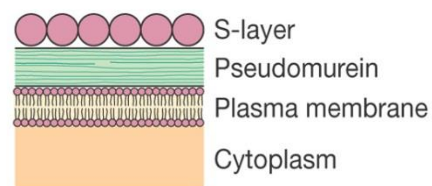

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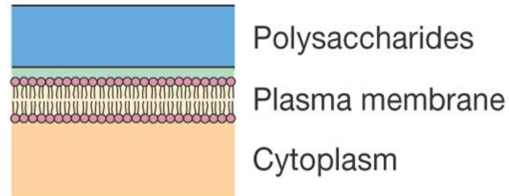

(e)

Figure 3.29

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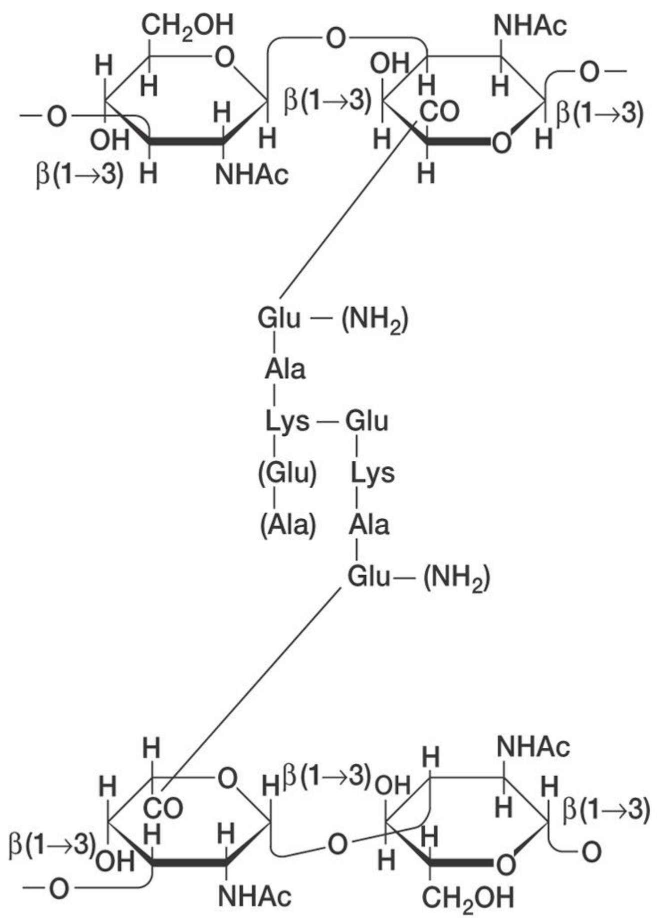

N-acetyltalosaminuronic acid *N*-acetylglucosamine

Bacterial and Archaeal Cytoplasmic Structures

Cytoskeleton

Intracytoplasmic membranes

Inclusions

Ribosomes

Nucleoid and plasmids

Protoplast and Cytoplasm

- **protoplast is plasma membrane and everything within**
- **cytoplasm - material bounded by the plasmid membrane**

The Cytoskeleton

- **homologs of all 3 eukaryotic cytoskeletal elements have been identified in bacteria and 2 in archaea**
- **functions are similar as in eukaryotes**
  - **Role in cell division, protein localization, and determination of cell shape**

Table 3.2

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Table 3.2 Bacterial Cytoskeletal Proteins

Type	*Function*	*Comments*
Tubulin homologs		
FtsZ	Cell division	Widely observed in *Bacteria* and *Archaea*
BtubA/BtubB	Unknown	Observed only in *Prosthecobacter*; thought to be encoded by eukaryotic tubulin genes obtained by horizontal gene transfer
Actin homologs		
FtsA	Cell division	Observed in many bacterial species
MamK	Positioning magnetosomes	Observed in magnetotactic species
MreB/Mbl	Maintains cell shape, segregates chromosomes, localizes proteins	Most rod-shaped bacteria
Intermediate filament homologs		
CreS (crescentin)	Induces curvature in curved rods	*Caulobacter crescentus*
Unique bacterial cytoskeletal proteins		
MinD	Prevents polymerization of FtsZ at cell poless	Many rod-shaped bacteria
ParA (chromosome-encoded form)	Segregates chromosomes	Observed in many species including *Vibrio cholerae* and *C. crescentus*

Best Studied Examples

- **FtsZ – many bacteria and archaea**
  - **forms ring during septum formation in cell division**
- **MreB – many rods, some archaea**
  - **maintains shape by positioning peptidoglycan synthesis machinery**
- **CreS – rare, maintains curve shape**

Figure 3.30; Ftsz, mbl and crescentin

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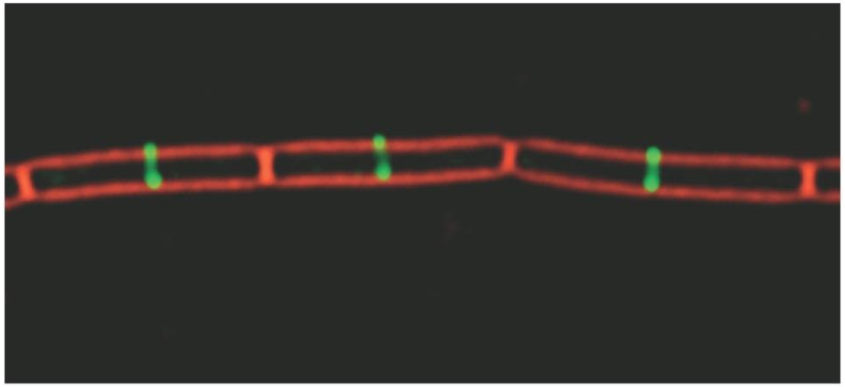

(a) FtsZ

Dr. Joseph Pogliano

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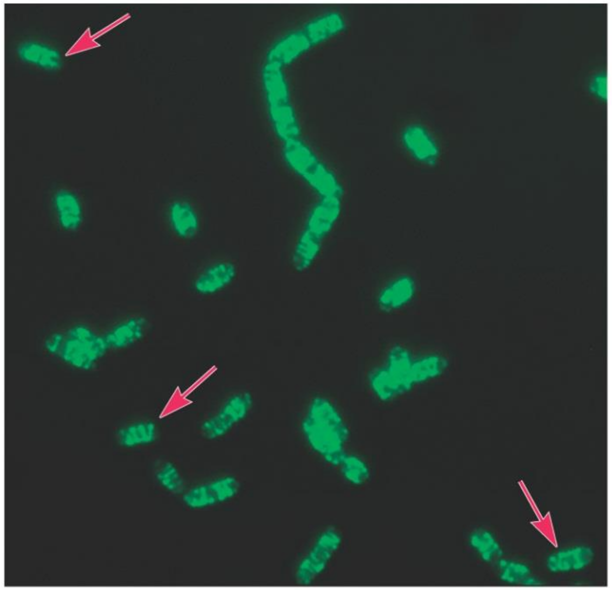

(b) Mbl

(c) Mbl

Image courtesy of Rut Carballido-Lo'pez and Jeff Errington

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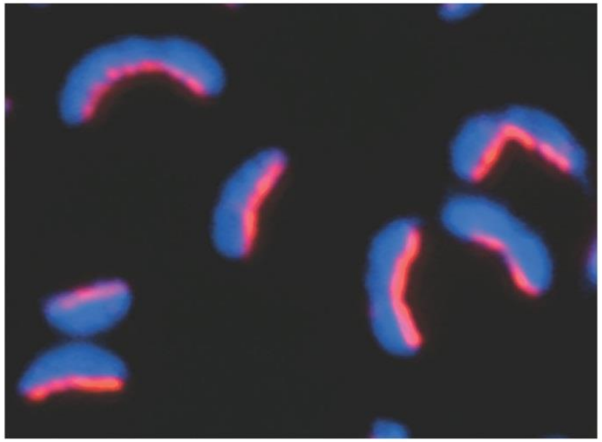


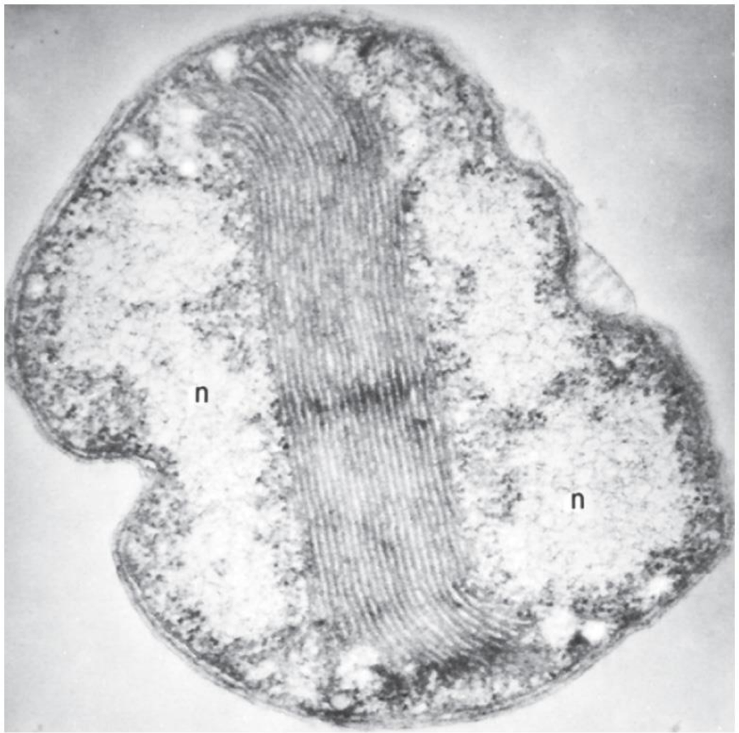
(d) Crescentin

Dr. Chistine Jacobs-Wagner

Intracytoplasmic Membranes

- **plasma membrane infoldings**
  - **observed in many photosynthetic bacteria**
    - **analogous to thylakoids of chloroplasts**
    - **reactions centers for ATP formation**
  - **observed in many bacteria with high respiratory activity**
- **anammoxosome in *Planctomycetes***
  - **organelle – site of anaerobic ammonia oxidation**

