3

Bacterial Cell Structure

3.1 The “Prokaryote” Controversy

1. List the characteristics originally used to describe prokaryotic cells
2. Form an opinion on the “prokaryote” controversy using current evidence about bacterial cells

3.2 A Typical Bacterial Cell

1. Distinguish a typical bacterial cell from a typical plant or animal cell in terms of cell shapes and arrangements, size, and cell structures
2. Discuss the factors that determine the size and shape of a bacterial cell.

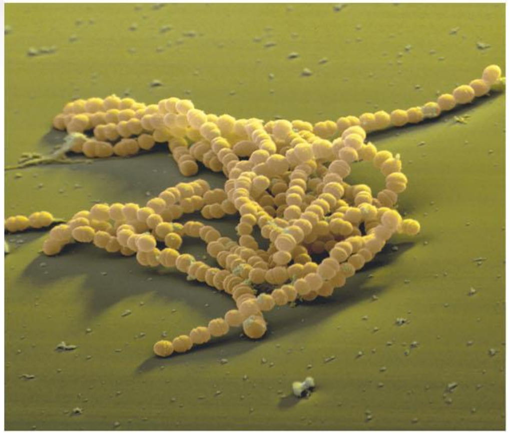
Bacterial and Archaea Structure and Function

- 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*
  - this chapter will cover *Bacteria* and their structures

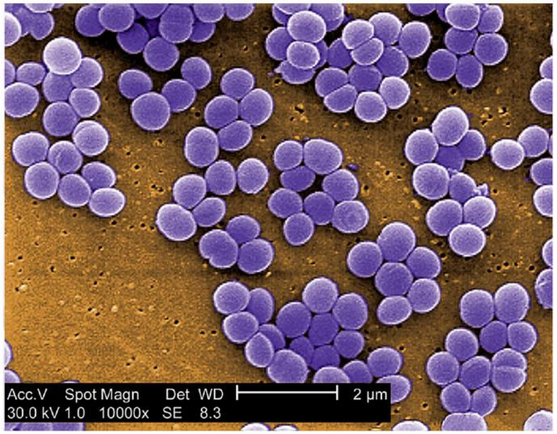
Size, Shape, and Arrangement

- 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

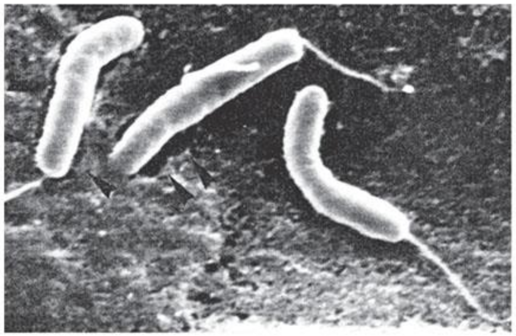


(b) *S. aureus*—cocci in clusters

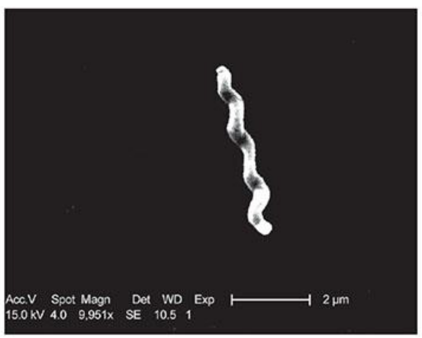
a: © Photo Researchers, Inc.; b: CDC/Janice Haney Carr

- 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

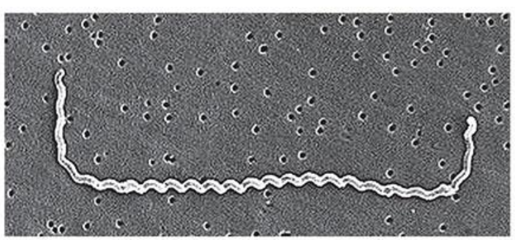
Shape and Arrangement-2



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

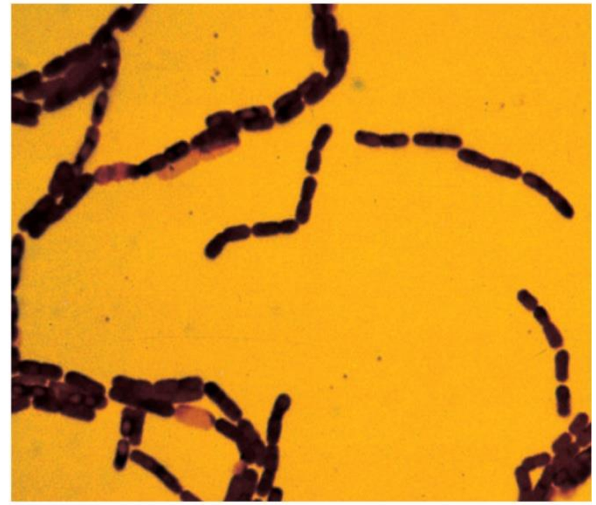


(b) *C. jejuni*—Spiral-shaped spirillum



(c) *Leptospira interrogans*—a spirochete

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



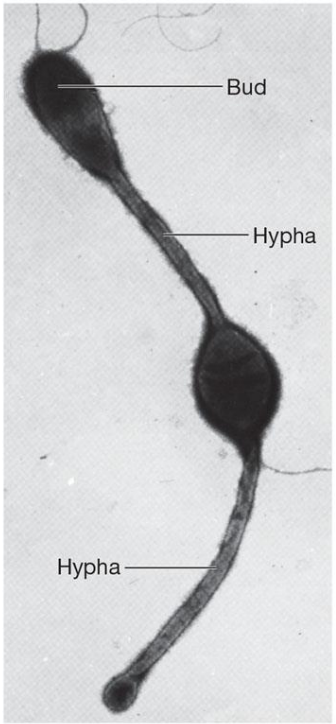
(c) *B. megaterium*—rods in chains

© George Wilder/Visuals Unlimited

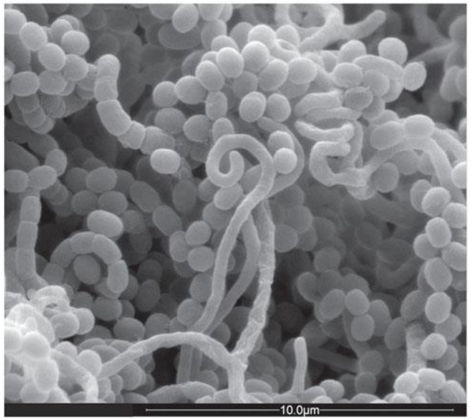
- bacilli (s., bacillus) – rods
  - coccobacilli – very short rods
- vibrios – resemble rods, comma shaped
- spirilla (s., spirillum) – rigid helices
- spirochetes – flexible helices

Shape and Arrangement-3

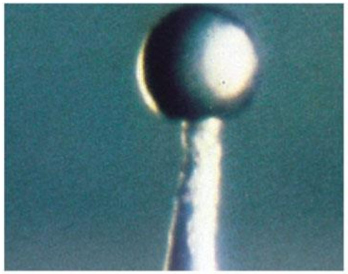
- mycelium – network of long, multinucleate filaments
- pleomorphic – organisms that are variable in shape



(d) *Hyphomicrobium*

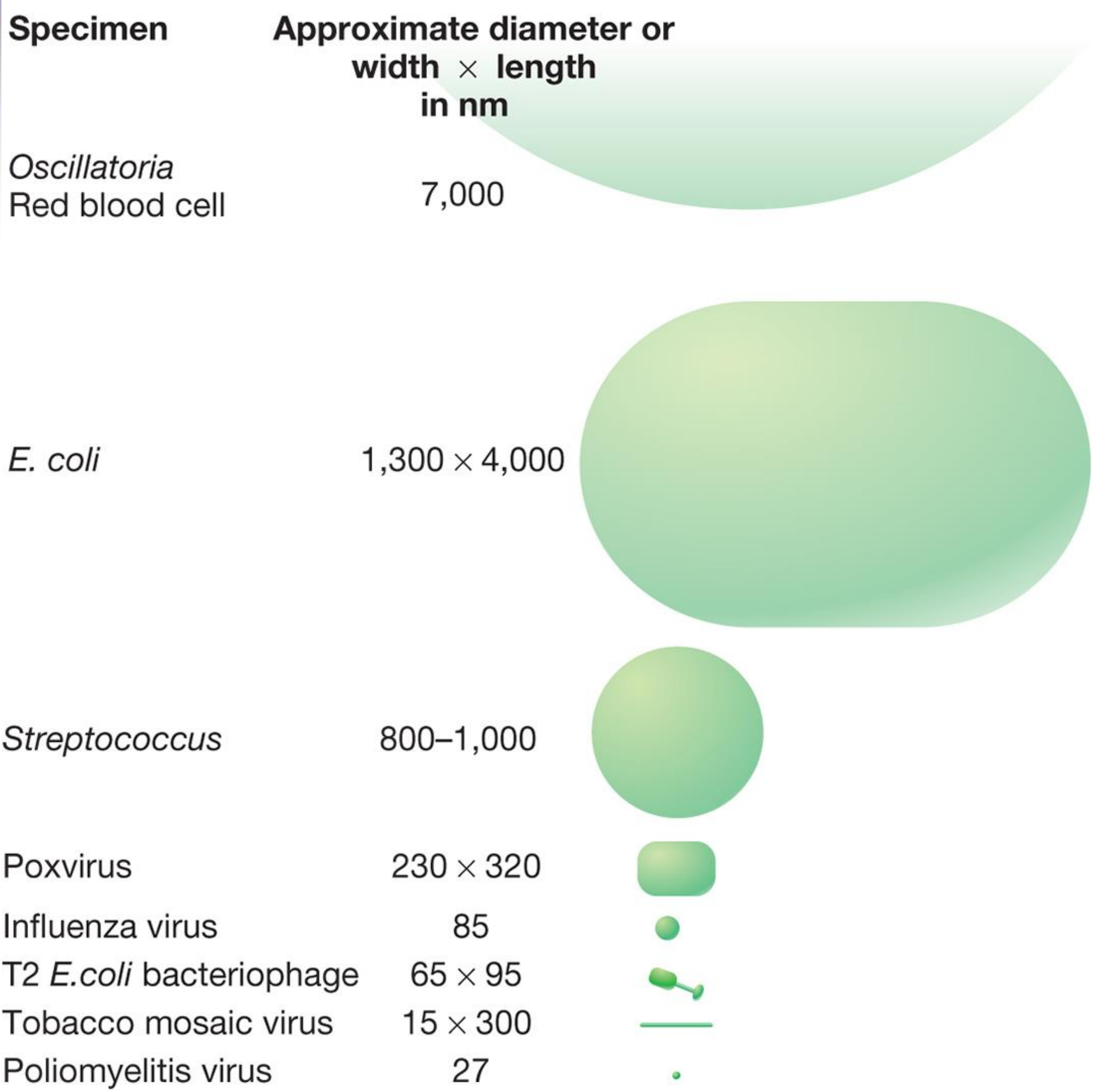


(e) *Streptomyces*—a filamentous bacterium



(f) *M. stipitatus* fruiting body

d: 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; e: Dr. Amy Gehring; f: © M. Dworkin-Hi. Reichenbach/Phototake

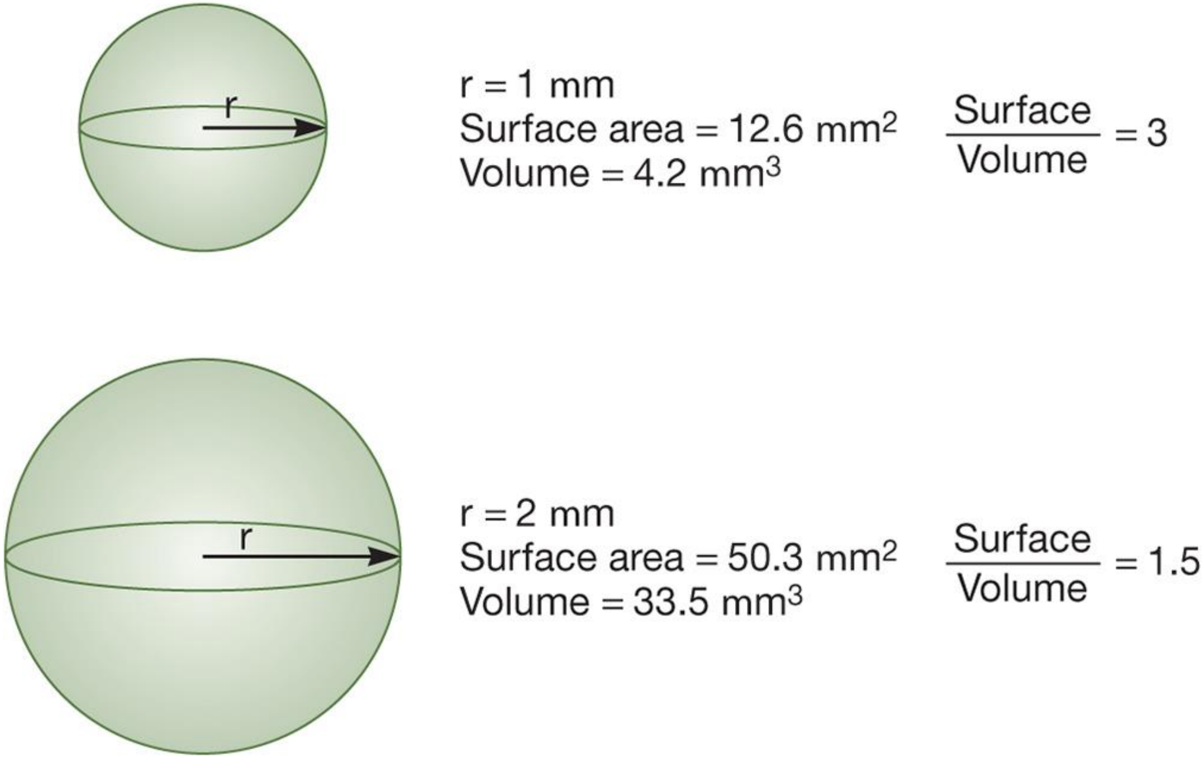


Size

- 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*

Size – Shape Relationship

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



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

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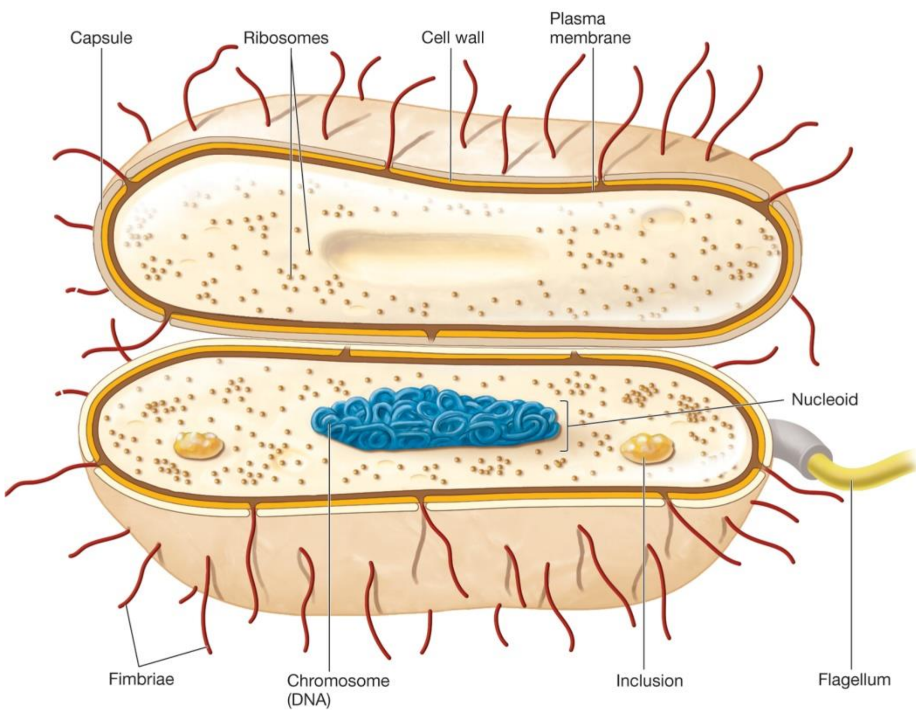


3.3 Bacterial Plasma Membranes

1. Describe the fluid mosaic model of membrane structure and identify the types of lipids typically found in bacterial membranes.
2. Distinguish macroelements (macronutrients) from micronutrients (trace elements) and provide examples of each.
3. Provide examples of growth factors needed by some microorganisms.
4. Compare and contrast passive diffusion, facilitated diffusion, active transport, and group translocation, and provide examples of each.
5. Discuss the difficulty of iron uptake and describe how bacteria overcome this difficulty.

