

Chapter 4. Prokaryotes (Bacteria)

- Cell shapes and arrangements
- Prokaryotic cell structure
- Taxonomy
- Medically important bacteria

Cell Shape

- Sphere



Scientific Term

Coccus

- Rod



Bacillus

- Spiral



Vibrio (comma)



Spirillum (wavy)



Spirochete (corkscrew)

- Variable



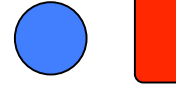
Pleomorphic

Cell arrangements

- Single cells

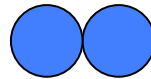
Scientific term

Unicellular



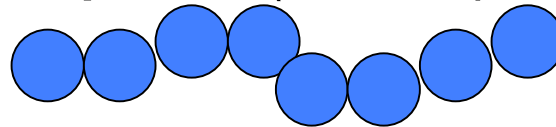
- Pairs

Diplo- (Ex. Diplococcus)



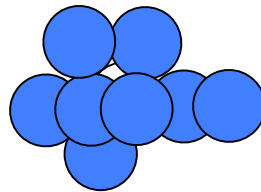
- Chains

Strepto- (Ex. Streptococcus)



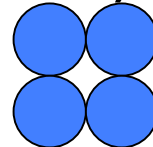
- Clusters

Staphylo-(Ex. Staphylococcus)

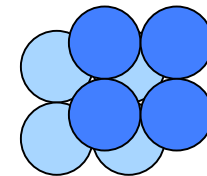


- Cube (4 cells)

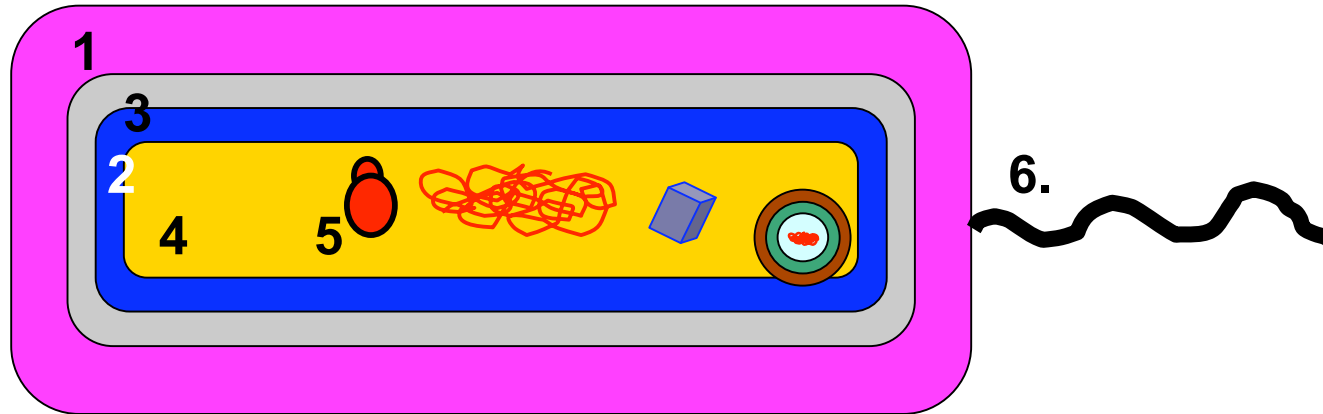
Tetrad (4 cells)



Sarcina (8-32 cells)



Prokaryotic Cell Structures



1. Cell wall

2. Cell membrane

3. Periplasmic space

4. Cytoplasm

5. Internal structures

6. External structures

Prokaryotic cell wall

- Outer cell layer
- Protects membrane and prevents cells from bursting
- Most medically important bacteria belong to **three major groups** based on the composition of their cell wall
 - Gram-positive bacteria
 - Gram-negative bacteria
 - Acid fast bacteria

Figure 4-12

1. Gram positive bacteria

- Cell wall is composed of:

- Peptidoglycan** --the main component

- Teichoic acids – give negative charge to wall

Peptidoglycan

- Polymer of : ***N*-acetylglucosamine** + ***N*-acetylmuramic acid** } Carbohydrates

- Cross-linked by short **peptides** (amino acid chains)

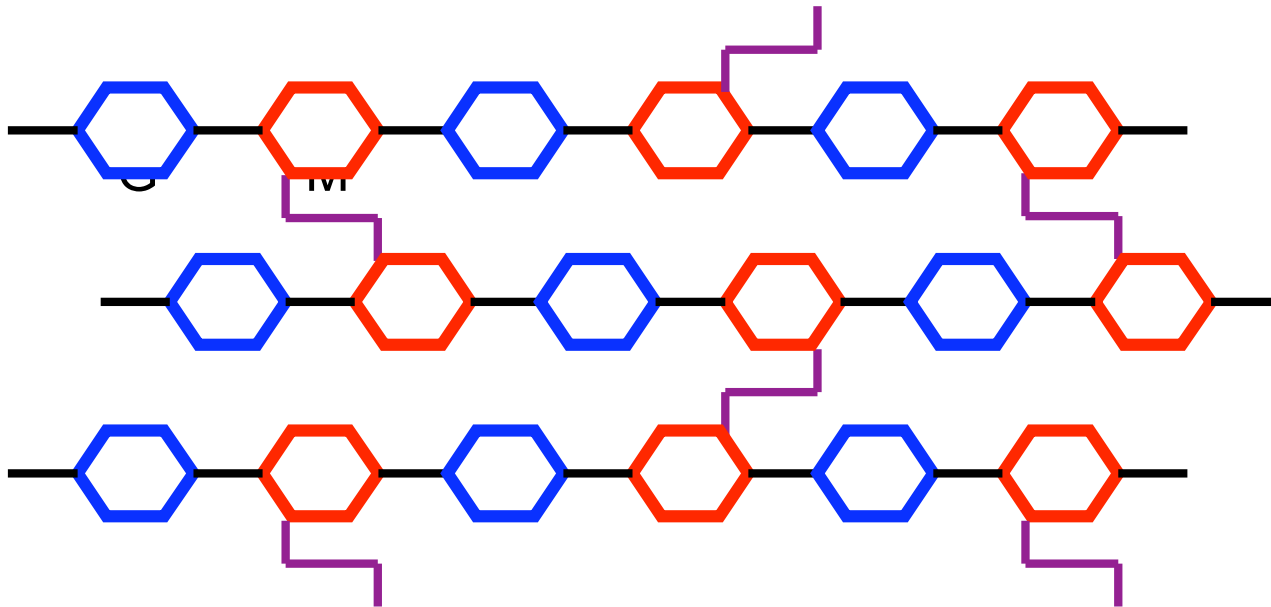
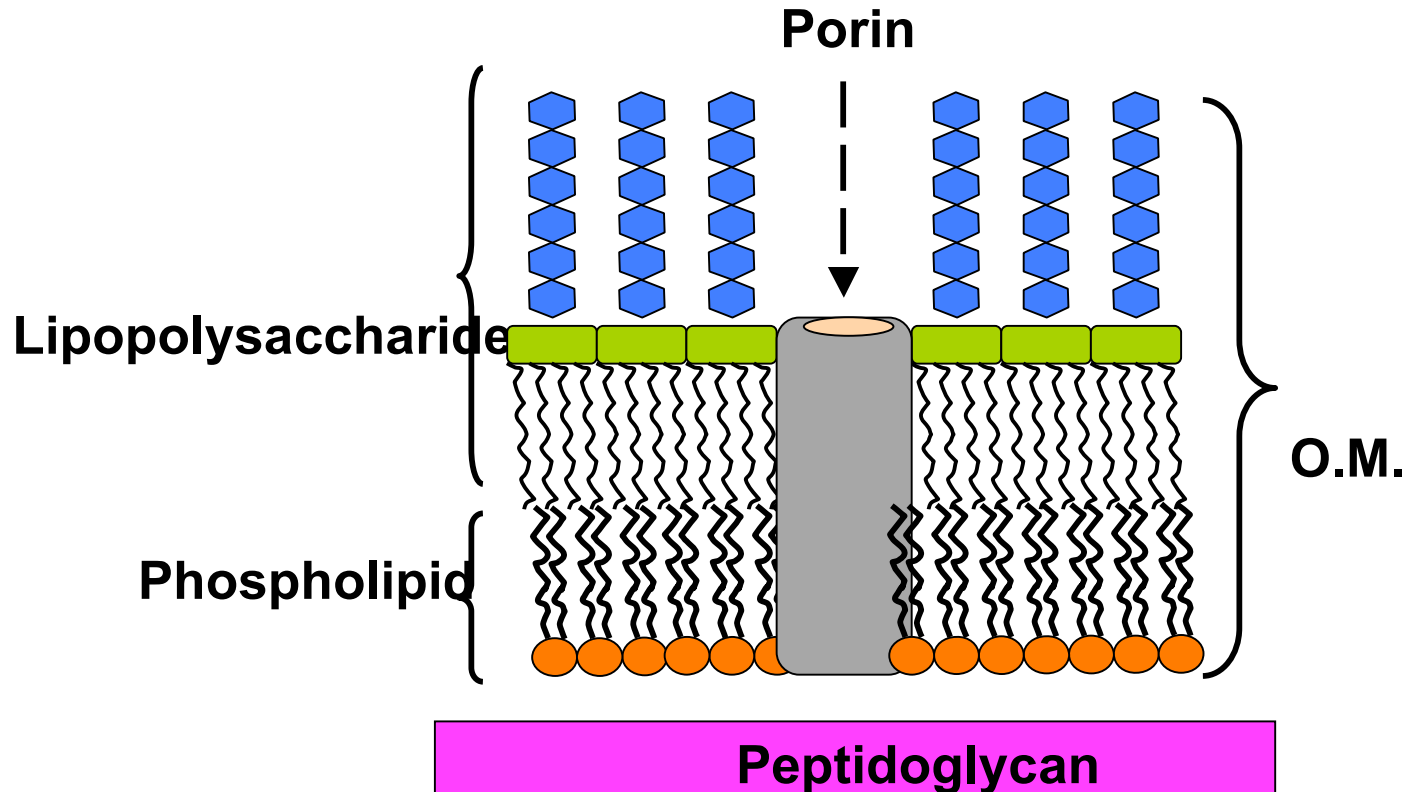