Figure 3.3; internal bacterial membranes



American Society for Microbiology

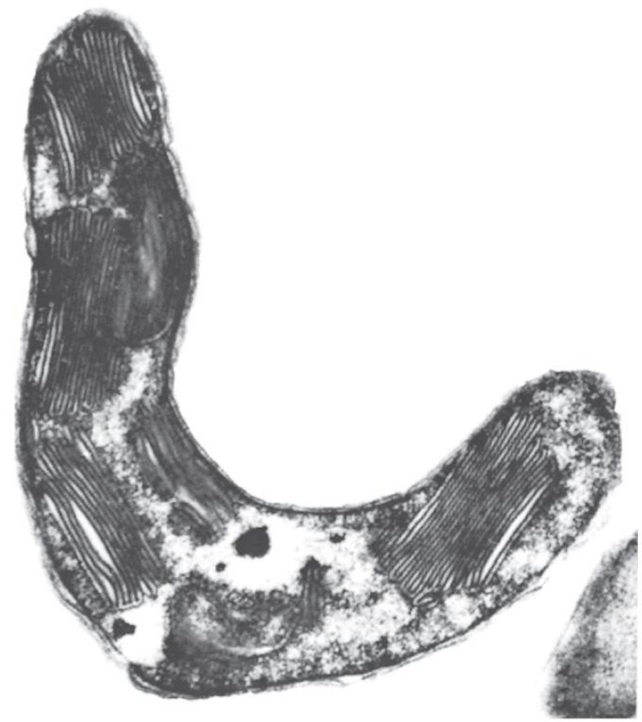


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Figure 3.32; ladderane lipids; these are unique to planctomycetes

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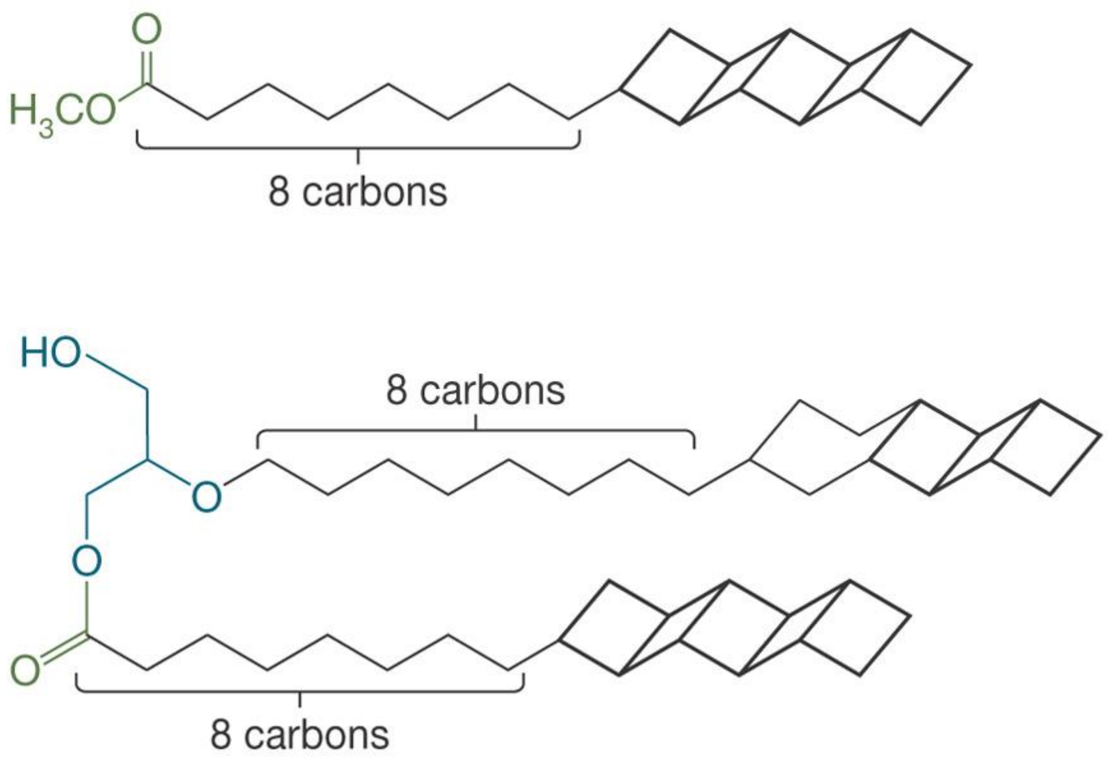

Inclusions

- 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

Figure 3.33

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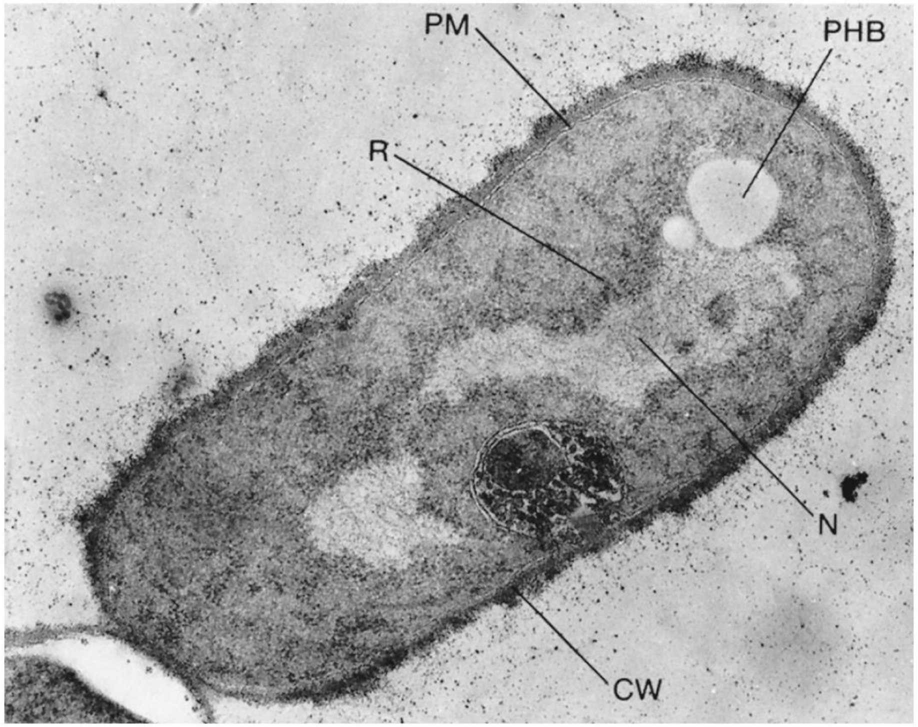

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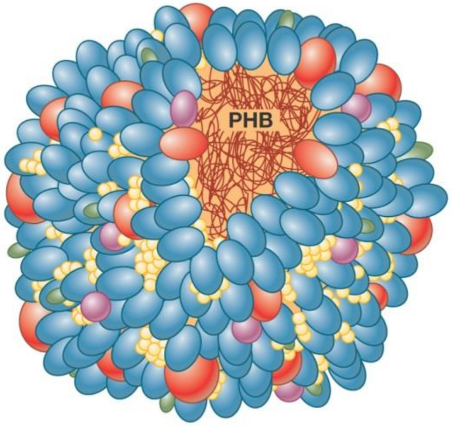

(b)

Figure 3.34

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Microcompartments

- **not bound by membranes but compartmentalized for a specific function**
- **carboxysomes - CO_2 fixing bacteria**
  - **contain the enzyme ribulose-1,5,-bisphosphate carboxylase (Rubisco), enzyme used for CO_2 fixation**

Figure 3.35

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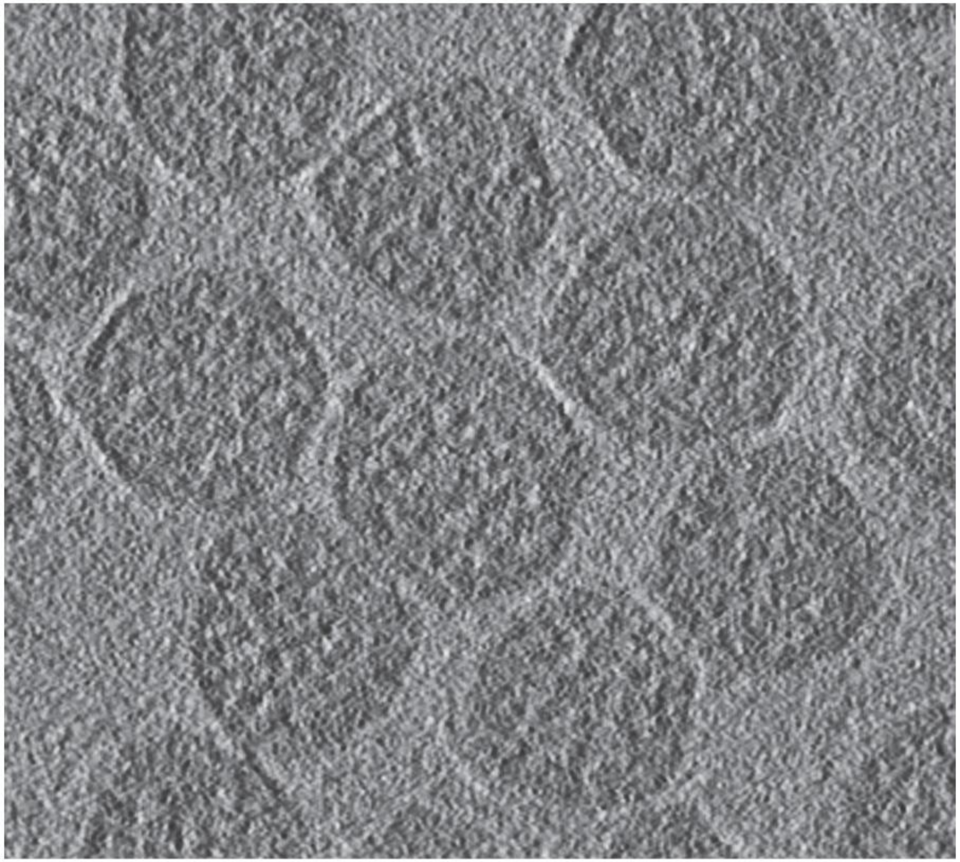