Bacterial Cell Envelope

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

Bacterial Plasma Membrane

- Absolute requirement for all living organisms

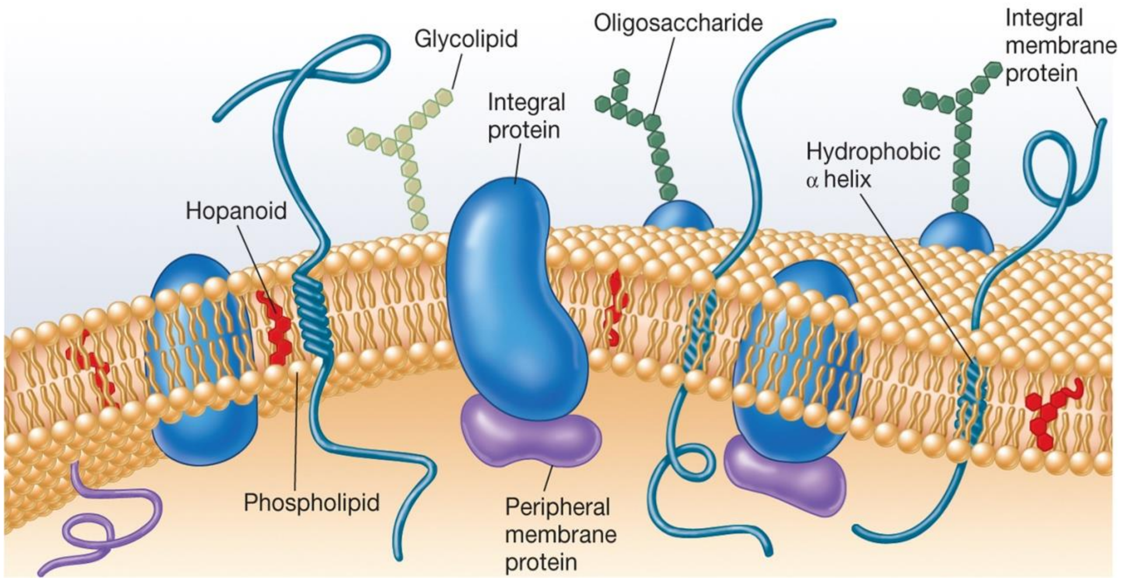
- Some bacteria also have internal membrane systems

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

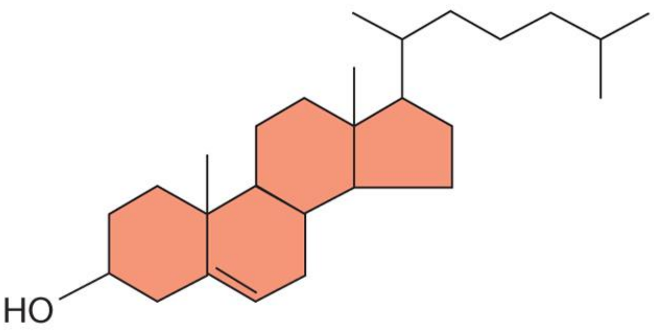


Membrane Proteins

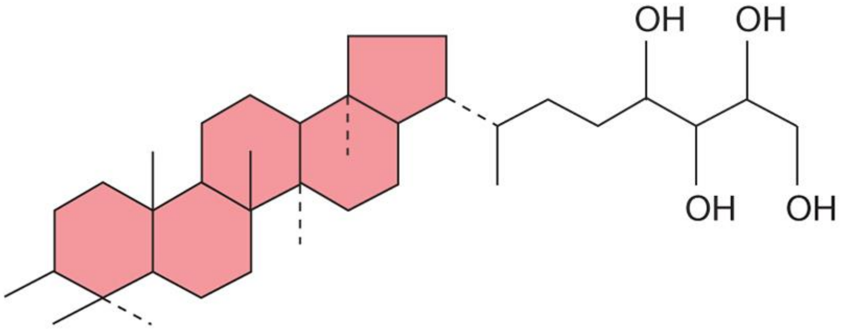
- Peripheral
  - loosely connected to membrane
  - easily removed
- Integral
  - amphipathic – embedded within membrane
  - carry out important functions
  - may exist as microdomains

Bacterial Lipids

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



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



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

Uptake of Nutrients – Getting Through the Barrier

- Macroelements (macronutrients)
  - C, O, H, N, S, P
    - found in organic molecules such as proteins, lipids, carbohydrates, and nucleic acids
  - K, Ca, Mg, and Fe
    - cations and serve in variety of roles including enzymes, biosynthesis
  - required in relatively large amounts

Uptake of Nutrients – Getting Through the Barrier

- Micronutrients (trace elements)
  - Mn, Zn, Co, Mo, Ni, and Cu
  - required in trace amounts
  - often supplied in water or in media components
  - ubiquitous in nature
  - serve as enzymes and cofactors
- Some unique substances may be required

Uptake of Nutrients – Getting Through the Barrier

- Growth factors
  - 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 of Growth Factors

- amino acids
  - needed for protein synthesis
- purines and pyrimidines
  - needed for nucleic acid synthesis
- vitamins
  - function as enzyme cofactors
- heme

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
  - facilitated diffusion – all microorganisms
  - active transport – all microorganisms
  - group translocation – *Bacteria* and *Archaea*
  - endocytosis – *Eukarya* only

Passive Diffusion

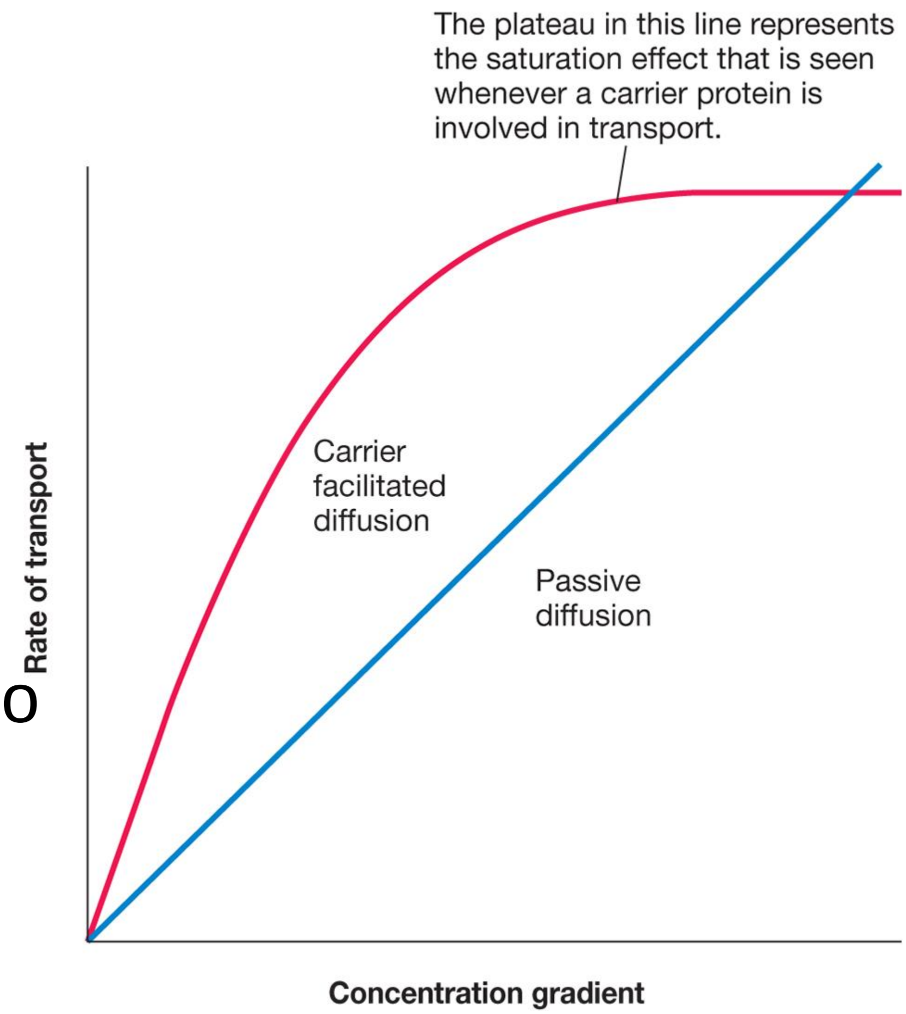
- Molecules move from region of higher concentration to one of lower concentration between the cell's interior and the exterior
- H_2O, O_2, and CO_2 often move across membranes this way

Facilitated Diffusion

- Similar to passive diffusion
  - movement of molecules <u>is not</u> energy dependent
  - direction of movement is from high concentration to low concentration
  - size of concentration gradient impacts rate of uptake

Facilitated Diffusion…

- Differs from passive diffusion
  – uses membrane bound carrier molecules (permeases)
  – smaller concentration gradient is required for significant uptake of molecules
  – effectively transports glycerol, sugars, and amino acids
- more prominent in eukaryotic cells than in bacteria or archaea




How Diffusion Works
Play
Pause
Audio
Text
Molecules dissolved in a solution are in constant random motion due to their kinetic energy. One result of this motion is that dissolved molecules become evenly distributed throughout the solution.
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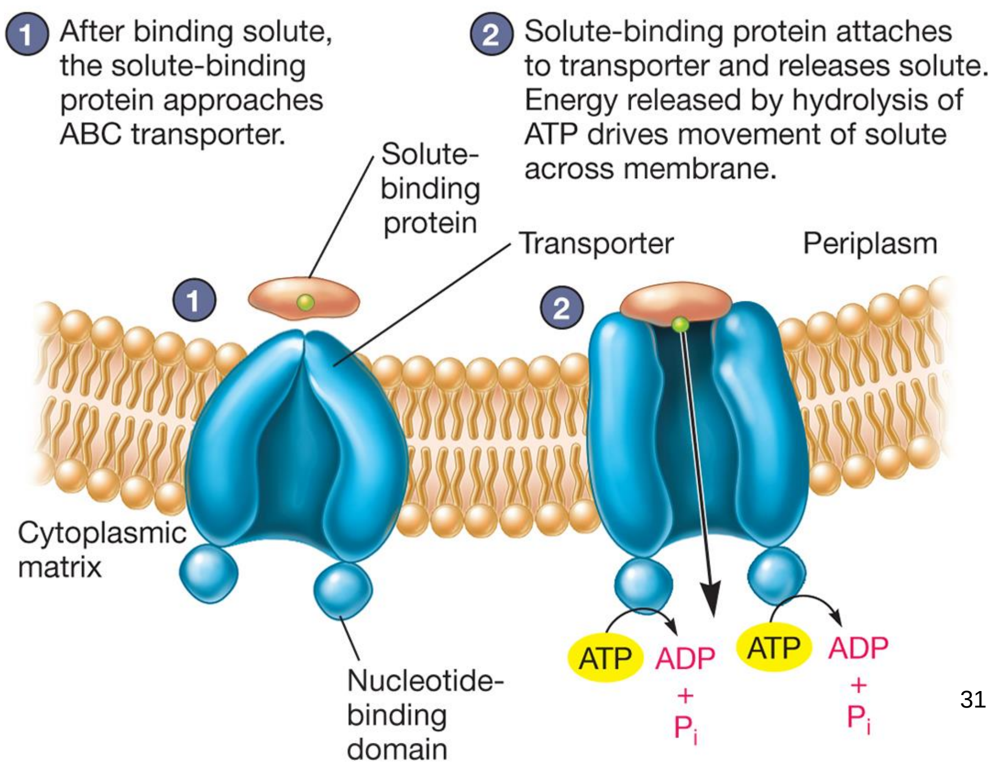
Active Transport

- 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

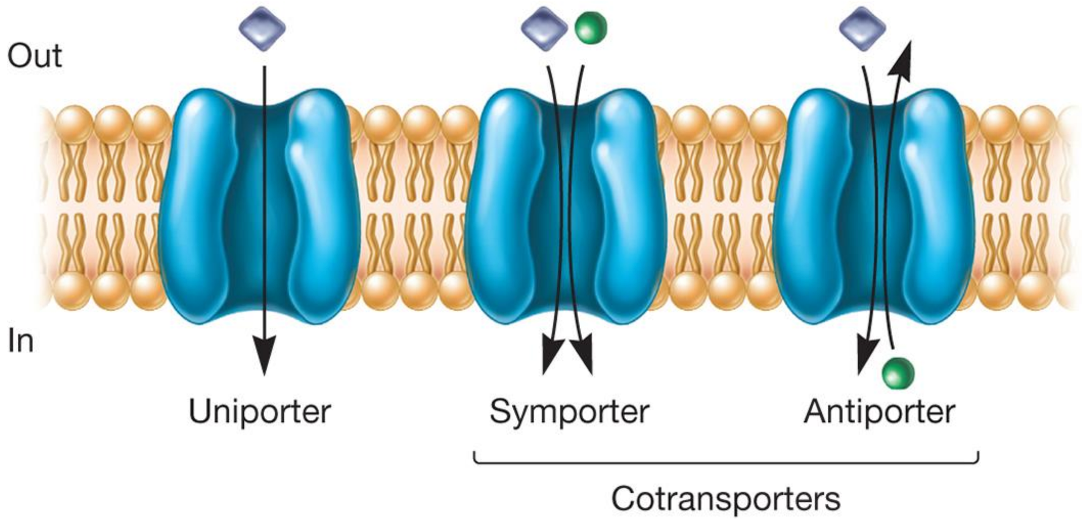
ABC Transporters

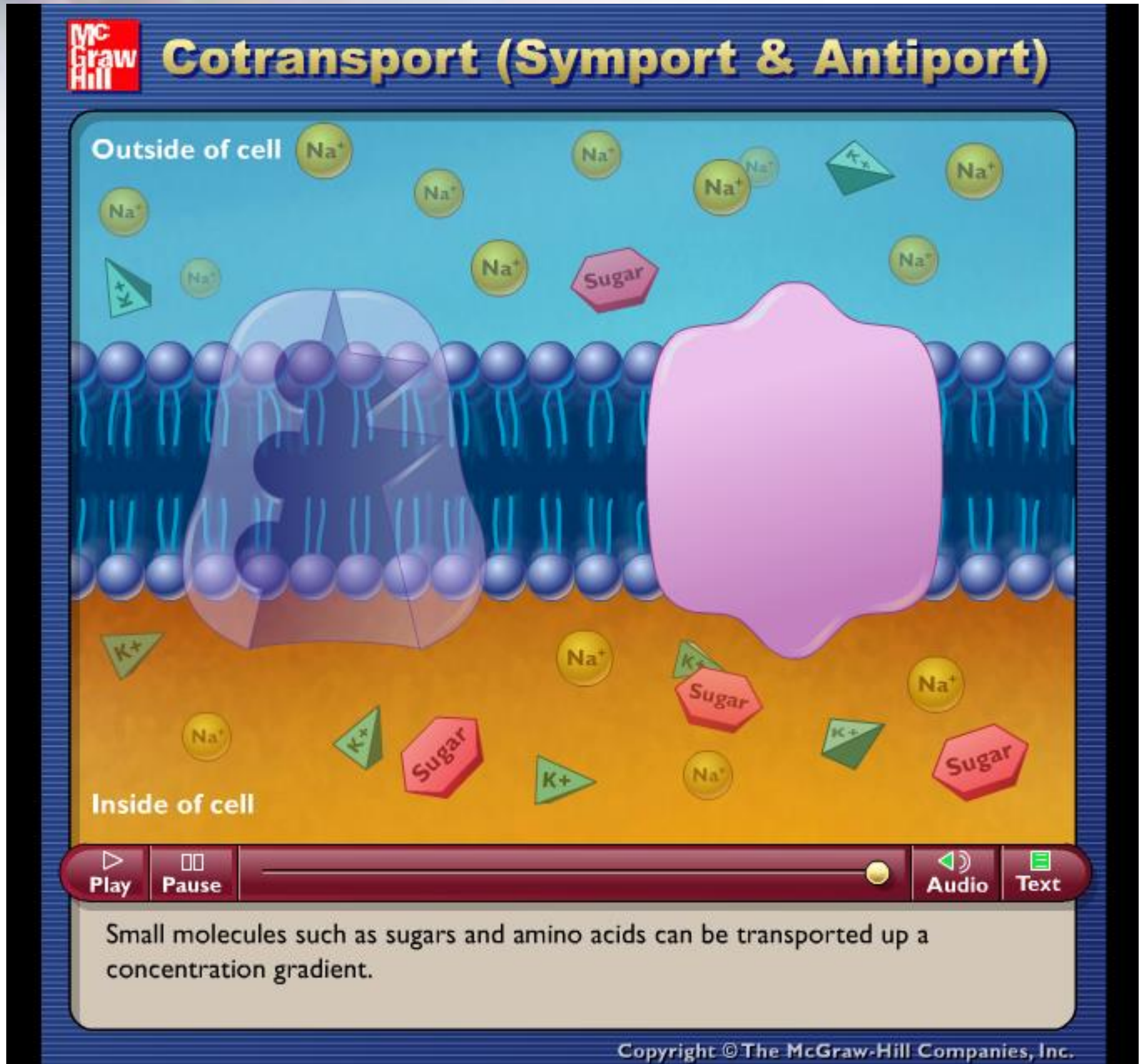
- Primary active transporters use ATP
- ATP-binding cassette (ABC) transporters
- Observed in *Bacteria, Archaea*, and eukaryotes
- Consist of
  - 2 hydrophobic membrane spanning domains
  - 2 cytoplasmic associated ATP-binding domains
  - Substrate binding domains



Secondary Active Transport

- Major facilitator superfamily (MFS)
- Use ion gradients to cotransport substances
  - protons
  - symport – two substances both move in the same direction
  - antiport – two substances move in opposite directions




Cotransport (Symport & Antiport)
Outside of cell
Inside of cell
Na+
K+
Sugar
Play
Pause
Audio
Text
Small molecules such as sugars and amino acids can be transported up a concentration gradient.
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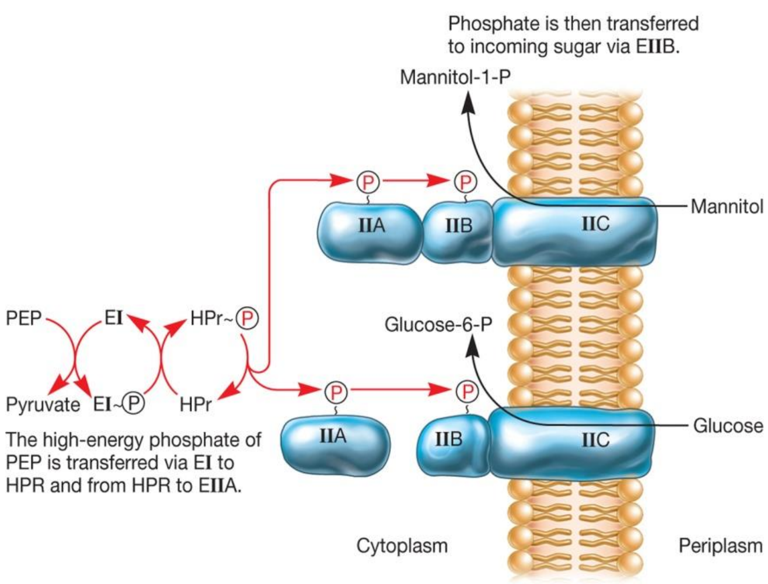
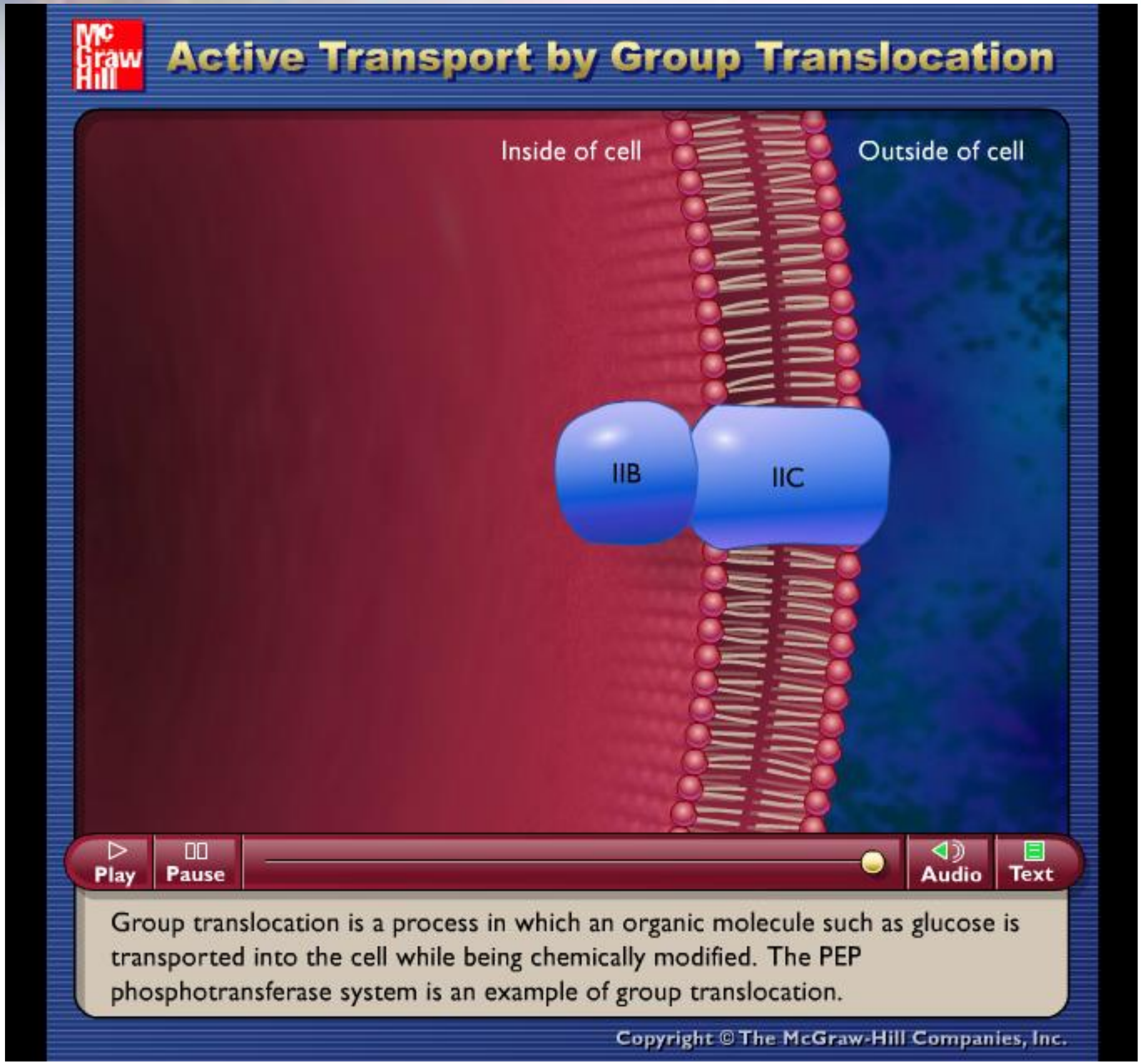
Group Translocation

- 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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Active Transport by Group Translocation
Inside of cell
Outside of cell
IIB
IIC
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Pause
Audio
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Group translocation is a process in which an organic molecule such as glucose is transported into the cell while being chemically modified. The PEP phosphotransferase system is an example of group translocation.
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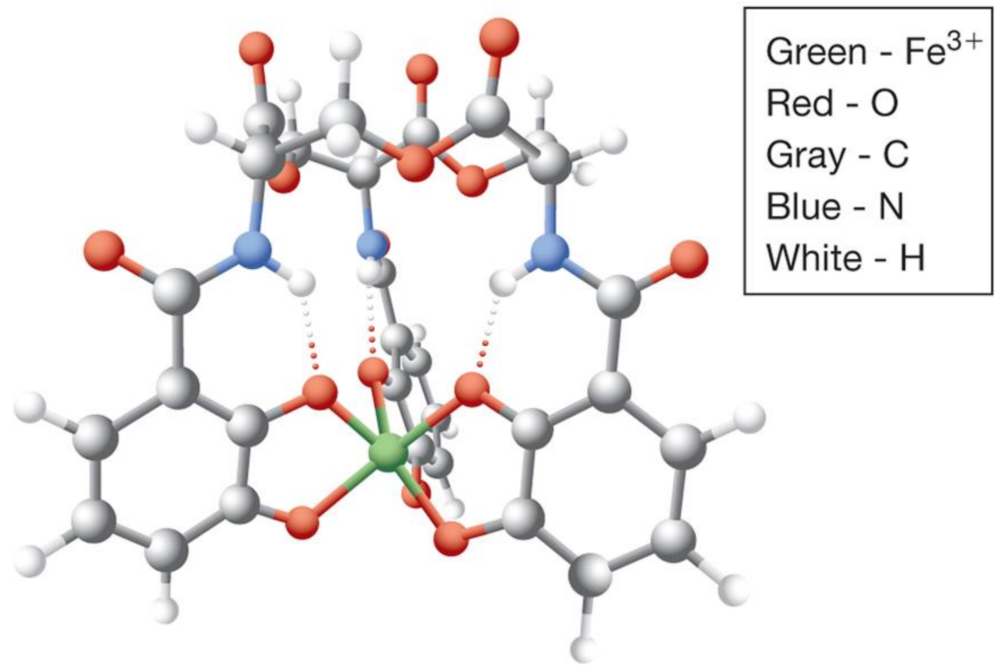
Iron Uptake

- 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 Bacterial Cell Walls

1. Describe peptidoglycan structure.
2. Compare and contrast the cell walls of typical Gram-positive and Gram-negative bacteria.
3. Relate bacterial cell wall structure to the Gram-staining reaction.

Bacterial Cell Wall

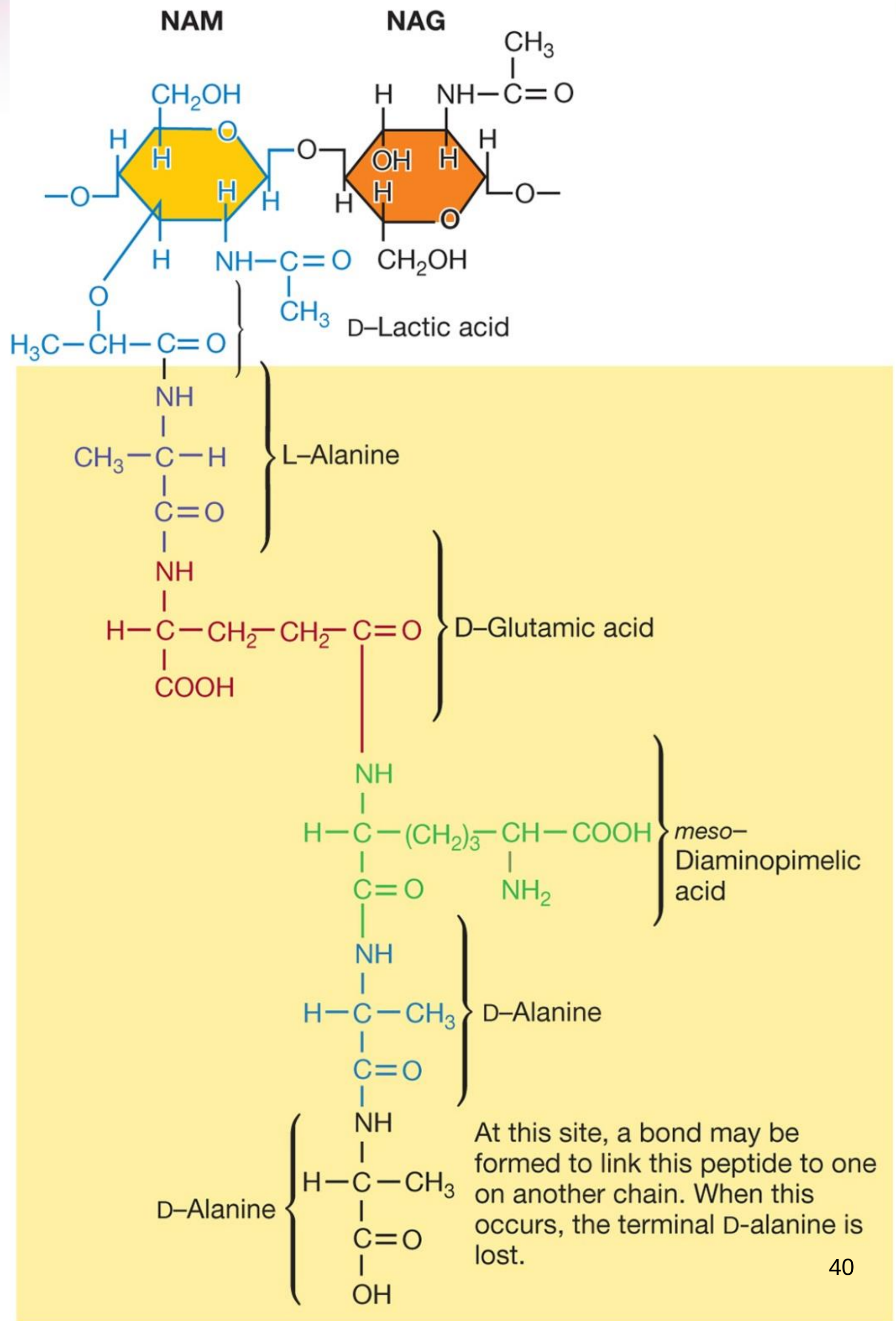
- Peptidoglycan (murein)
  - rigid structure that lies just outside the cell plasma membrane
  - two types based on Gram stain
    - Gram-positive: stain purple; thick peptidoglycan
    - Gram-negative: stain pink or red; thin peptidoglycan and outer membrane

Cell Wall Functions

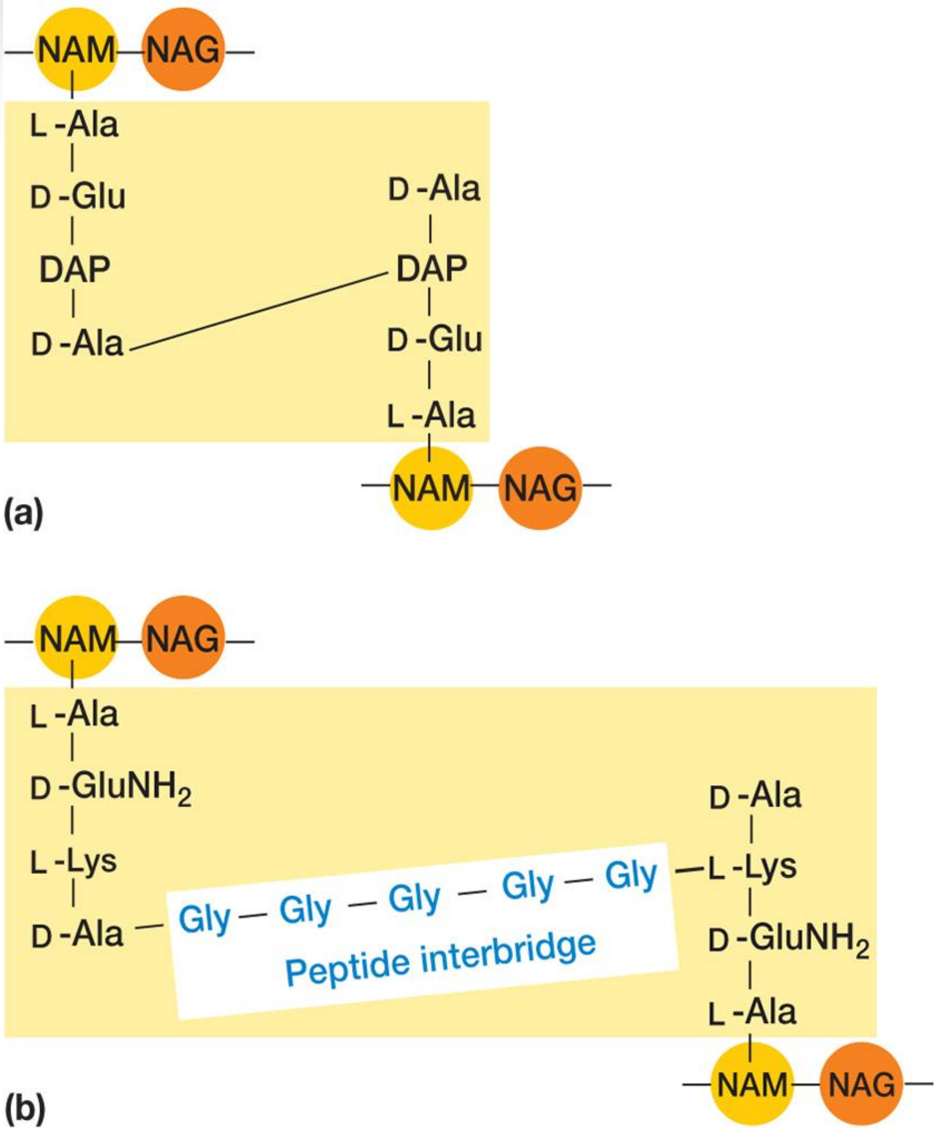
- Maintains shape of the bacterium
  - almost all bacteria have one
- Helps protect cell from osmotic lysis
- Helps protect from toxic materials
- May contribute to pathogenicity