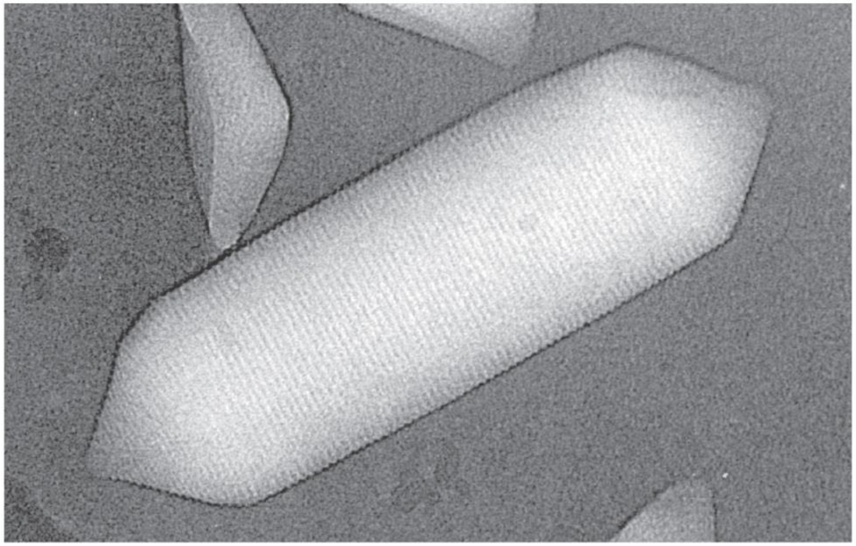
Michael Schmid

Other Inclusions

- **gas vacuoles**
  - **found in aquatic, photosynthetic bacteria and archaea**
  - **provide buoyancy in gas vesicles**
- **magnetosomes**
  - **found in aquatic bacteria**
  - **magnetite particles for orientation in Earth's magnetic field**
  - **cytoskeletal protein MamK**
    - **helps form magnetosome chain**

Figure 3.36

Courtesy of Daniel Branton, Harvard University



(b)

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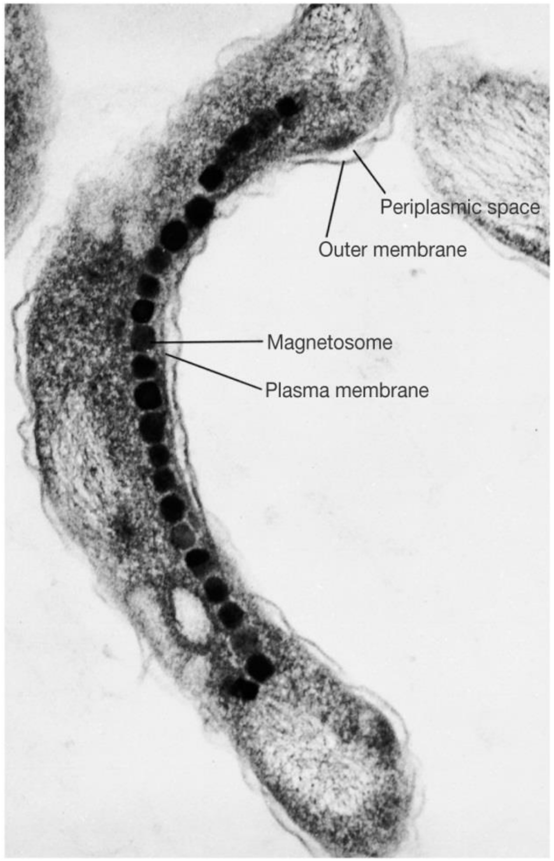

(a)

Y. Gorby

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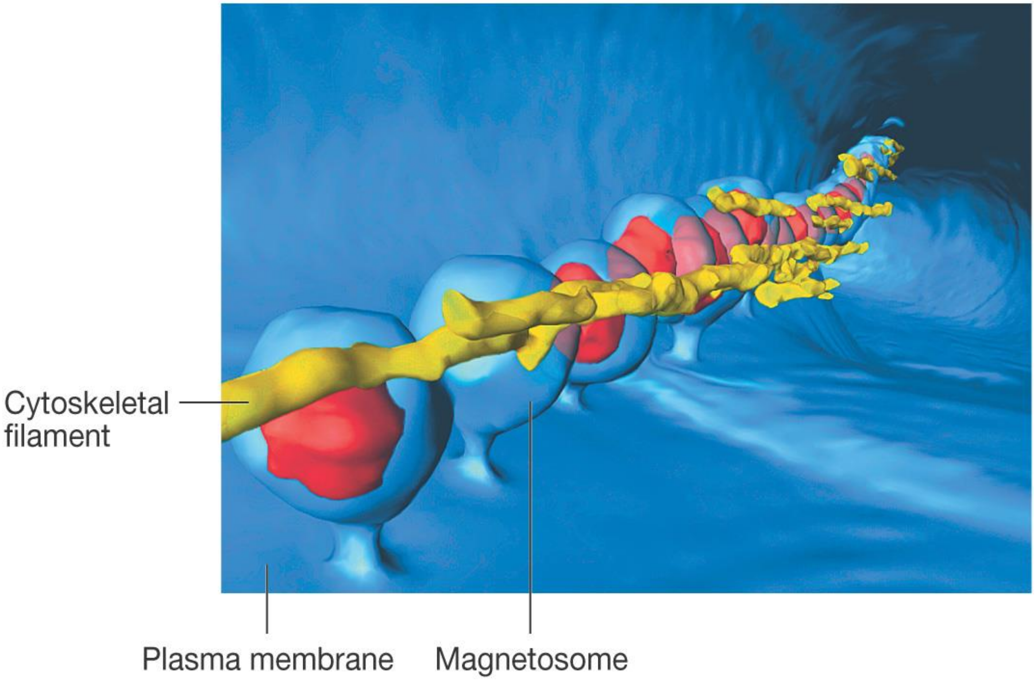

(b)

Zhuo Li and Grant Jensen

Ribosomes

- **complex structures**
  - **consisting of protein and RNA**
  - **sites of protein synthesis**
- **entire ribosome**
  - **bacterial and archaea ribosome = 70S**
  - **eukaryotic (80S) S = Svedburg unit**
- **bacterial and archaeal ribosomal RNA**
  - **16S small subunit**
  - **23S and 5S in large subunit**
  - **archaea has additional 5.8S (also seen in eukaryotic large subunit)**
- **proteins vary**
  - **archaea more similar to eukarya than to bacteria**

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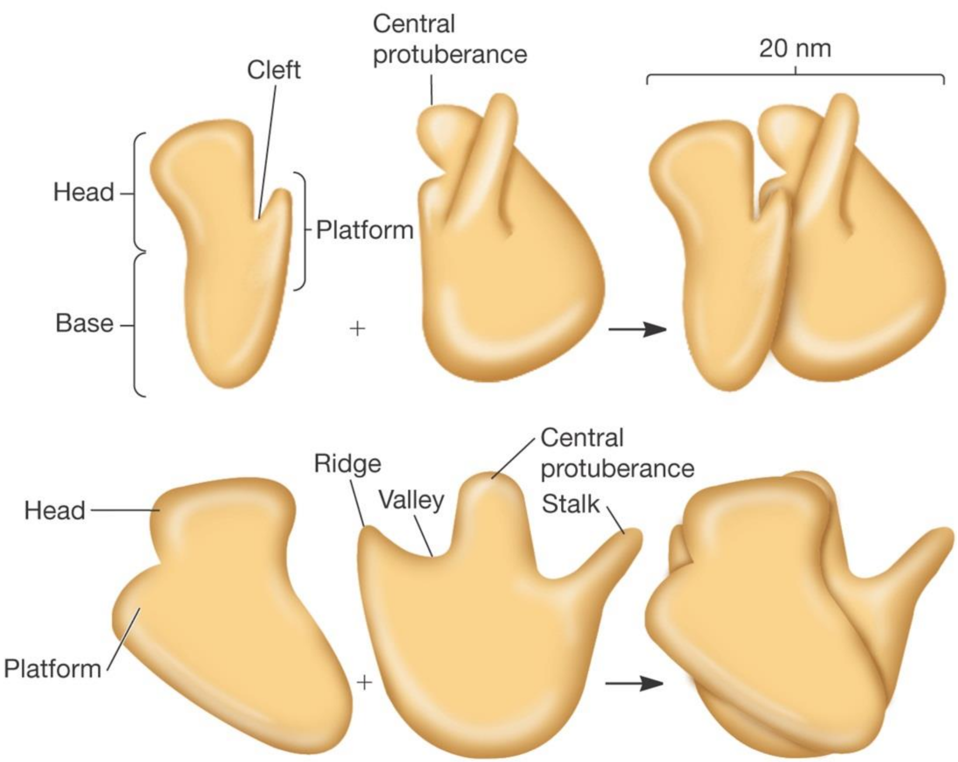

(a) 30S subunit (b) 50S subunit (c) 70S subunit

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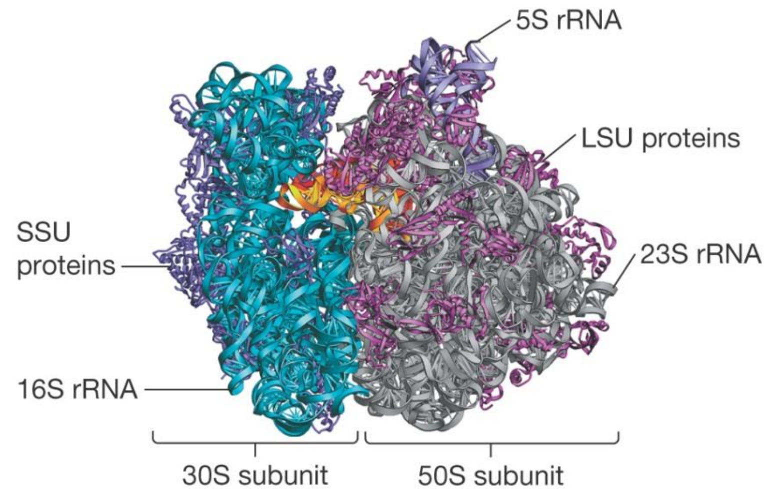

(d)

Harry Noller, University of California, Santa Cruz

The Nucleoid

- **irregularly shaped region in bacteria and archaea**
- **usually not membrane bound (few exceptions)**
- **location of chromosome and associated proteins**
- **usually 1**
  - **a closed circular, double-stranded DNA molecule**
- **supercoiling and nucleoid proteins (HU) probably aid in folding**
  - **nucleoid proteins differ from histones**

Figure 3.39

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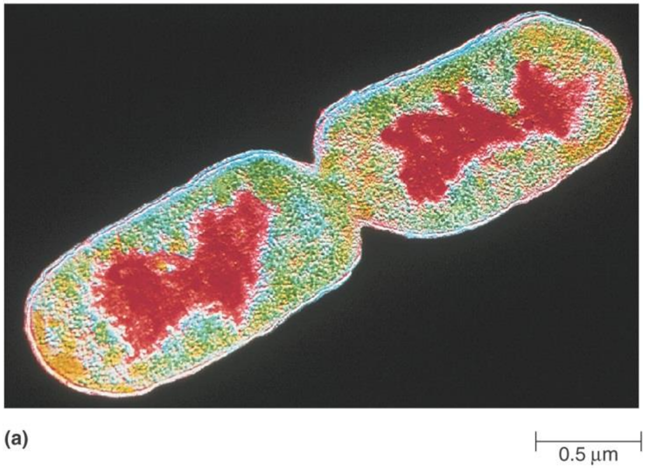
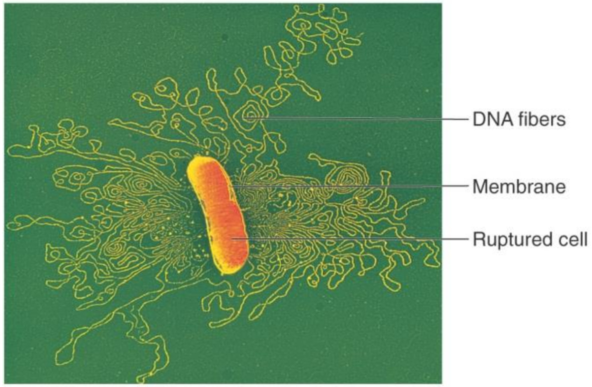


(a)



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(c)

Ohniwa R. Morikawa K, Kim J, Kobori T, Hizume K, et al. 2007. Microsec. Microanal. 13:3–12

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**
- **contain few genes that are non-essential**
  - **confer selective advantage to host (e.g., drug resistance)**

Plasmids

- may exist in many copies in cell
- inherited stably during cell division
- curing is the loss of a plasmid
- classification of plasmids based on mode of existence, spread, and function
- see Table 3.3

Table 3.3

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Table 3.3 Major Types of Bacterial Plasmids

Type	*Representatives*	*Approximate Size (kbp)*	*Copy Number (Copies/ Chromosome)*	*Hosts*	*Phenotypic Features*[a]
Conjugative Plasmids[b]	F factor	95–100	1–3	*E. coli, Salmonella, Citrobacter*	Sex pilus, conjugation
R Plasmids	RP4	54	1–3	*Pseudomonas* and many other gram-negative bacteria	Sex pilus, conjugation, resistance to Amp, Km, Nm, Tet
	pSH6	21		*Staphylococcus aureus*	Resistance to Gm, Tet, Km
Col Plasmids	ColE1	9	10–30	*E. coli*	Colicin E1 production
	CloDF13	10	50–70	*E. coli*	Cloacin DF13
Virulence Plasmids	Ent (P307)	83		*E. coli*	Enterotoxin production
	Ti	200		*Agrobacterium tumefaciens*	Tumor induction in plants
Metabolic Plasmids	CAM	230		*Pseudomonas*	Camphor degradation
	TOL	75		*Pseudomonas putida*	Toluene degradation

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

External Structures

- **extend beyond the cell envelop in bacteria and archaea**
- **function**
  - **protection, attachment to surfaces, horizontal gene transfer, cell movement**
- **pili and fimbriae**
- **flagella**

Pili and Fimbriae

- fimbriae (s., fimbria); pili (s., pillus)
  - short, thin, hairlike, proteinaceous appendages (up to 1,000/cell)
  - mediate attachment to surfaces
  - some (type IV fimbriae) required for motility or DNA uptake
- sex pili (s., pilus)
  - similar to fimbriae except longer, thicker, and less numerous (1-10/cell)
  - genes for formation found on plasmids
  - required for conjugation

Figure 3.40

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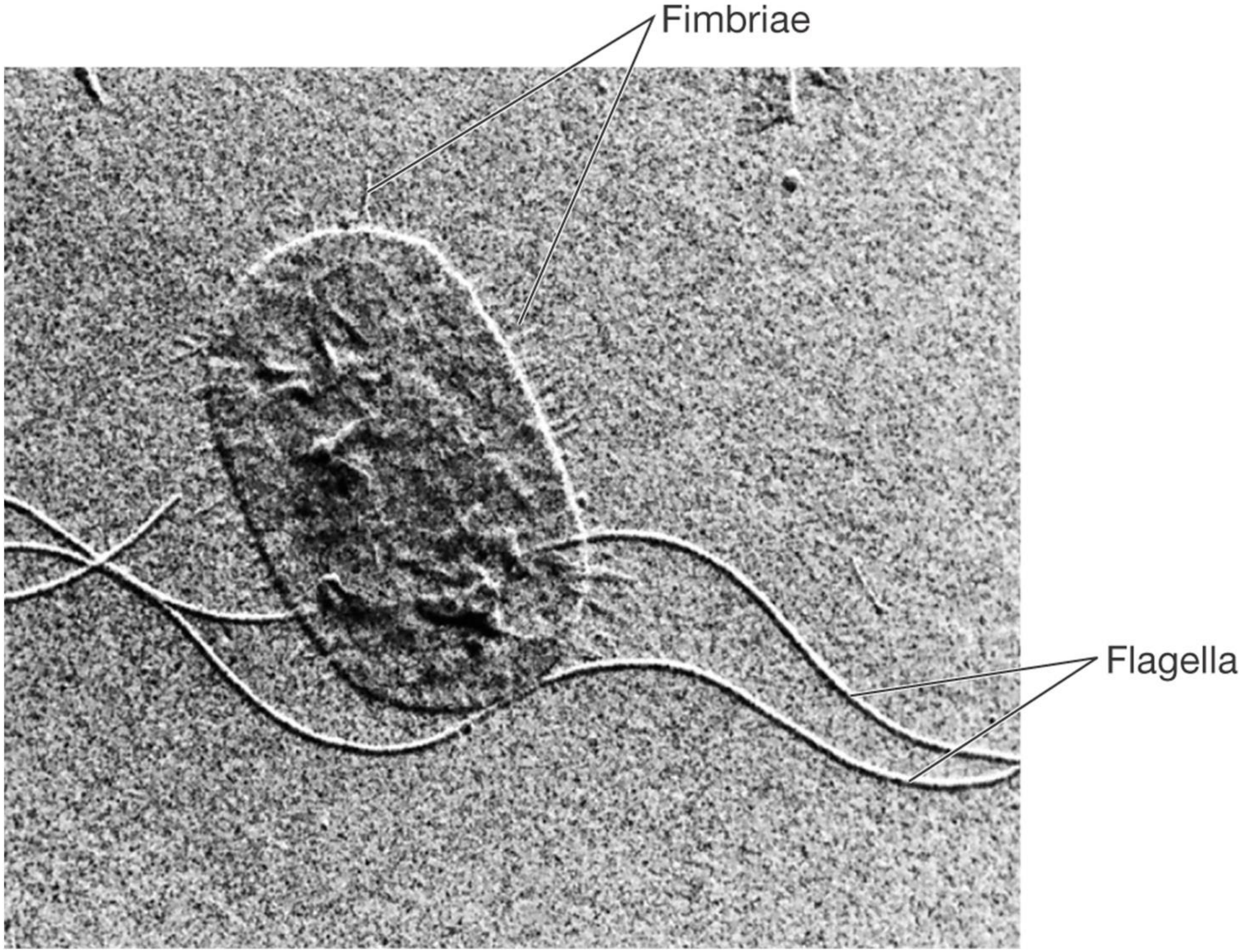

Flagella

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

Bacterial Flagella

- thin, rigid protein structures that cannot be observed with bright-field microscope unless specially stained
- ultrastructure composed of three parts
- pattern of flagellation varies

Patterns of Flagella Distribution

- **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**

Figure 3.41

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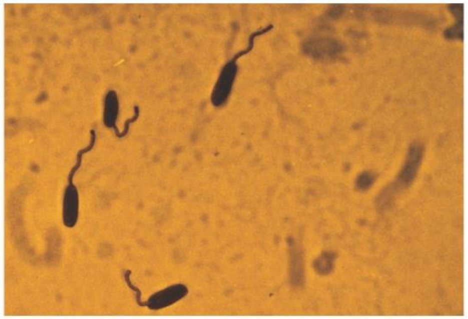