Peptidoglycan Structure

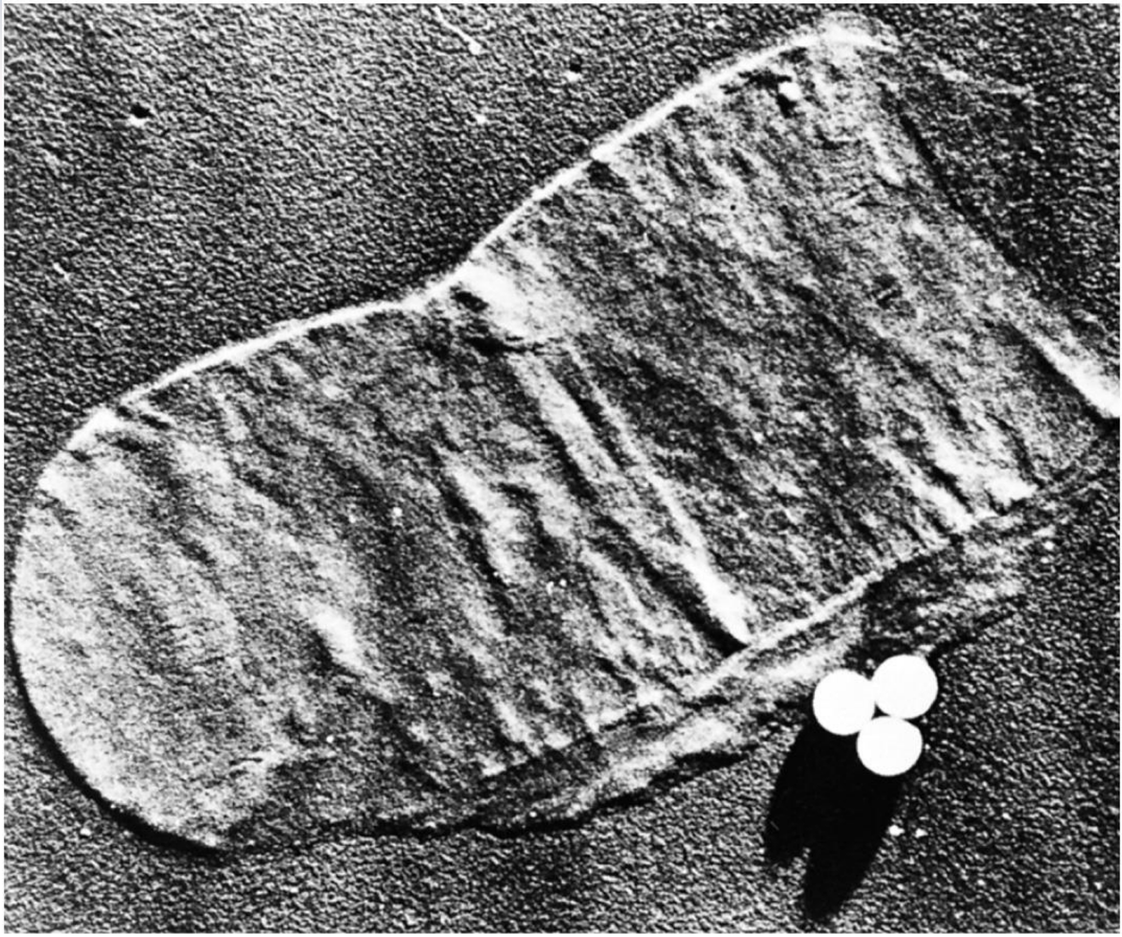
- Meshlike polymer of identical subunits forming long strands
  - two alternating sugars
    - *N*-acetylglucosamine (NAG)
    - *N*- acetylmuramic acid
  - alternating D- and L- amino acids



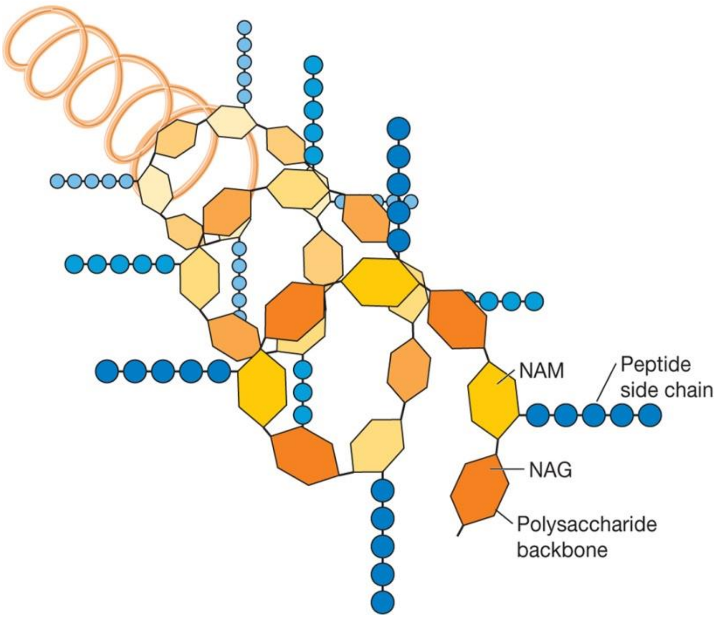
Strands Are Crosslinked



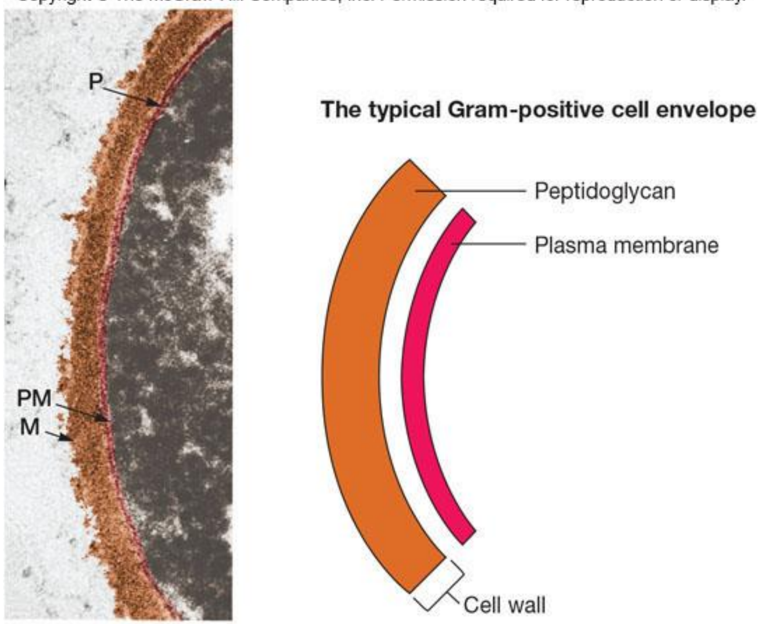
- Peptidoglycan strands have a helical shape
- Peptidoglycan chains are crosslinked by peptides for strength
  - interbridges may form
  - peptidoglycan sacs – interconnected networks
  - various structures occur



Courtesy of M.R. J. Salton, NYU Medical Center



Gram-Positive Cell Walls



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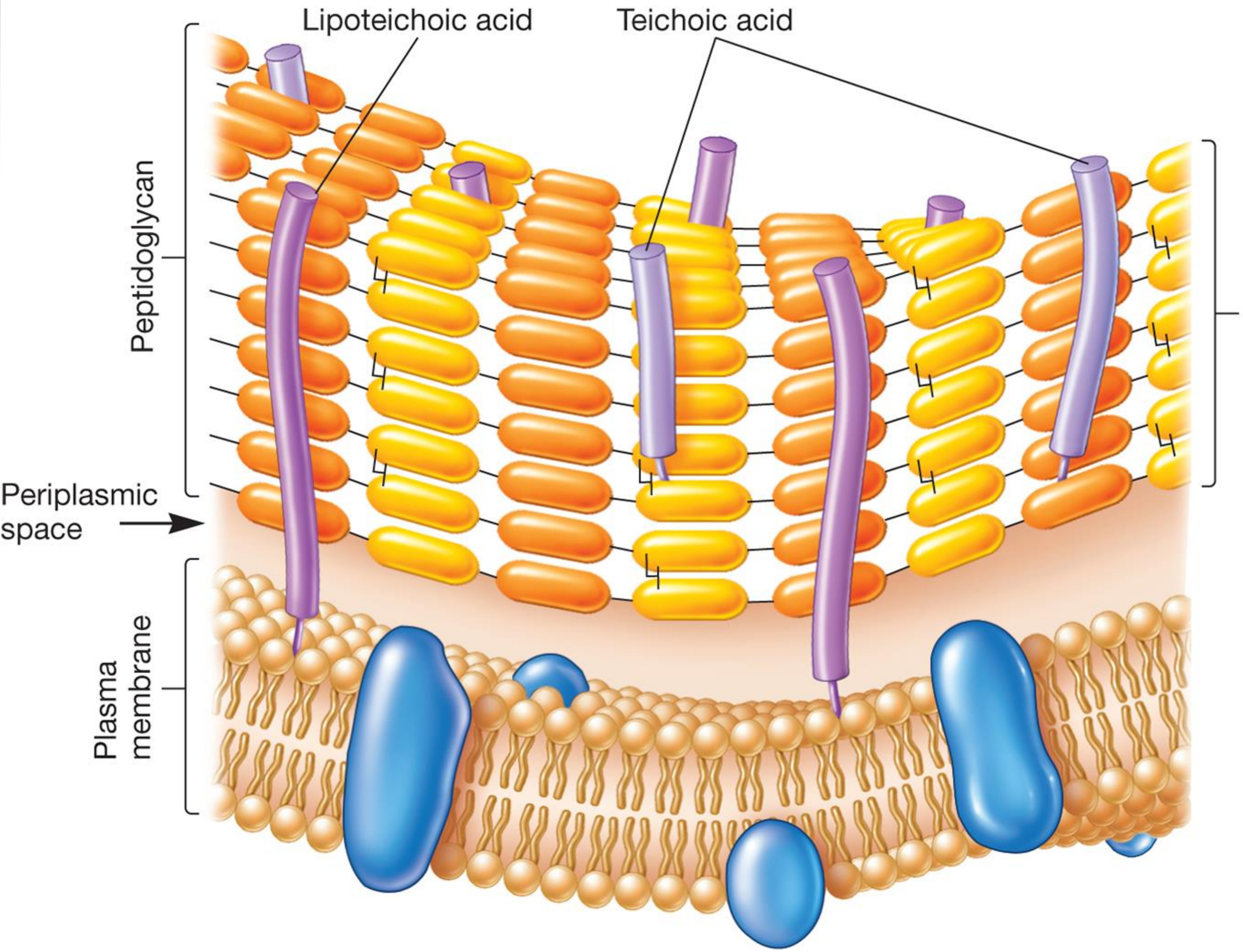
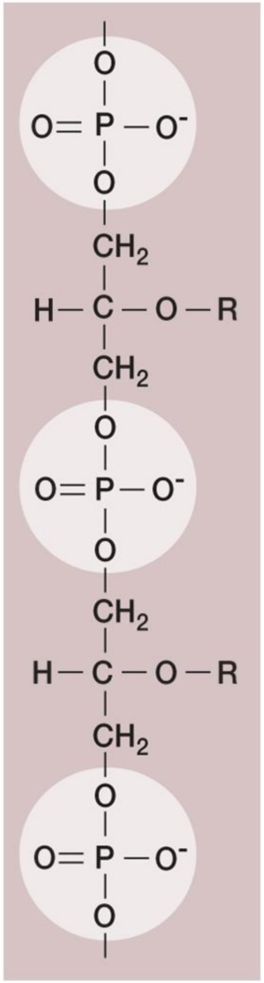
- Composed primarily of peptidoglycan
- May also contain teichoic acids (negatively charged)
  - help maintain cell envelope
  - protect from environmental substances
  - may bind to host cells
- some gram-positive bacteria have layer of proteins on surface of peptidoglycan



Lipoteichoic acid
Teichoic acid
Peptidoglycan
Periplasmic space
Plasma membrane
Cell wall



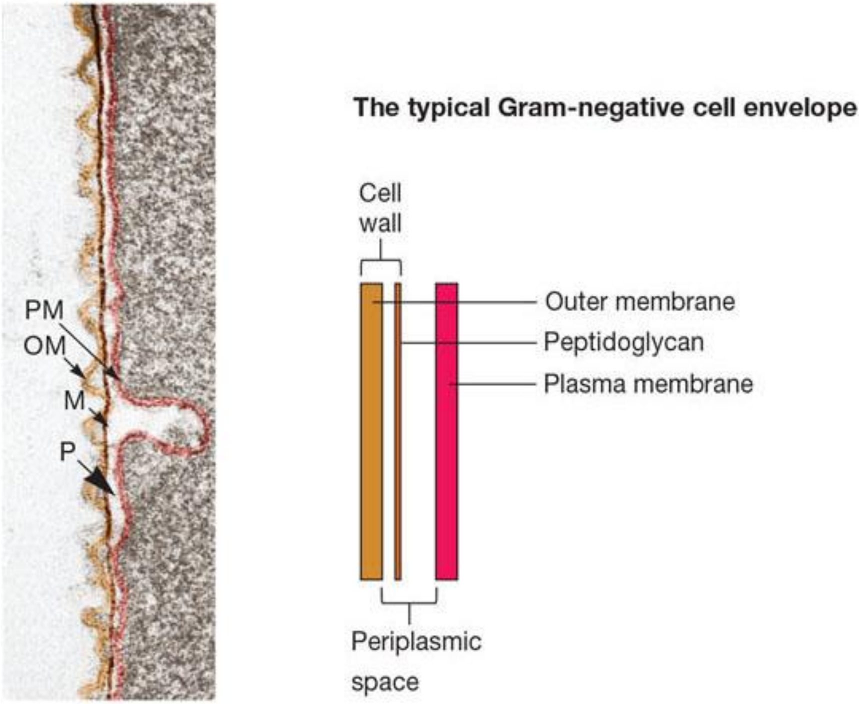
O
O= P – O⁻
O
CH2
H – C – O – R
CH2
O
O= P – O⁻
O
CH2
H – C – O – R
CH2
O
O= P – O⁻
O

Periplasmic Space of Gram + 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

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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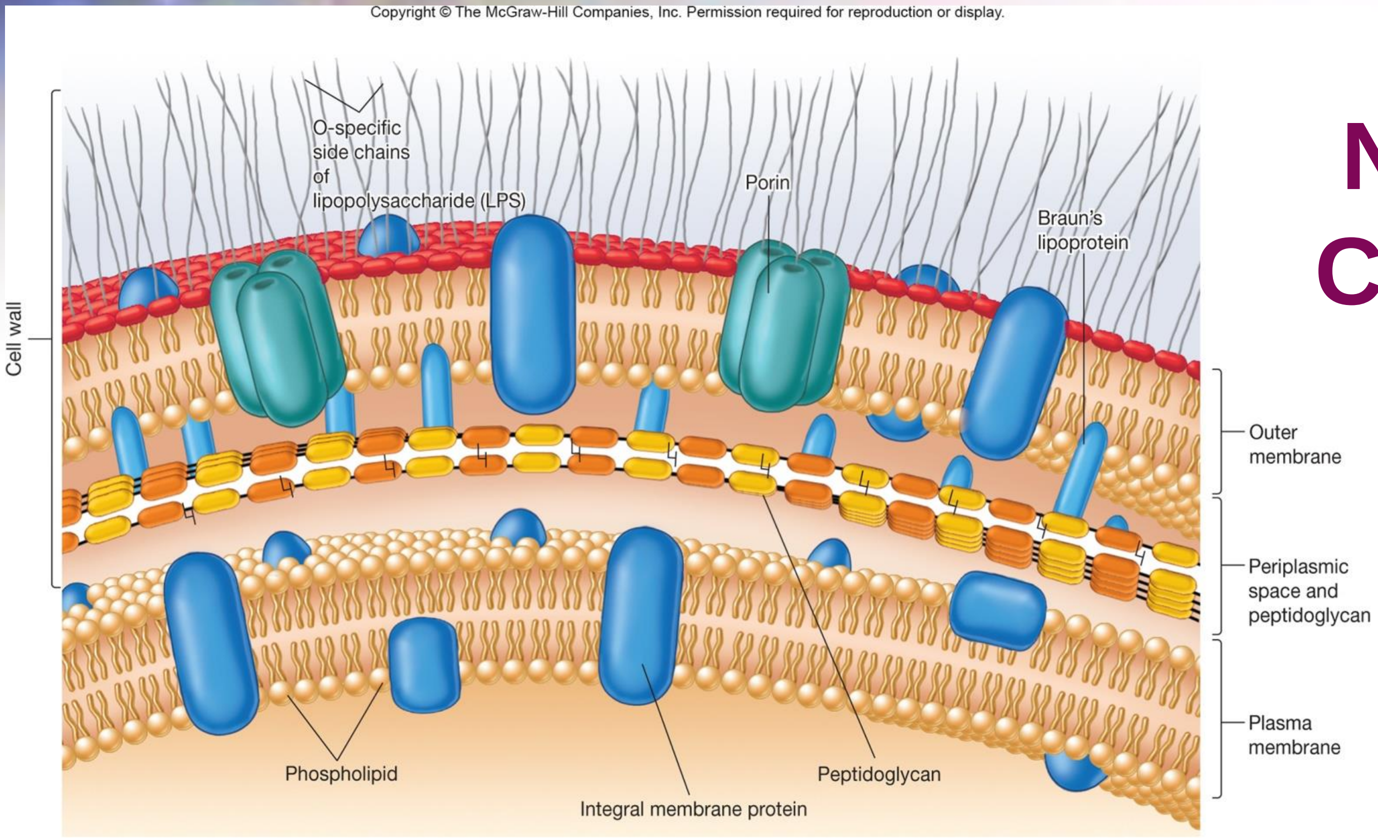
Gram-Negative Cell Walls

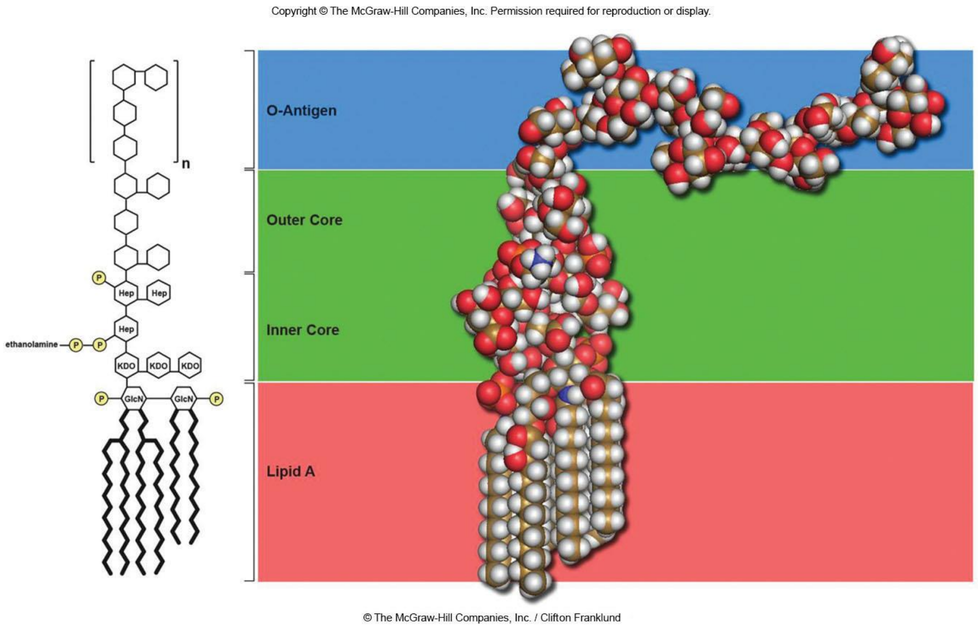
- Peptidoglycan is ~5-10% of cell wall weight
- Periplasmic space differs from that in Gram-positive cells
  - may constitute 20–40% of cell volume
  - many enzymes present in periplasm
    - hydrolytic enzymes, transport proteins and other proteins

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)



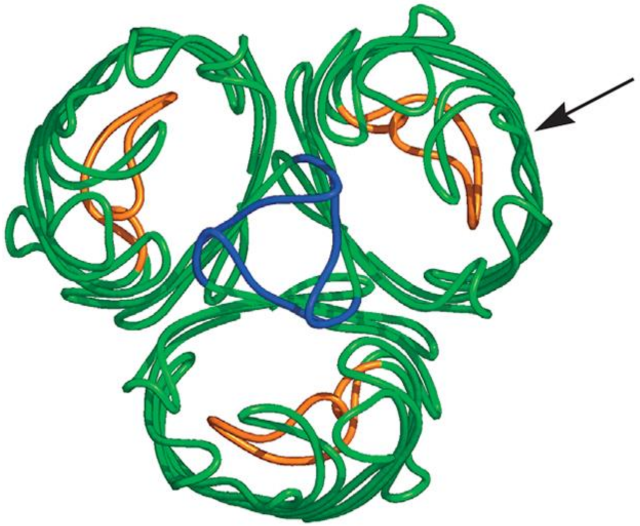
- Consists of three parts
  - lipid A
  - core polysaccharide
  - O side chain (O antigen)
- Lipid A embedded in outer membrane
- Core polysaccharide, O side chain extend out from the cell

Importance of LPS

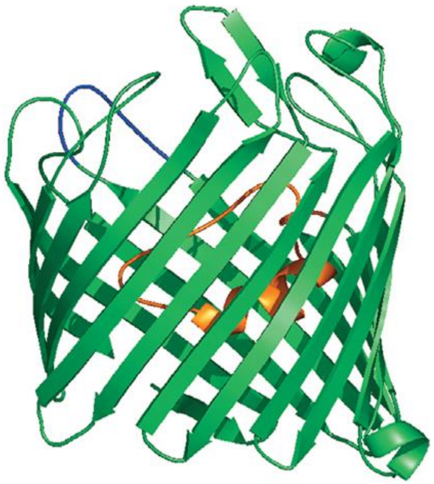
- contributes to negative charge on cell surface
- helps stabilize outer membrane structure
- may contribute to attachment to surfaces and biofilm formation
- creates a permeability barrier
- protection from host defenses (O antigen)
- can act as an endotoxin (lipid A)

Gram-Negative Outer Membrane Permeability

- More permeable than plasma membrane due to presence of porin proteins and transporter proteins
  - porin proteins form channels to let small molecules (600–700 daltons) pass



(a) Porin trimer



(b) OmpF side view

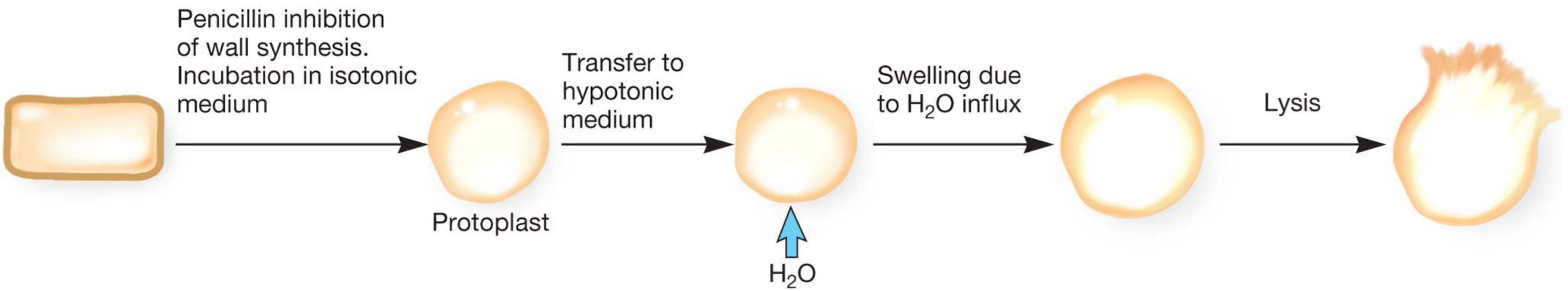
Mechanism of Gram Stain Reaction

- 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

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

Cells that Lose a Cell Wall May Survive in Isotonic Environments

- Protoplasts
- Spheroplasts
- *Mycoplasma*
  - does not produce a cell wall
  - plasma membrane more resistant to osmotic pressure

3.5 Cell Envelope Layers Outside the Cell Wall

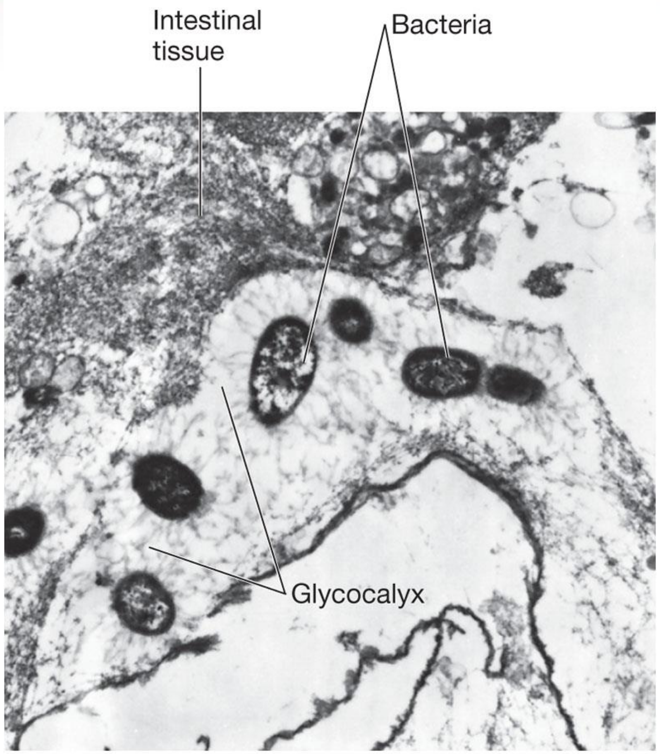
1. Compile a list of all the structures found in all the layers of bacterial cell envelopes, noting the functions and the major component molecules of each.

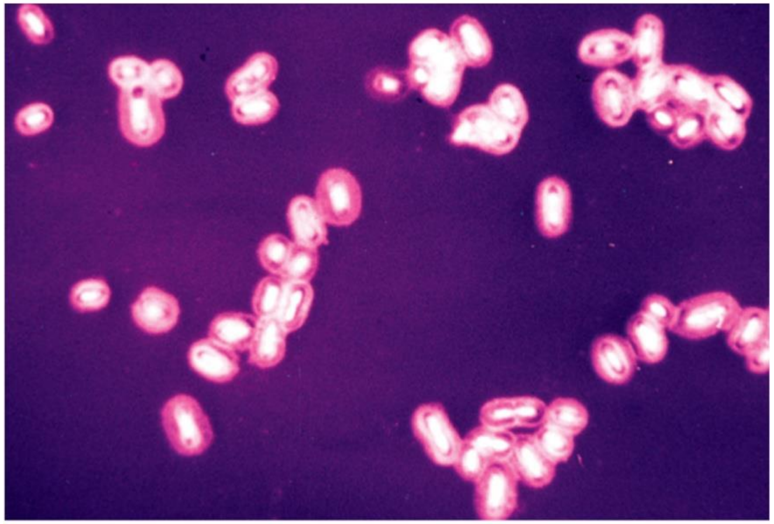
Components Outside of the Cell Wall

- 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





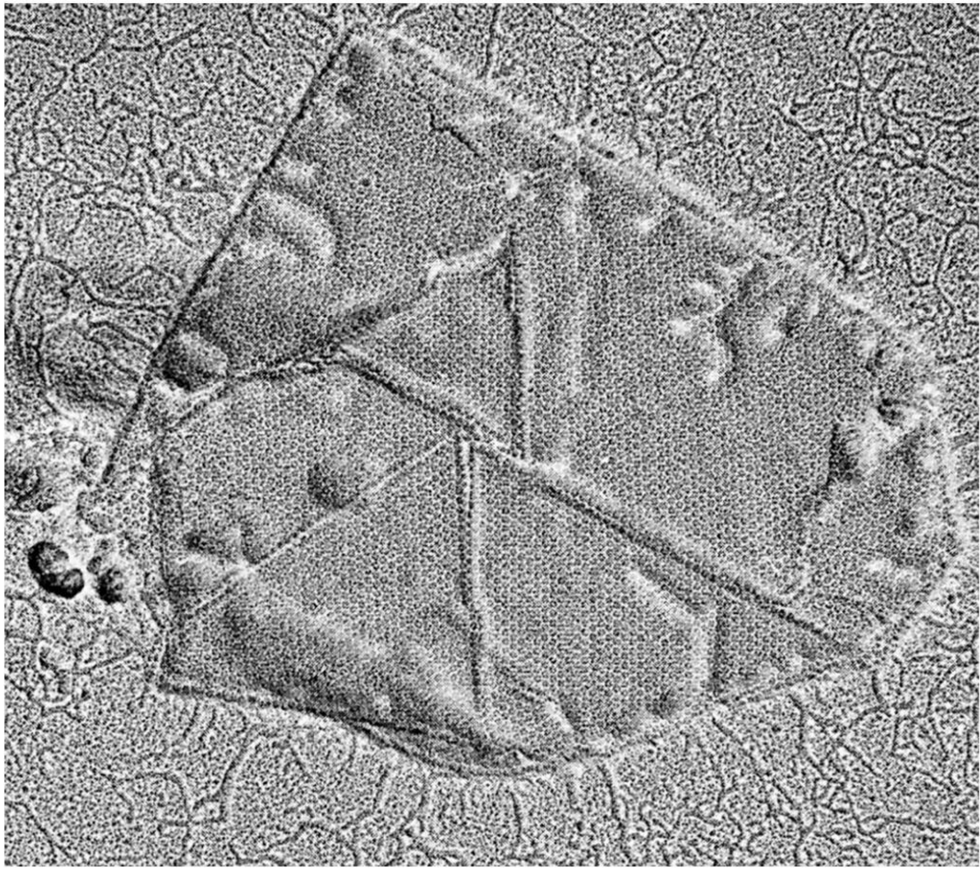
K. pneumoniae

Slime Layers

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

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



Dr. Robert G.E. Murray

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
  - S layer spontaneously associates

3.6 Bacterial Cytoplasm

1. Create a table or concept map that identifies the components of the bacterial cytoplasm and describes their structure, molecular makeup, and functions.