(a) *Pseudomonas*—monotrichous polar flagellation

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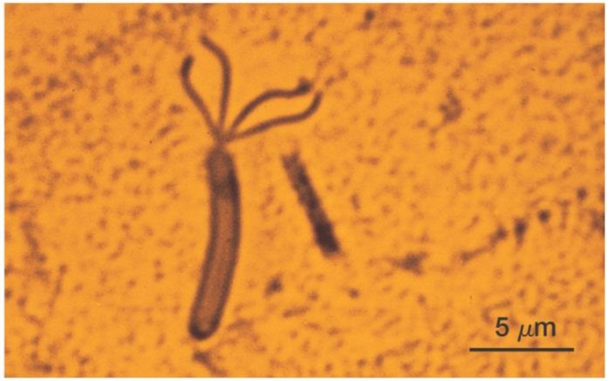

(b) *Spirillum*—lophotrichous flagellation

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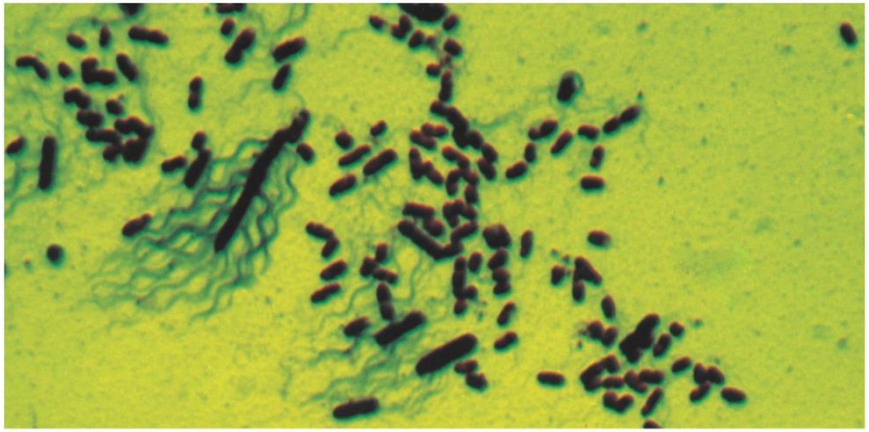

(c) *P. vulgaris*—peritrichous flagellation

Three Parts of Flagella

- **filament**
  - **extends from cell surface to the tip**
  - **hollow, rigid cylinder**
  - **composed of the protein flagellin**
  - **some bacteria have a sheath around filament**
- **hook**
  - **links filament to basal body**
- **basal body**
  - **series of rings that drive flagellar motor**

Figure 3.42

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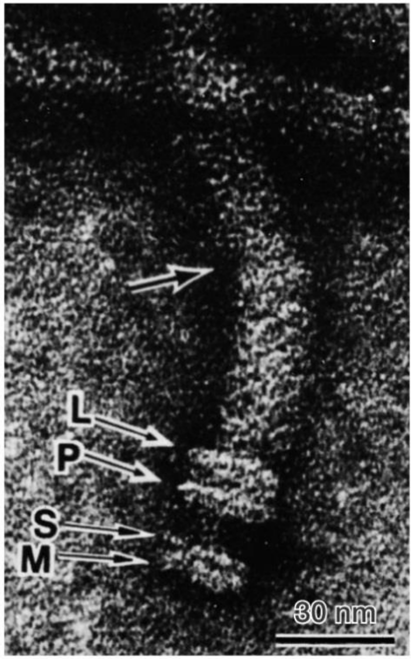

(a)

Courtesy of Dr. Julius Adler

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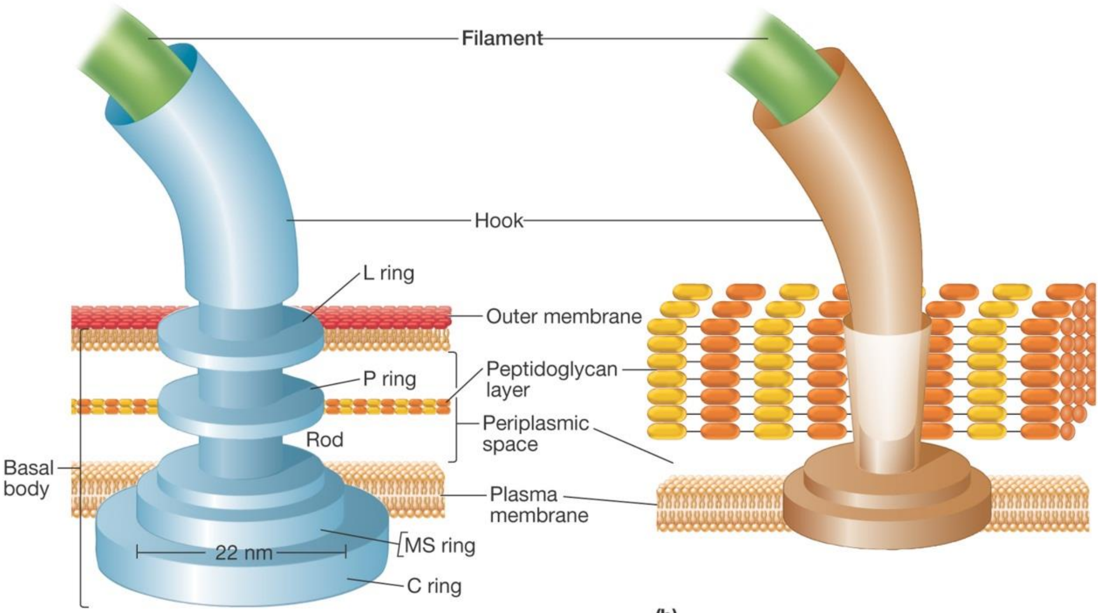

(b)

Flagellar Synthesis

- complex process involving many genes and gene products
- new molecules of flagellin are transported through the hollow filament using Type III-like secretion system
- filament subunits self-assemble with help of filament cap
- growth is from tip, not base

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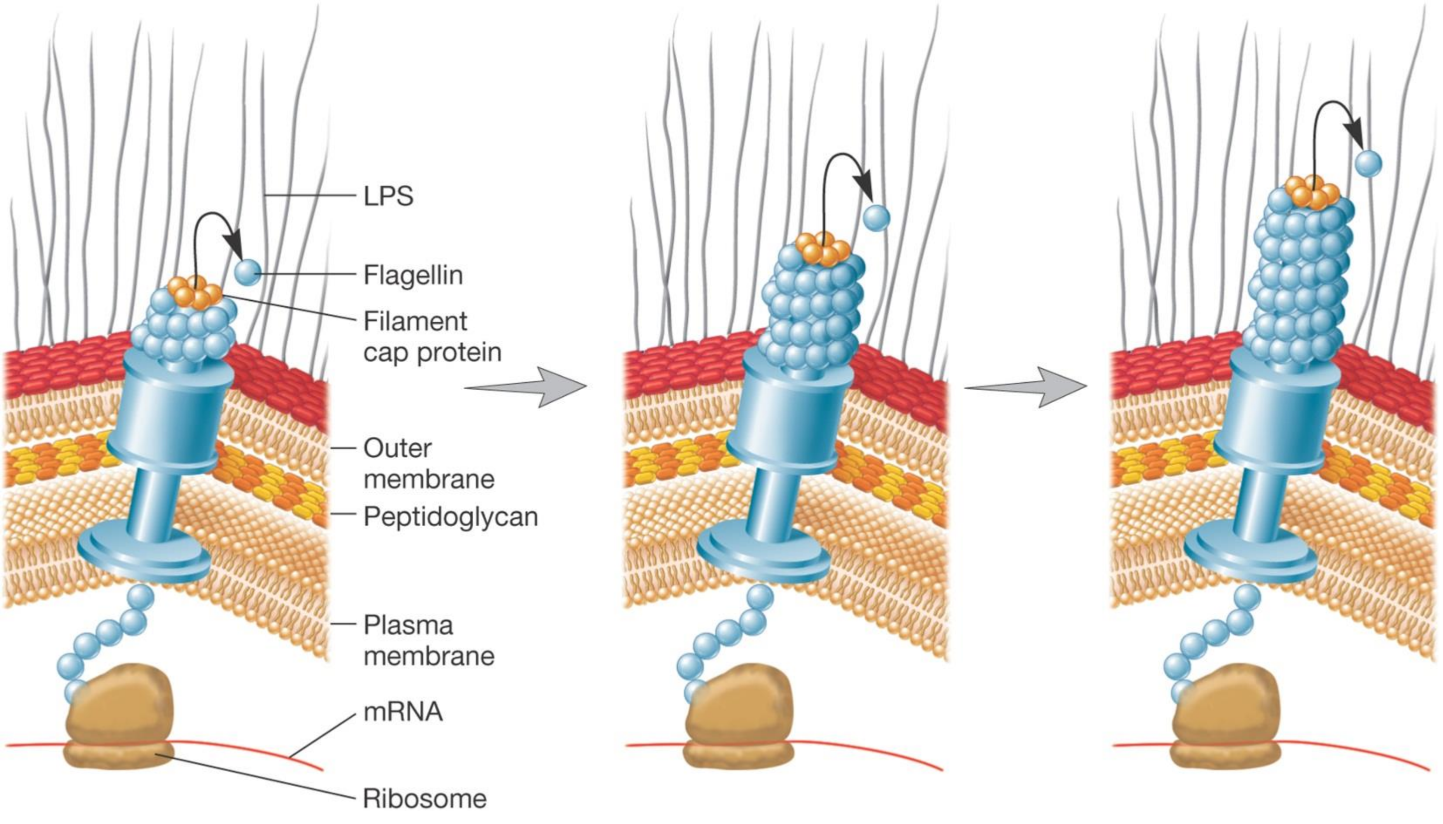

Differences of Archaeal Flagella

- **flagella thinner**
- **more than one type of flagellin protein**
- **flagellum are not hollow**
- **hook and basal body difficult to distinguish**
- **more related to Type IV secretions systems**
- **growth occurs at the base, not the end**

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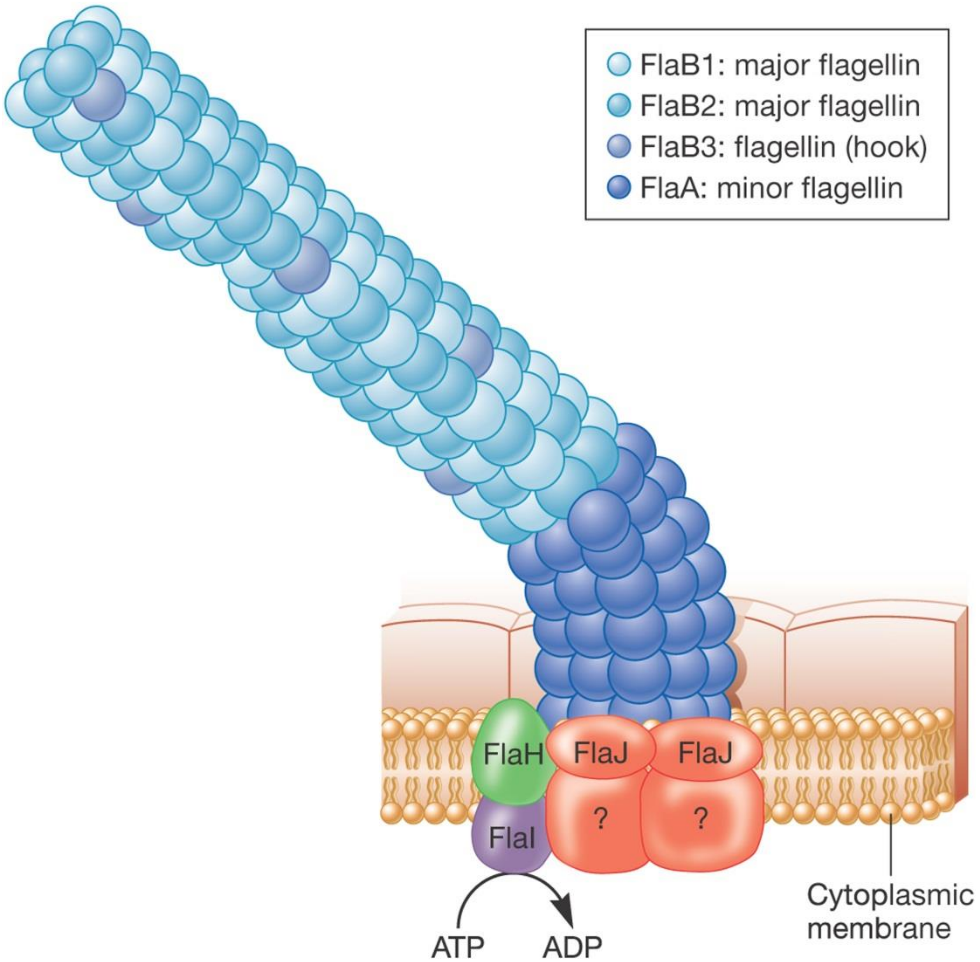


Motility

Flagellar movement

Spirochete motility

Twitching motility

Gliding motility

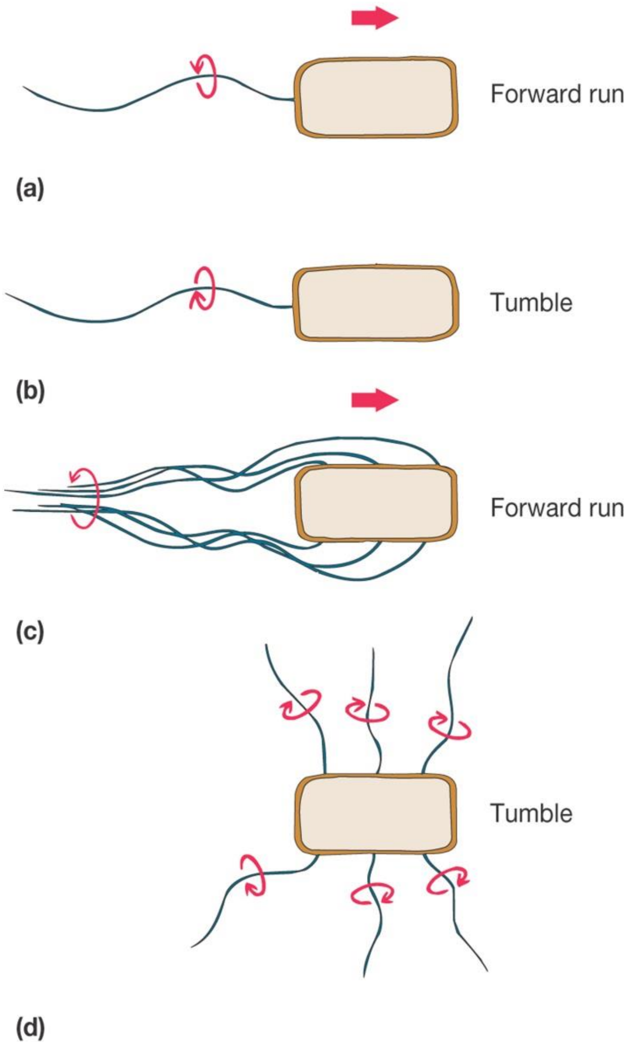
Motility

- ***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**

Bacterial 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

Figure 3.45



Mechanism of Flagellar Movement

- **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 and produce energy through proton motive force**
  - **torque powers rotation of the basal body and filament**

Figure 3.46

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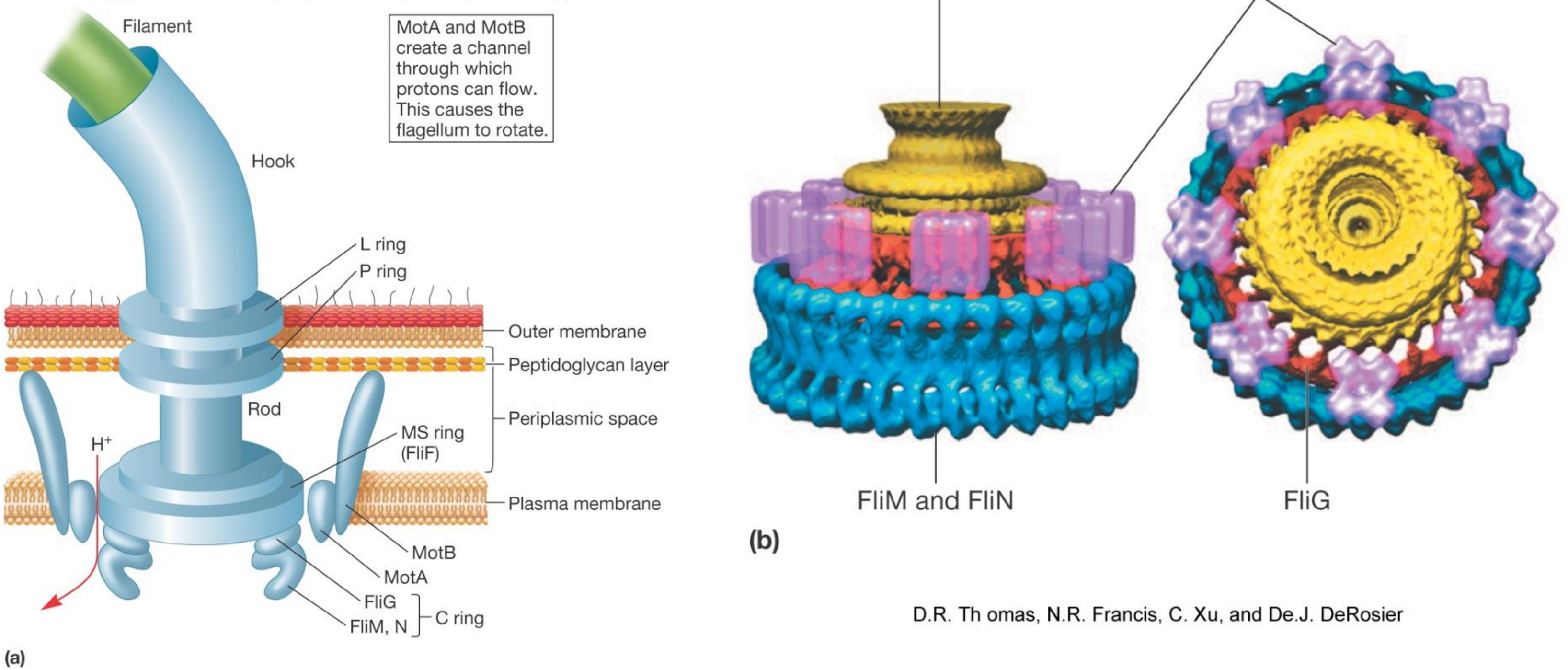

D.R. Th omas, N.R. Francis, C. Xu, and De.J. DeRosier

Spirochete Motility

- multiple flagella form axial fibril which winds around the cell
- flagella remain in periplasmic space inside outer sheath
- corkscrew shape exhibits flexing and spinning movements

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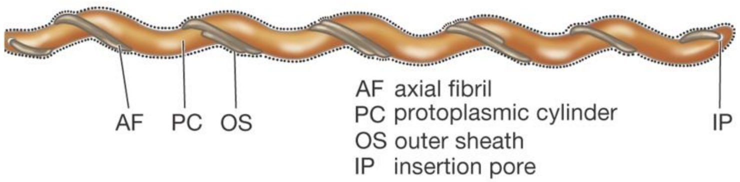

a)