Bacterial 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

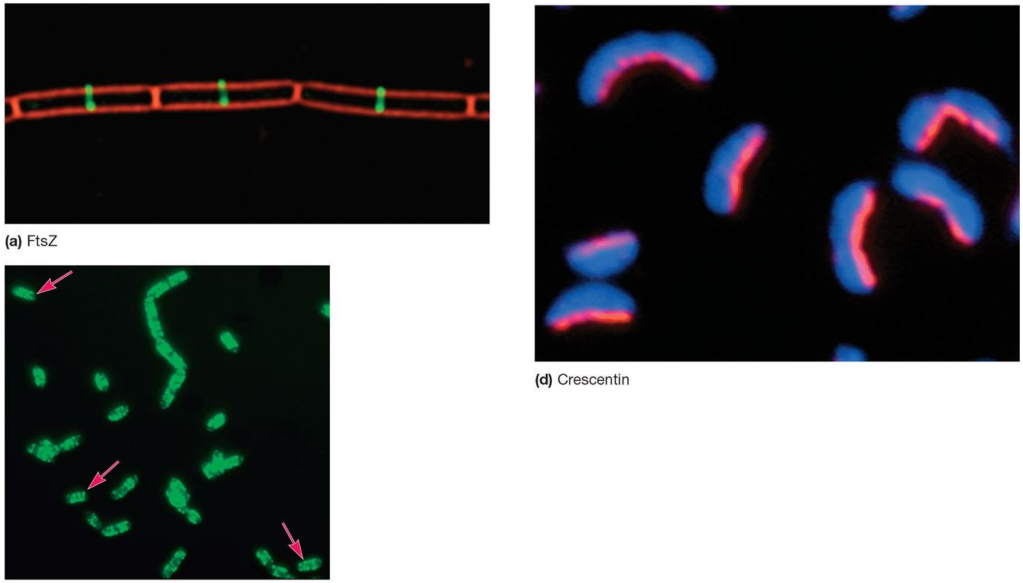
- Homologs of all 3 eukaryotic cytoskeletal elements have been identified in bacteria
- Functions are similar as in eukaryotes

Table 3.2 Bacterial Cytoskeletal Proteins

Type	Function	Comments
Tubulin Homologues		
FtsZ	Cell division	Widely observed in bacteria and archaea
BtubA/BtubB	Unknown	Observed only in *Prosthecobacter* spp.; thought to be encoded by eukaryotic tubulin genes obtained by horizontal gene transfer
TubZ	Possibly plasmid segregation	Encoded by large plasmids observed in members of the genus *Bacillus*
Actin Homologues		
MamK	Positioning magnetosomes	Observed in magnetotactic species
MreB/Mbl	Helps determine cell shape, may be involved in chromosome segregation, localizes proteins	Most rod-shaped bacteria
ParM	Plasmid segregation	Plasmid encoded
Intermediate Filament Homologues		
CreS (crescentin)	Induces curvature in curved rods	*Caulobacter crescentus*
Unique Bacterial Cytoskeletal Proteins		
MinD	Prevents polymerization of FtsZ at cell poles	Many rod-shaped bacteria
ParA	Segregates chromosomes and plasmids	Observed in many species, including *Vibrio cholerae, C. crescentus,* and *Thermus thermophilus*

Best Studied Examples

- 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



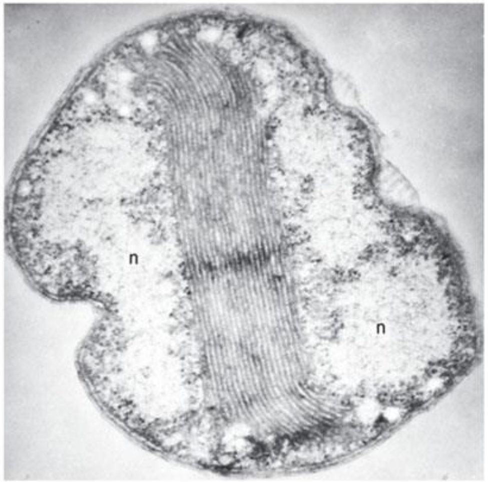
(a) FtsZ

(b) Mbl

(d) Crescentin

a: Dr. Joseph Pogliano; b: Image courtesy of Rut Carballido-Lo'pez and Jeff Errington; d: Dr. Christine Jacobs-Wagner

Intracytoplasmic Membranes



(a)

(b)

a: R.G.E. Murray & S.W. Watson, Journal of Bacteriology 89 (6): 1597, fig Nitrocystis Oceanus, 1965. American Society for Microbiology; b: 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

- Plasma membrane infoldings
  - observed in many photosynthetic bacteria
  - observed in many bacteria with high respiratory activity
- Anammoxosome in *Planctomycetes*
  - organelle – site of anaerobic ammonia oxidation

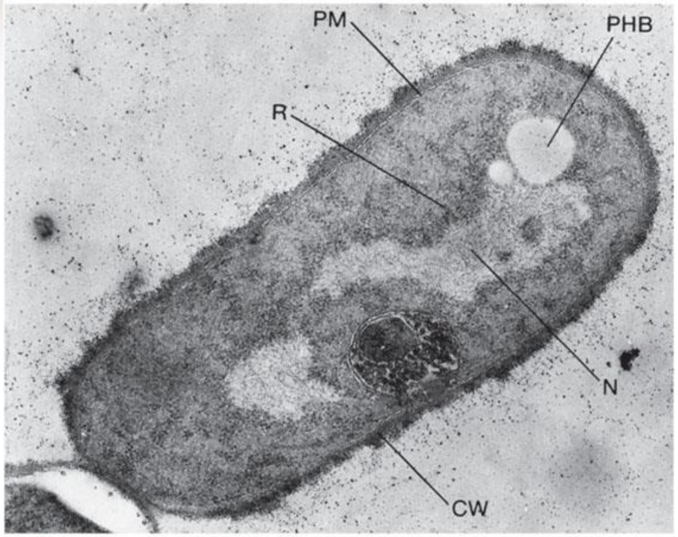
Inclusions

- 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



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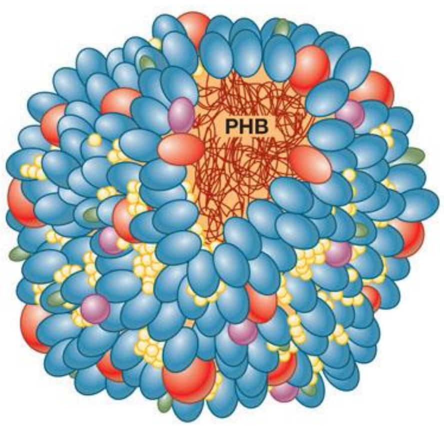

(b)

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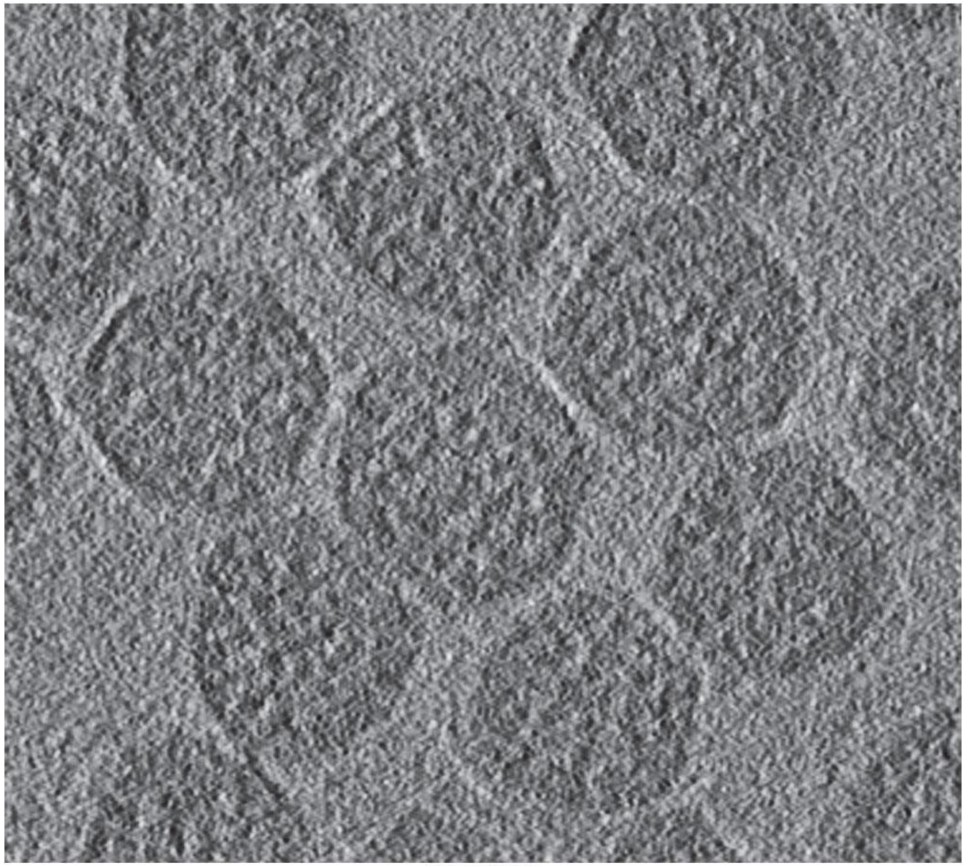
Microcompartments

- 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

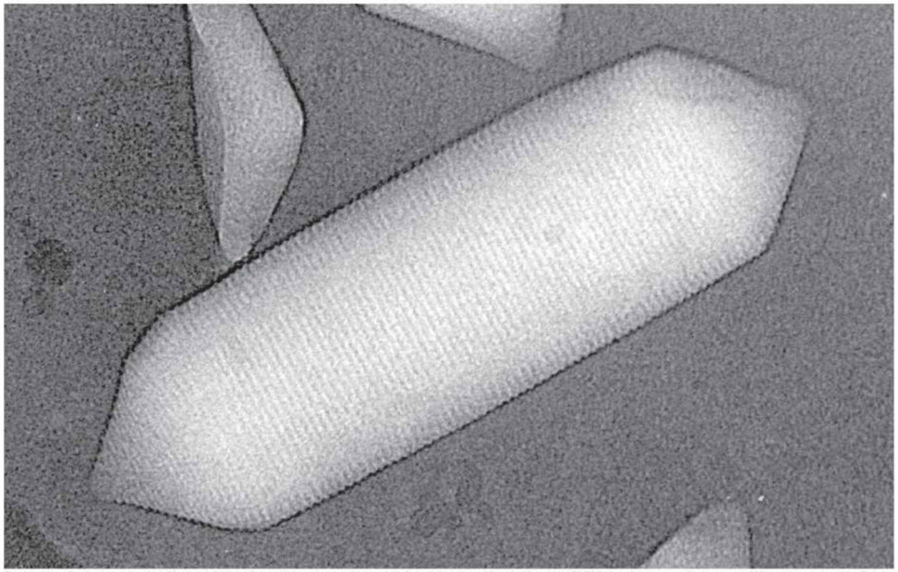


Michael Schmid

Other Inclusions

- Gas vacuoles
  - found in aquatic, photosynthetic bacteria and archaea
  - provide buoyancy in gas vesicles

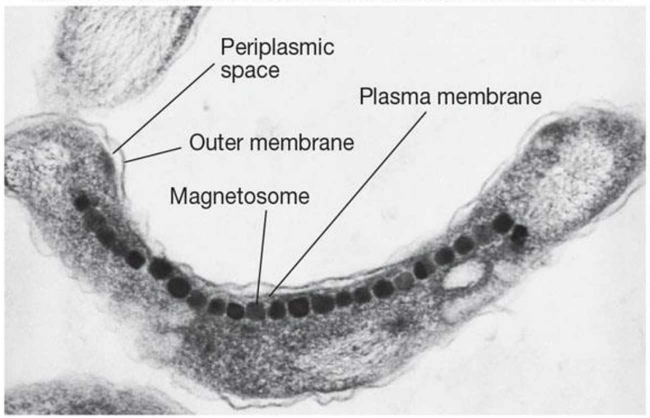
Courtesy of Daniel Branton, Harvard University



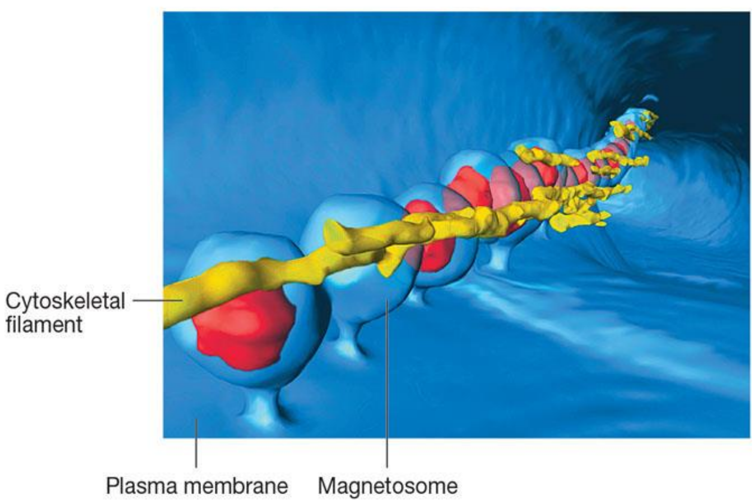
Reprinted from *Biophysical Journal* Vol. 86, Marina Belenky, Rebecca Meyers and Judith Herzfeld, Subunit Structure of Gas Vesicles: A MALDI-TOF Mass Spectrometry Study, January 2004, with permission from Elsevier

Other Inclusions

- Magnetosomes
  - found in aquatic bacteria
  - magnetite particles for orientation in Earth’s magnetic field
  - cytoskeletal protein MamK
    - helps form magnetosome chain



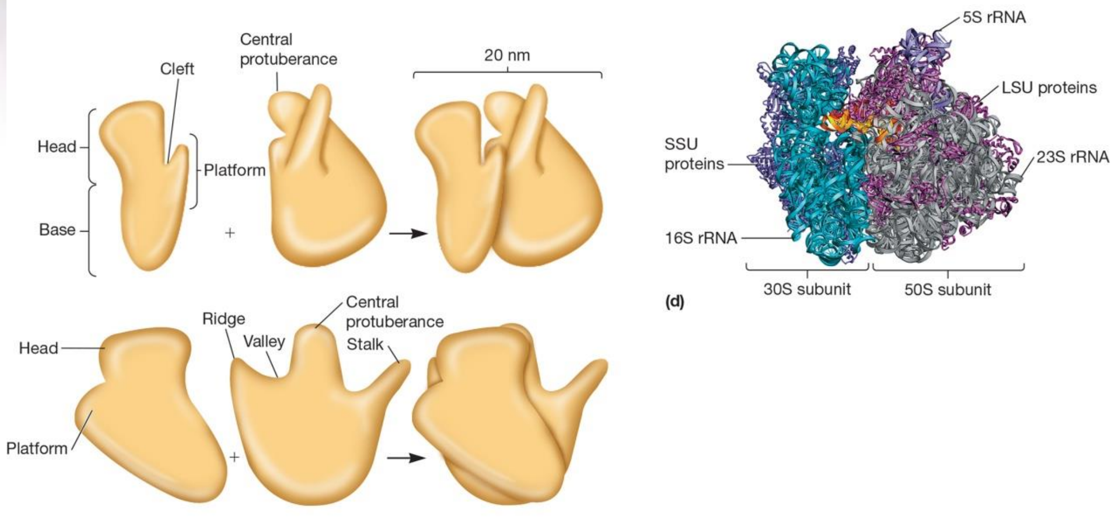
(a)



(b)

a: Y. Gorby; b: Zhuo Li and Grant Jensen

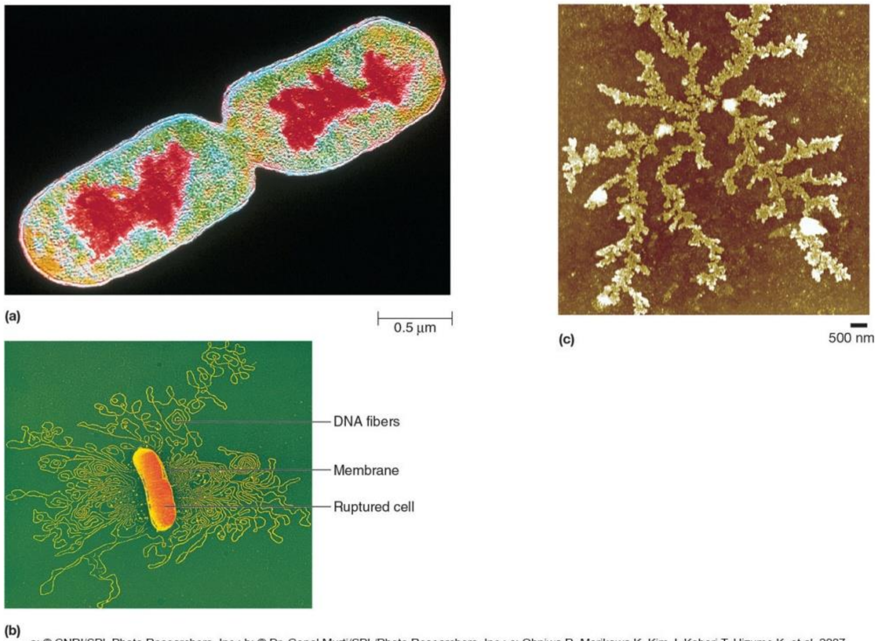
Ribosomes



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

- 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



a: © CNRI/SPL Photo Researchers, Inc.; b: © Dr. Gopal Murti/SPL/Photo Researchers, Inc.; c: Ohniwa R. Morikawa K, Kim J, Kobori T, Hizume K, et al. 2007. *Microsec. Microana.* 13:3–12. Reprinted with the permission of Cambridge University Press

- 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.

3.7 External Structures

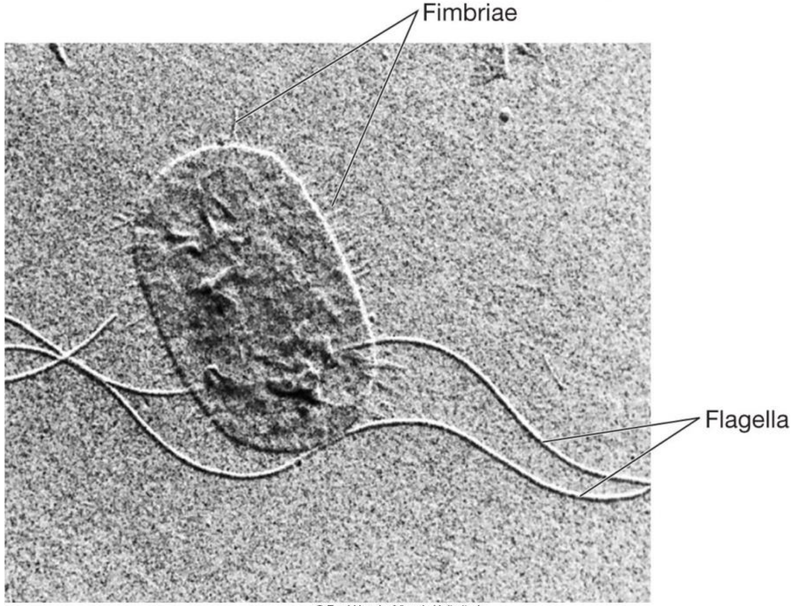
1. Distinguish pili (fimbriae) and flagella.
2. Illustrate the various patterns of flagella distribution.

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

- 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



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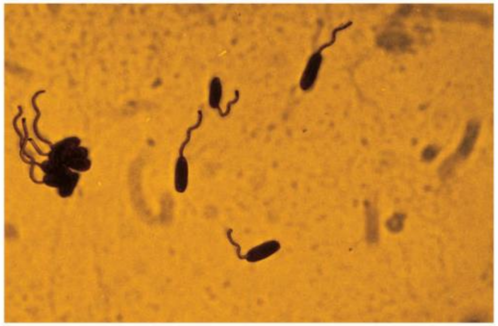
Flagella

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

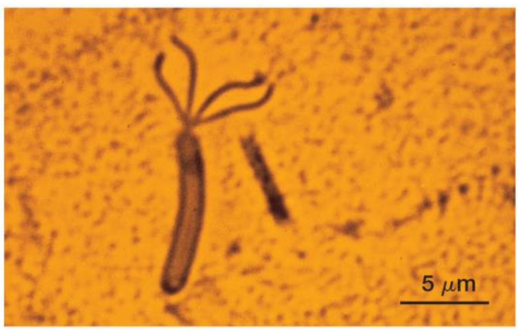
Bacterial Flagella

- Thin, rigid protein structures that cannot be observed with bright-field microscope unless specially stained
- Ultrastructure composed of three parts
- Pattern of flagellation varies

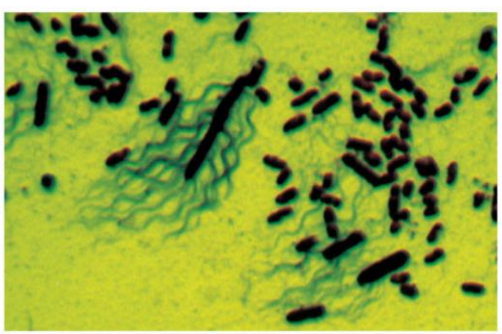
Patterns of Flagella Distribution



(a) *Pseudomonas*—monotrichous polar flagellation



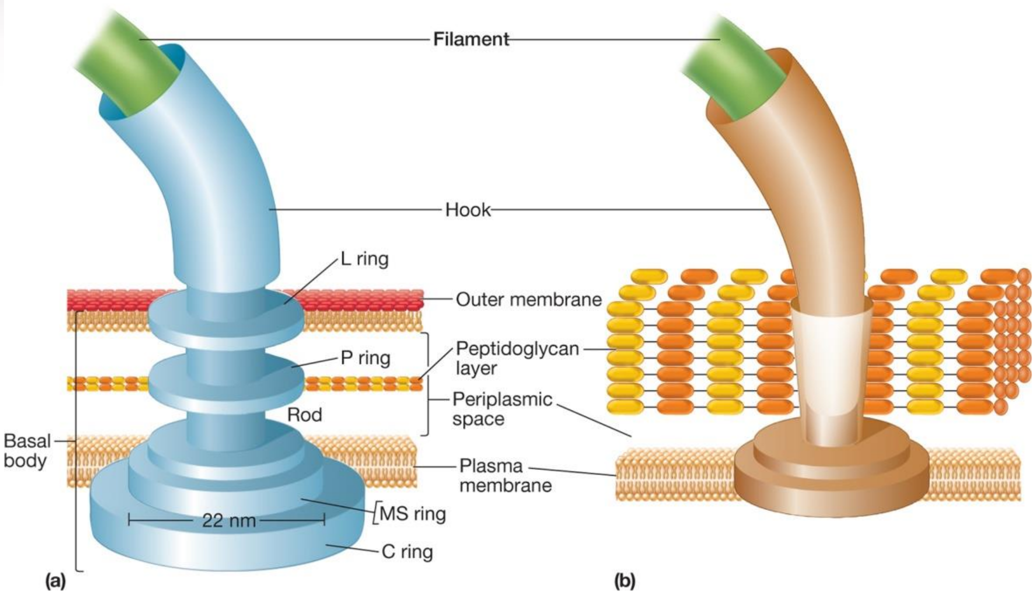
(b) *Spirillum*—lophotrichous flagellation



(c) *P. vulgaris*—peritrichous 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

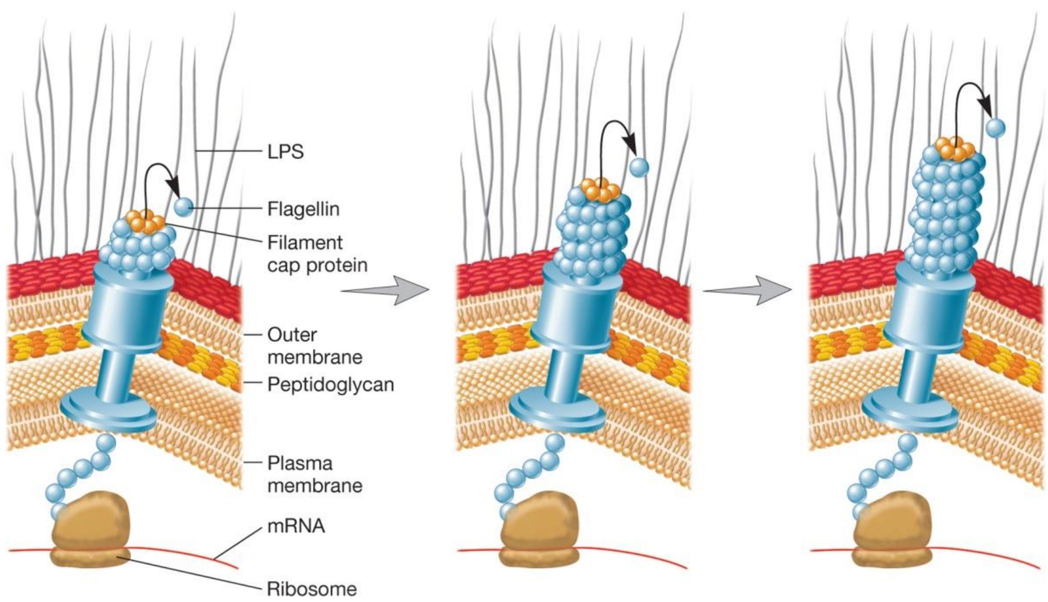
Three Parts of Flagella



- Filament
  - extends from cell surface to the tip
  - hollow, rigid cylinder of flagellin protein
- Hook
  - links filament to basal body
- Basal body
  - series of rings that drive flagellar motor

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



3.8 Bacterial Motility and Chemotaxis

1. Compare and contrast flagellar swimming motility, spirochete flagellar motility, and twitching and gliding motility.
2. State the source of energy that powers flagellar motility.
3. Explain why bacterial chemotaxis is referred to as a “biased random walk.”

Motility

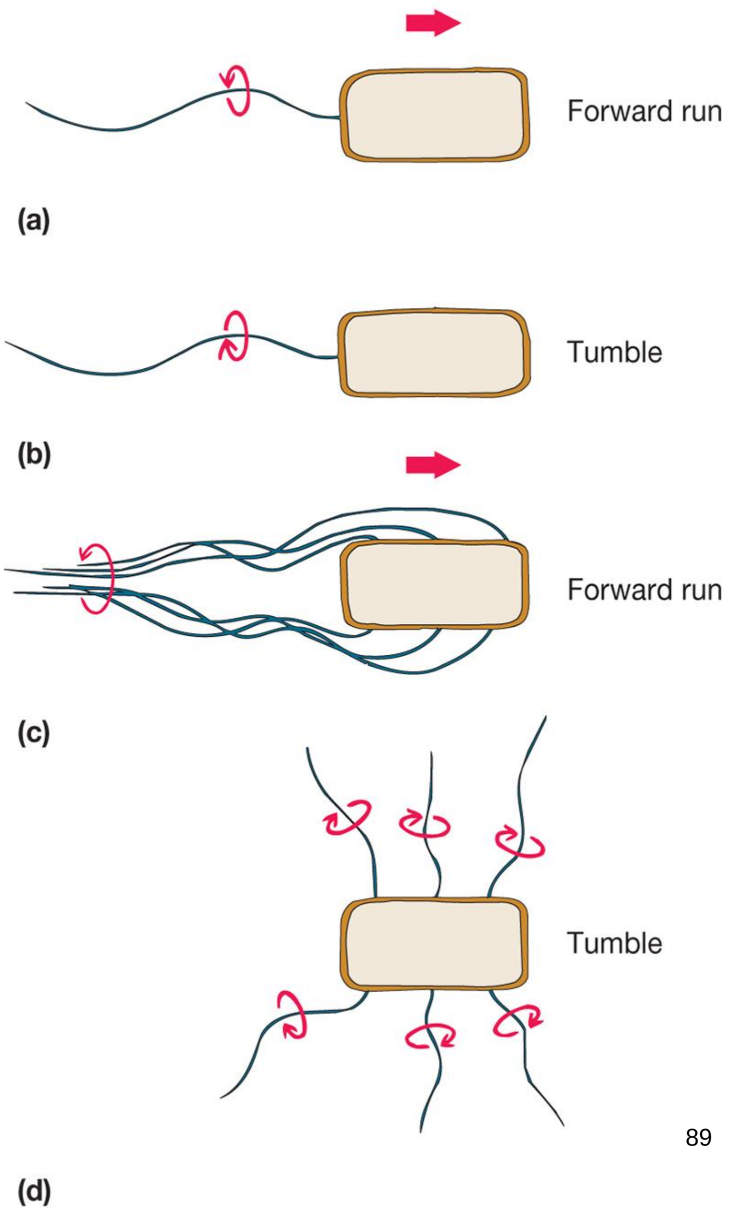
- Flagellar movement
- Spirochete motility
- Twitching motility
- Gliding motility

Motility

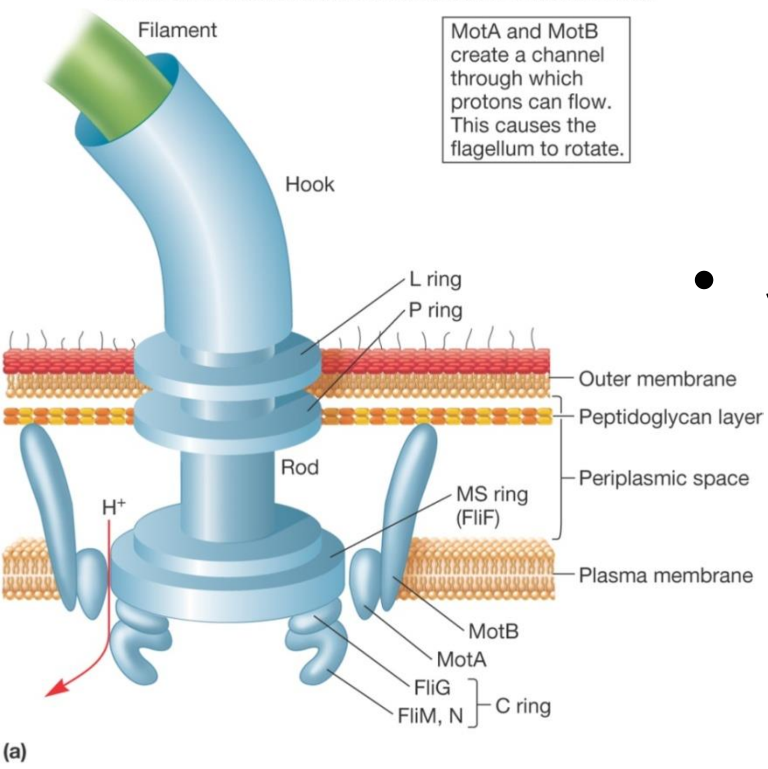
- *Bacteria* and *Archaea* have directed movement
- Chemotaxis
  - move toward chemical attractants such as nutrients, away from harmful substances
- Move in response to temperature, light, oxygen, osmotic pressure, and gravity

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



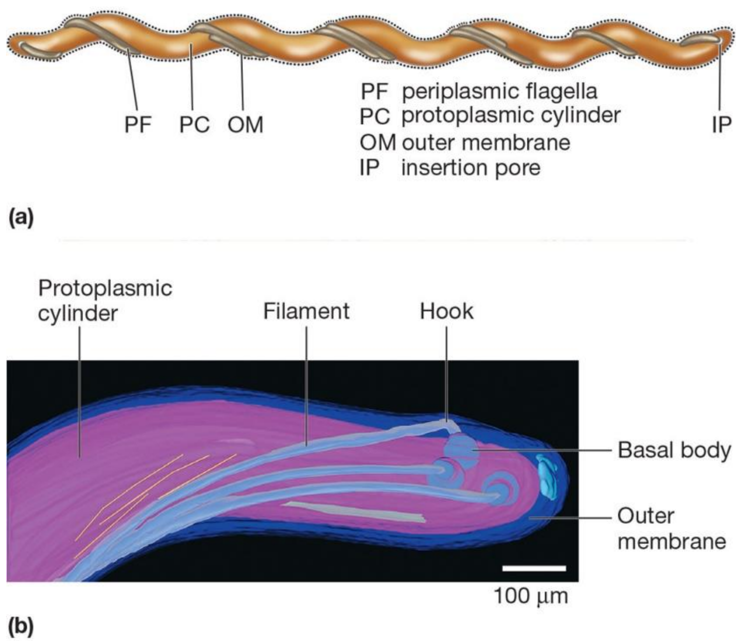
Mechanism of Flagellar Movement



- 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 using energy of proton motive force
  - torque powers rotation of the basal body and filament