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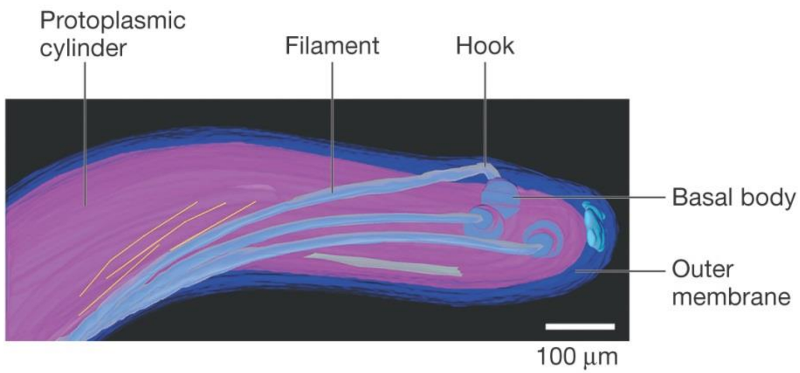


(b)

Courtesy of Dr. Jacques Izard, Forsyth Institute, Boston

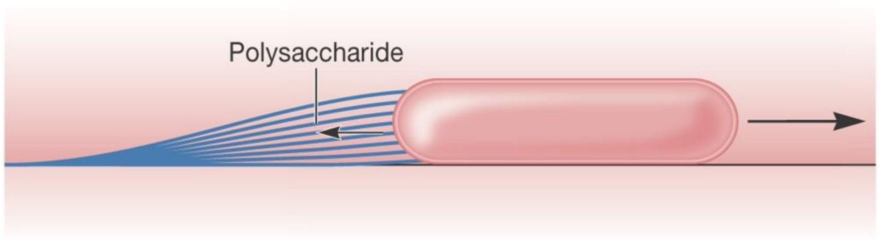
Twitching and Gliding Motility

- **may involve Type IV pili and slime**
- **twitching**
  - **pili at ends of cell**
  - **short, intermittent, jerky motions**
  - **cells are in contact with each other and surface**
- **gliding**
  - **smooth movements**

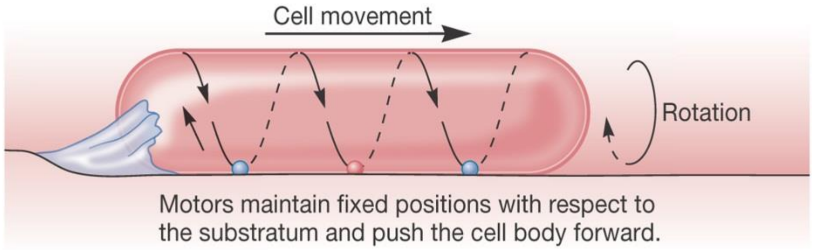
Myxococcus xanthus Movement

- **social**
  - **Type IV pili move together in large groups of cells**
- **adventurous (Gliding)**
  - **alime released moves cell forward**
  - **adhesion complexes move in track provided by cytoskeleton**

Figure 3.48



(a)



(b)

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**

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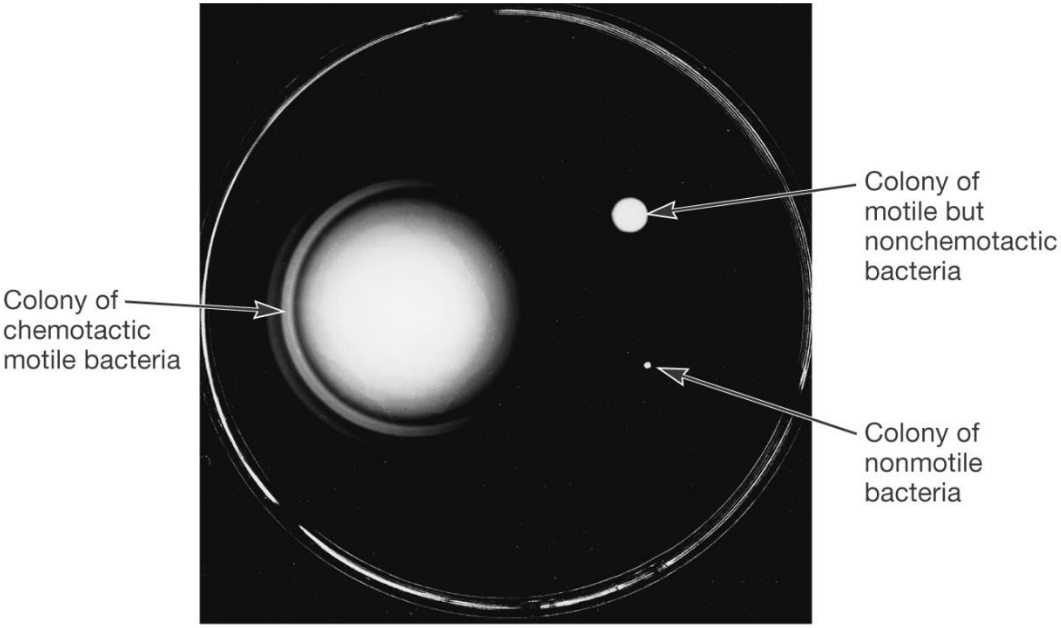
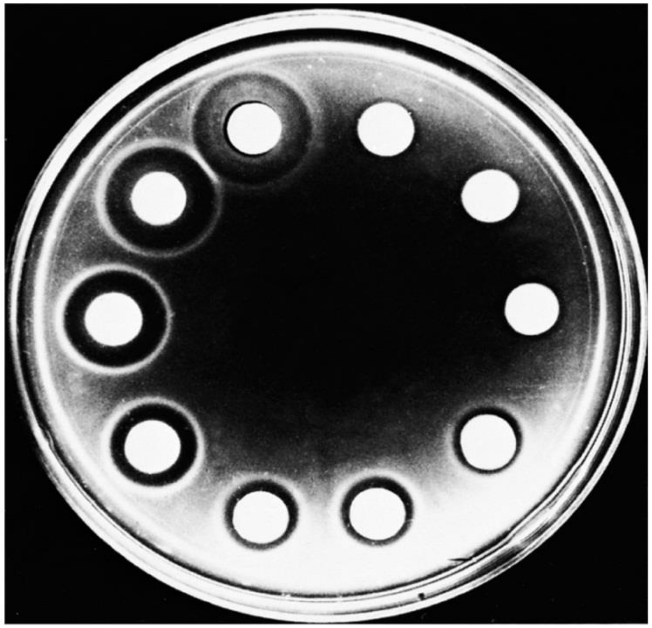


(a) Positive chemotaxis



(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**

Figure 3.50

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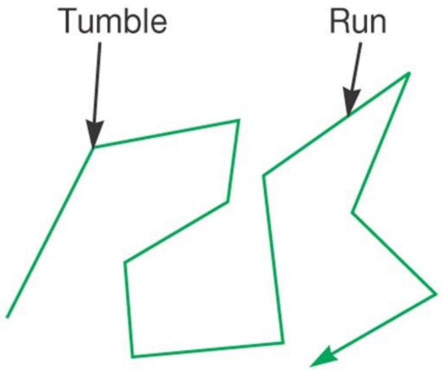

(a)

(b)

The Bacterial Endospore

- complex, dormant structure formed by some bacteria
- various locations within the cell
- resistant to numerous environmental conditions
  - heat
  - radiation
  - chemicals
  - desiccation