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

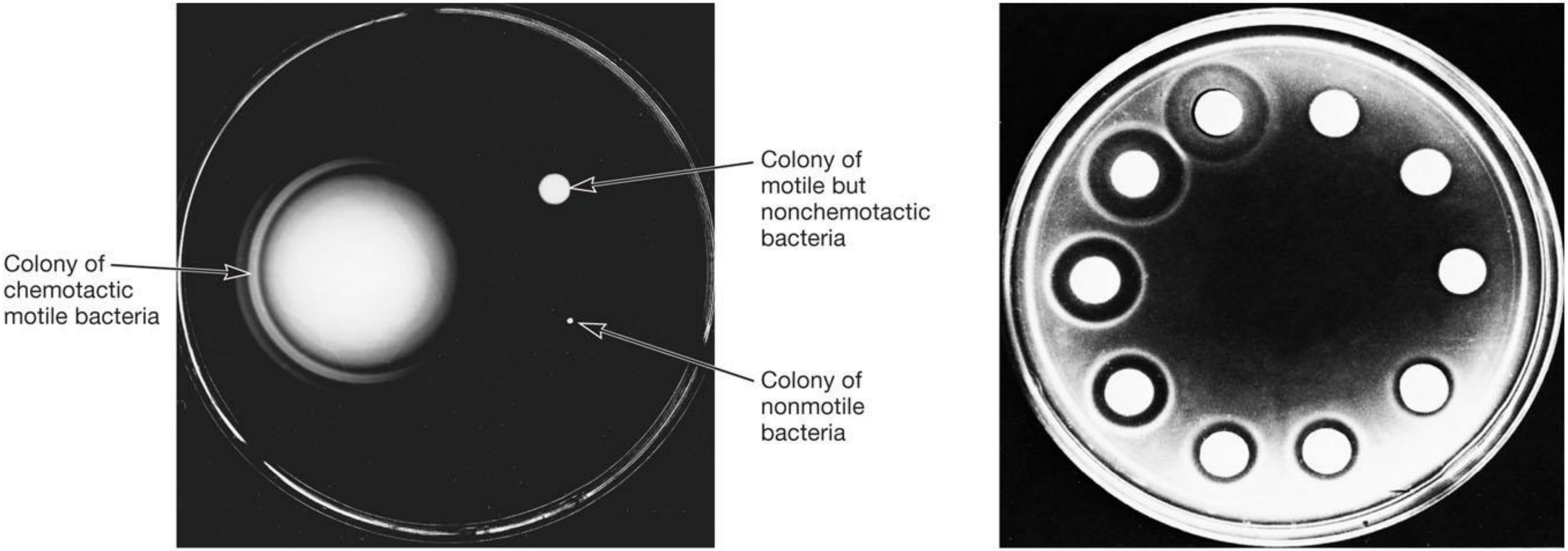


Twitching and Gliding Motility

- 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

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

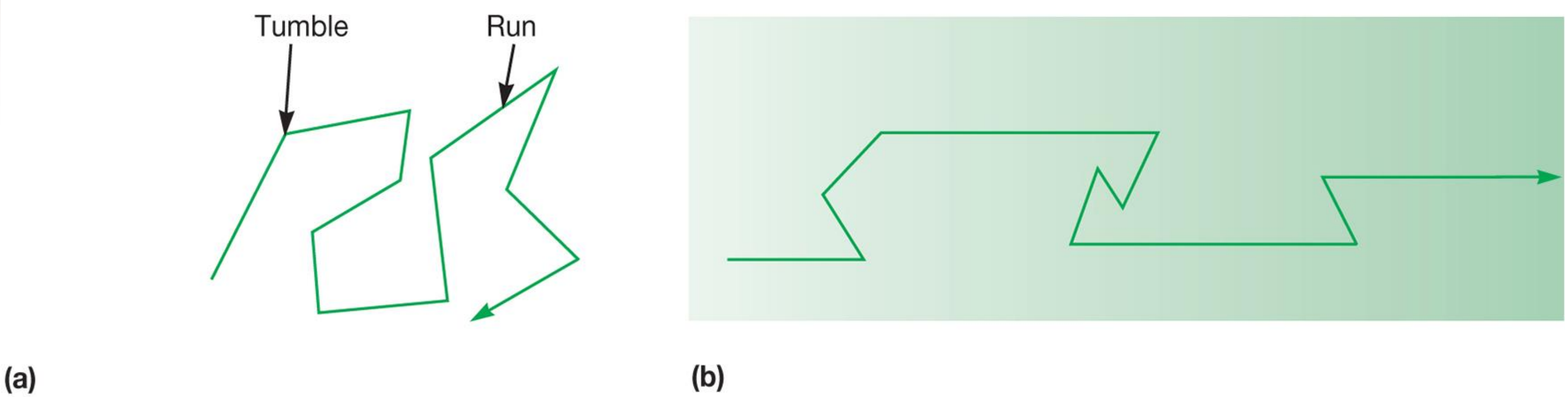


(a) Positive chemotaxis

(b) Negative chemotaxis

Courtesy of Dr. Julius Adler

Chemotaxis



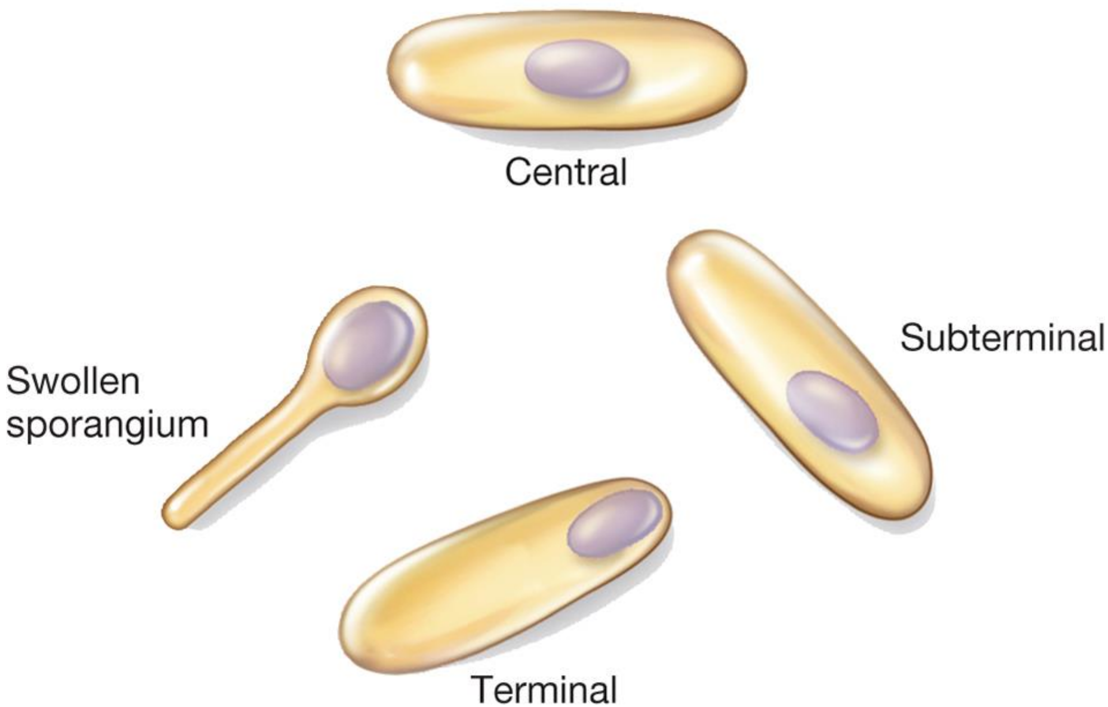
- In presence of attractant (b) tumbling frequency is intermittently reduced and runs in direction of attractant are longer
- Behavior of bacterium is altered by temporal concentration of chemical
- Chemotaxis away from repellent involves similar but opposite responses

3.9 Bacterial Endospores

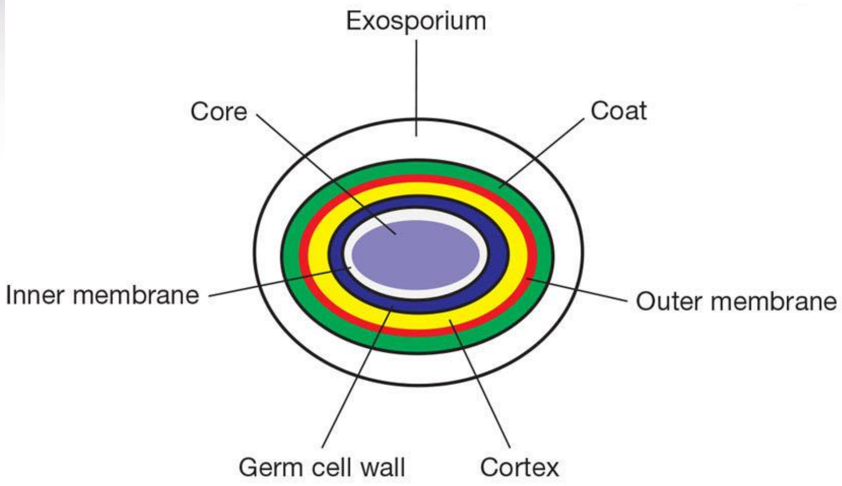
1. Describe the structure of the bacterial endospore.
2. Explain why the bacterial endospores are of particular concern to the food industry and why endospore-forming bacteria are important model organisms.
3. Describe in general terms the process of sporulation.
4. Describe those properties of endospores that are thought to contribute to its resistance to environmental stresses.
5. Describe the three stages that transform an endospore into an active vegetative cell.

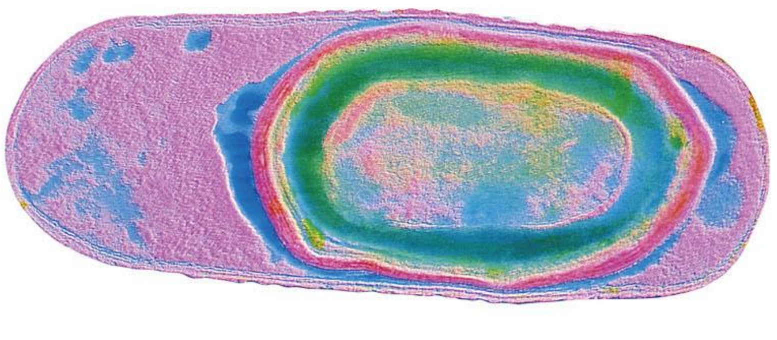
The Bacterial Endospore

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



Endospore Structure





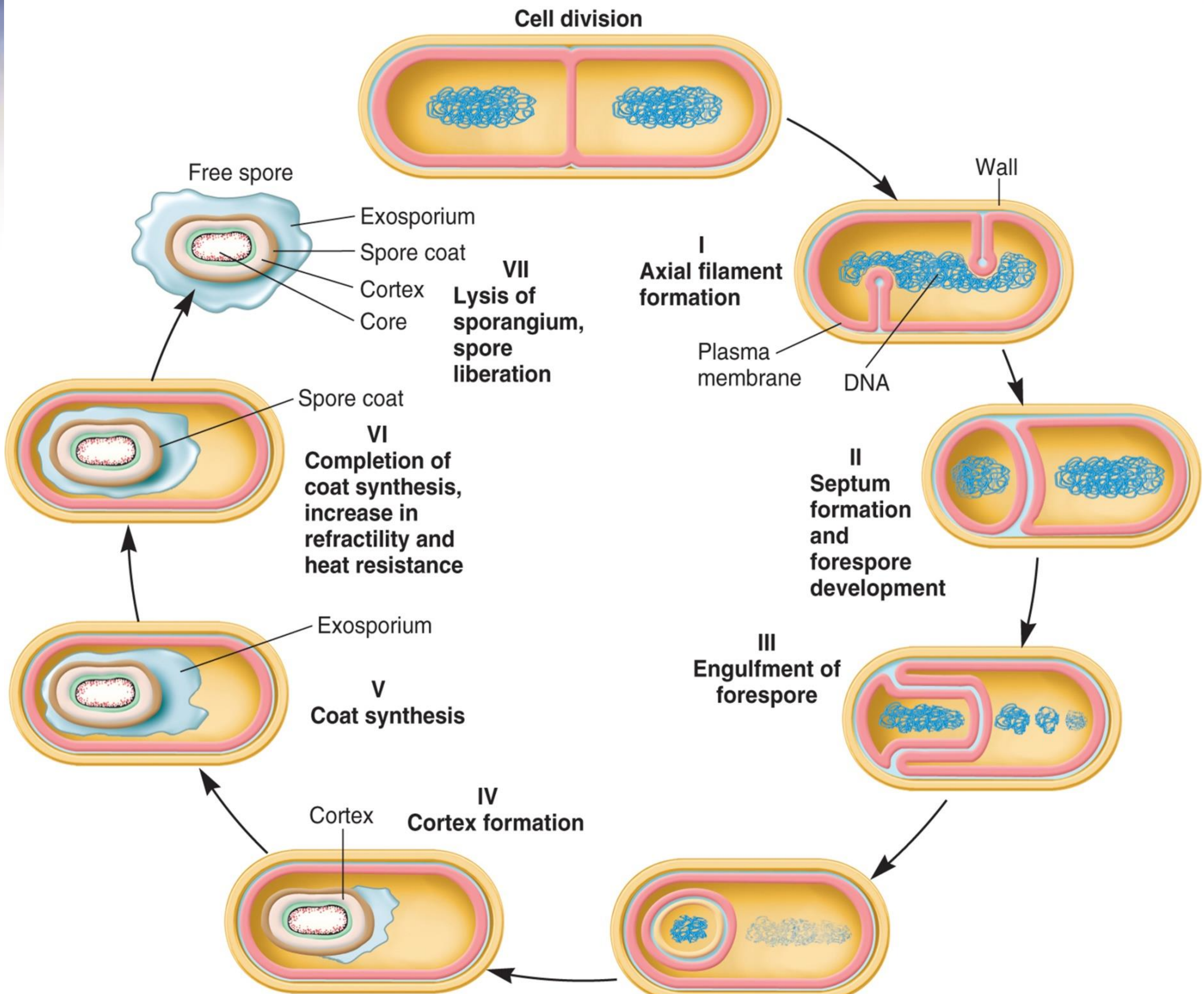
- Spore surrounded by thin covering called exosporium
- Thick layers of protein form the spore coat
- Cortex, beneath the coat, thick peptidoglycan
- Core has nucleoid and ribosomes

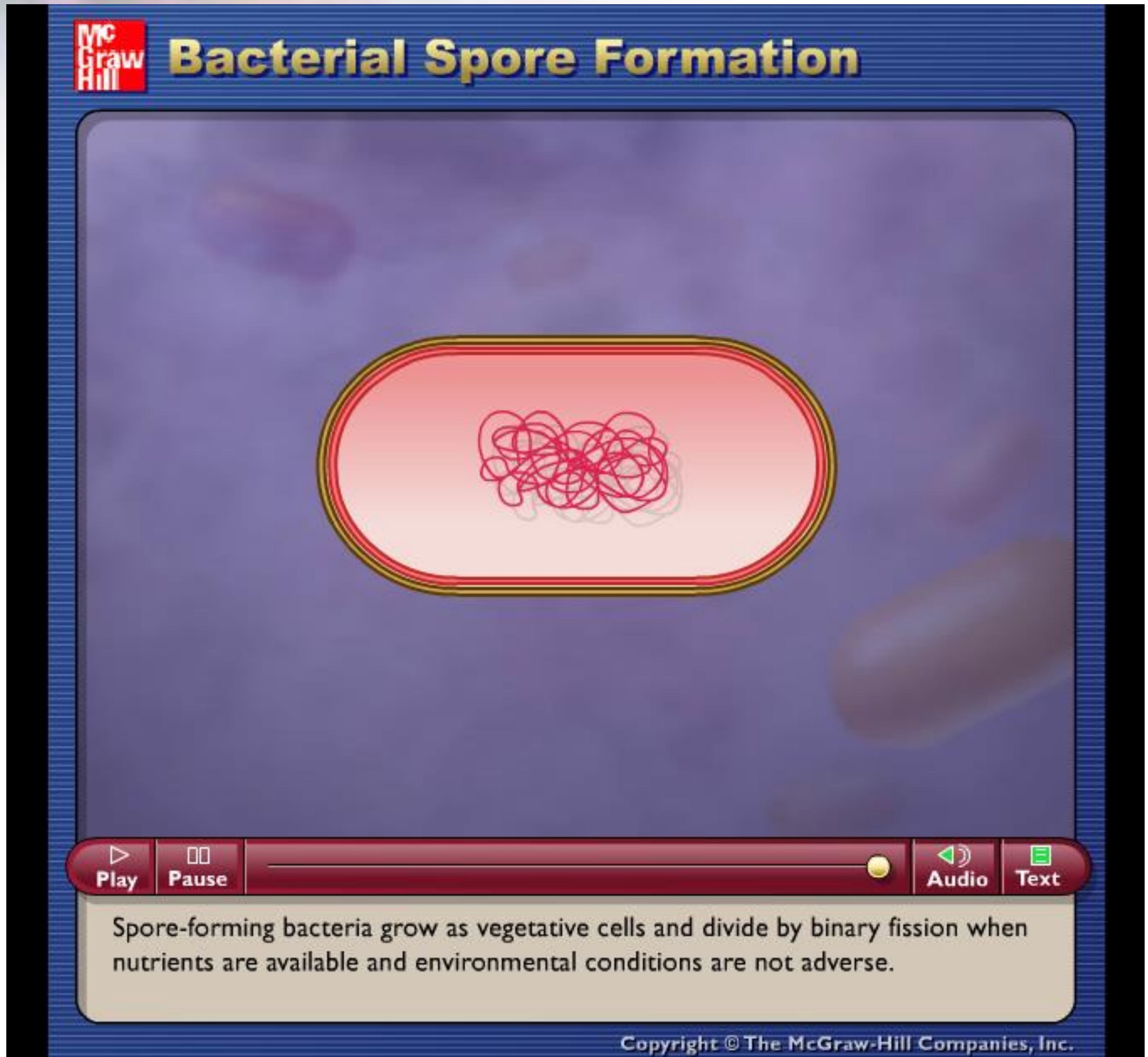
What Makes an Endospore so Resistant?

- 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


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


Bacterial Spore Formation
Play
Pause
Audio
Text
Spore-forming bacteria grow as vegetative cells and divide by binary fission when nutrients are available and environmental conditions are not adverse.
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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