Figure 3.51

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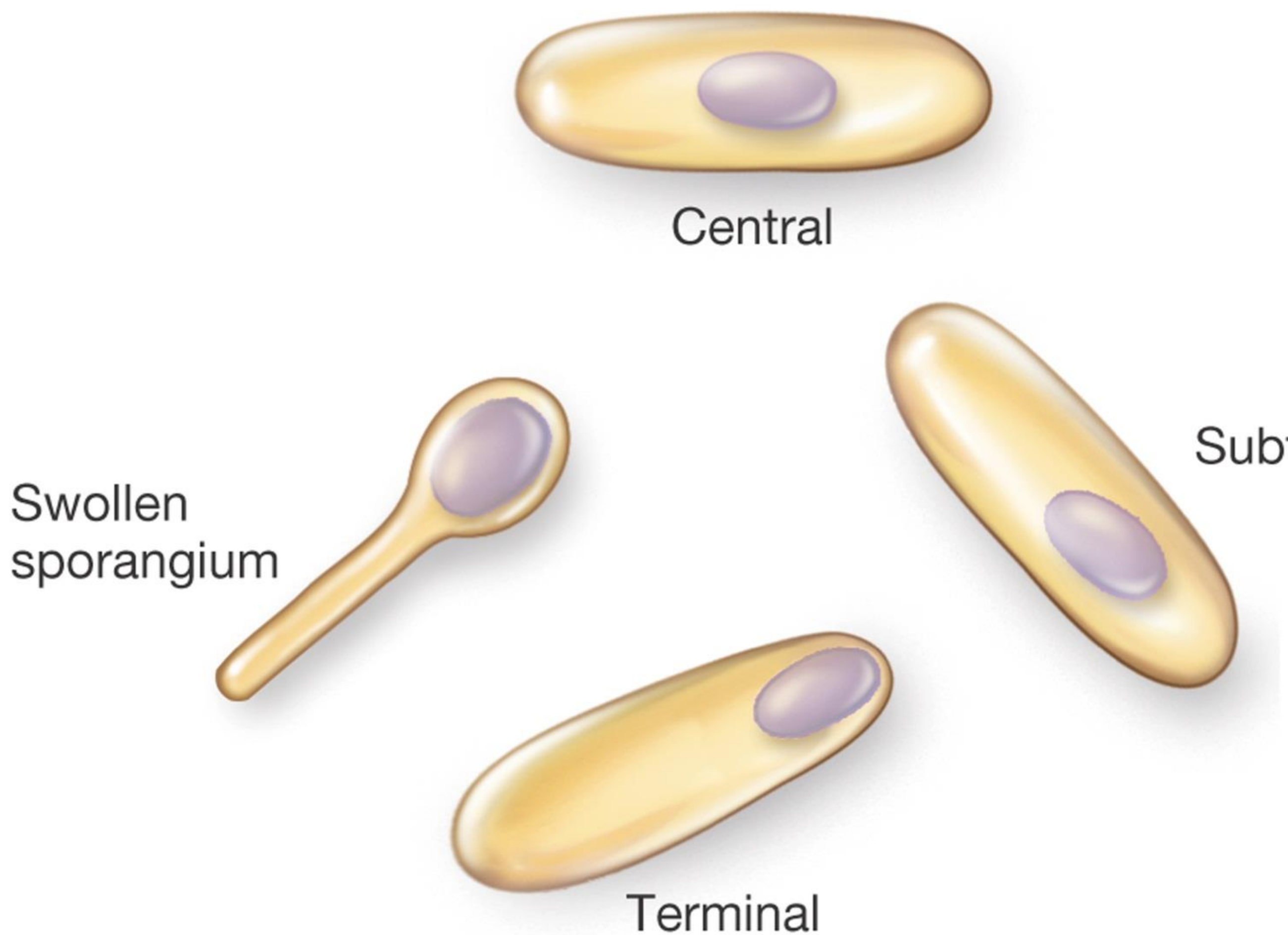
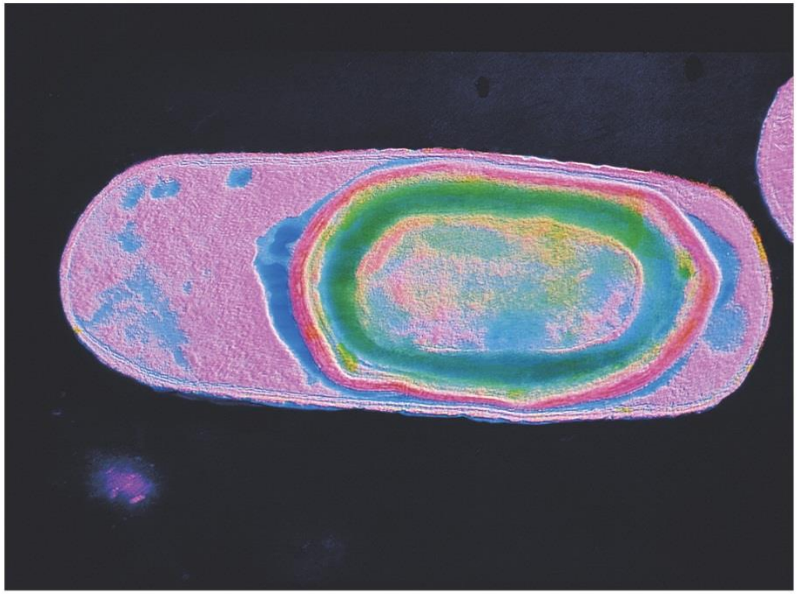


Endospore Structure

- 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

Figure 3.52



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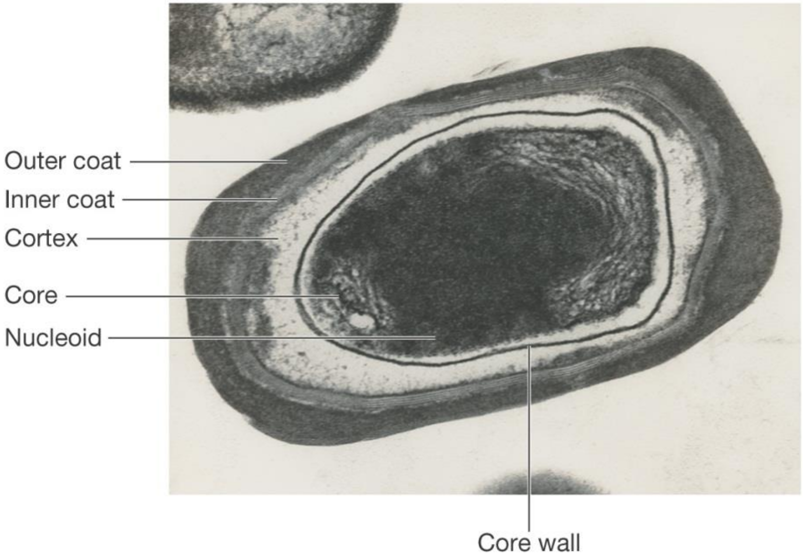

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What Makes an Endospore so Resistant?

- **calcium (complexed with dipicolinic acid)**
- **small, acid-soluble, DNA-binding proteins (SASPs)**
- **dehydrated core**
- **spore coat and exosporium protect**

Sporulation

- **process of endospore formation**
- **occurs in a hours (up to 10 hours)**
- **normally commences when growth ceases because of lack of nutrients**
- **complex multistage process**

Figure 3.53

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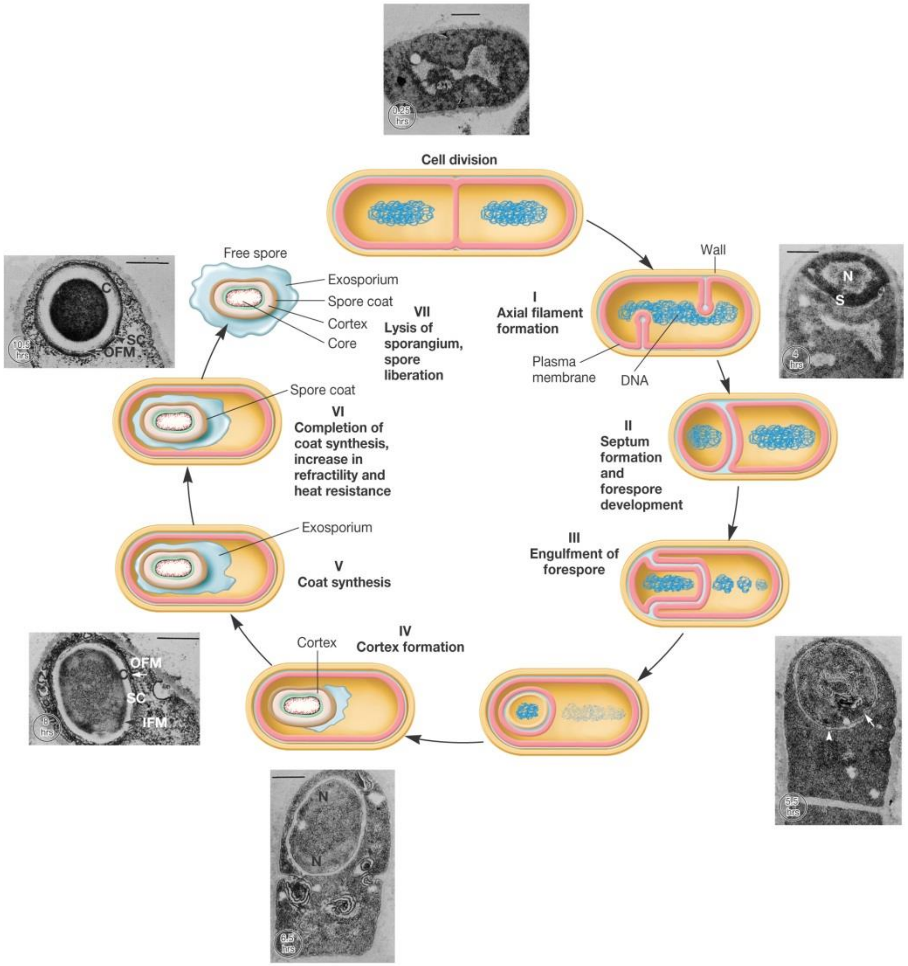

From A.N. Barker et al. (Eds.), Spore Research, 1974, pages 161–174, 1971 Academic Press

Germination

- **transformation of endospore into vegetative cell complex, multistage process**

Figure 3.54

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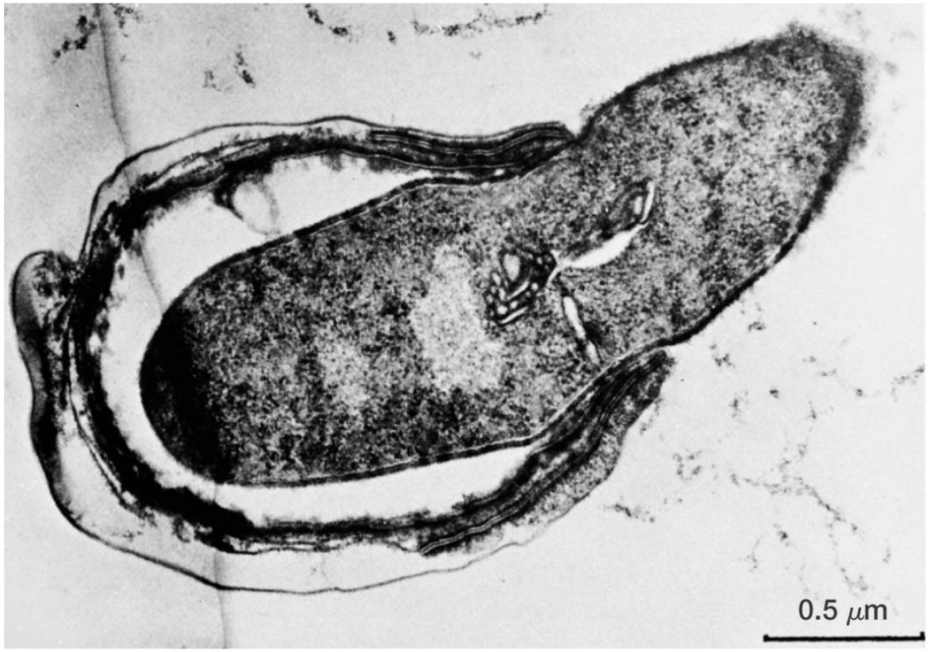

American Society for Microbiology

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**
  - **loss of resistance**
  - **increased metabolic activity**
- **outgrowth - emergence of vegetative cell**