Figure 4-13

2. Gram negative bacteria cell wall

- Peptidoglycan + Outer membrane



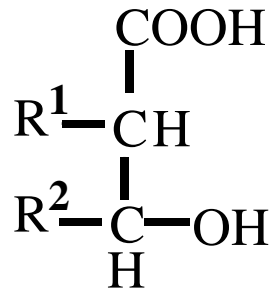
O. M. is an additional barrier to entry of substances into Gram negative cells

- **Porins.** Proteins that form pores (water-filled channels) that allow small molecules such as phosphate ions, sugars, amino acids, etc. to pass through outer membrane.
- **Lipopolysaccharide** (endotoxin) is toxic to humans

Figure 4-14

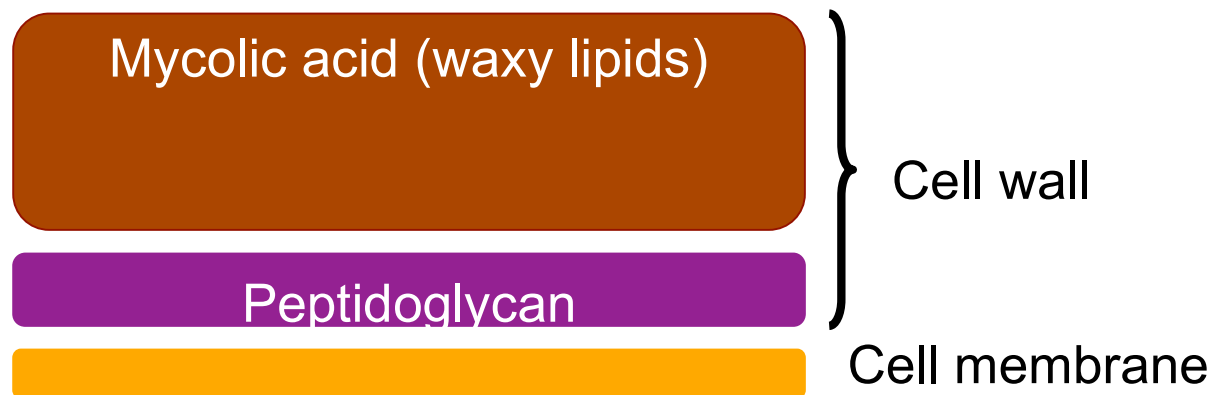
3. Acid fast bacteria (Mycobacteria) cell wall

- Peptidoglycan covered by waxy lipids (mycolic acids)



Mycolic acid

R^1 and R^2 = long hydrocarbon chains ($\text{C}_{20}\text{-C}_{60}$)



➤ **Mycoplasmas**

Bacteria that do not have a cell wall
Cell membrane is stabilized by sterols
Pleomorphic

Mycoplasma pneumoniae

Figure 4-15

Bacterial cell walls

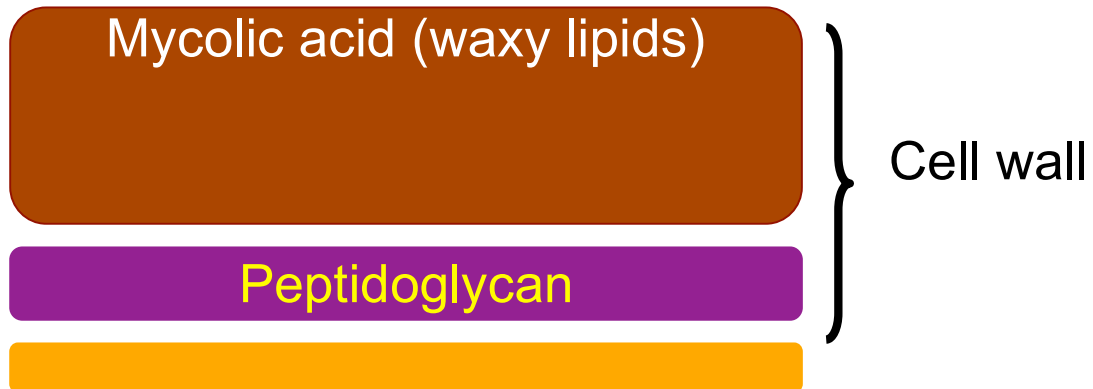
Gram positive



Gram negative



Mycobacteria



Cell membrane **Thickness of peptidoglycan in cell walls**

Gram negative (8 – 11 nm)

E. coli. 2.5-3 nm single layer 75-80%
7 nm triple layer 20-25%

Strands are short ~25 nm

Acid fast

Mycobacterium leprae 4-5 nm

M. tuberculosis 10-15 nm

Gram positive (20 – 80 nm thick)

Bacillus subtilis 33 nm

Staphylococcus aureus 19 nm

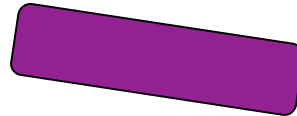
Effects of cell wall on staining

➤ Cell wall affects ability to be stained by Gram and acid-fast stains

- Gram positive: thick peptidoglycan layer, no outer membrane

Not decolorized by alcohol (crystal violet is retained)

Ex. *Clostridium botulinum*

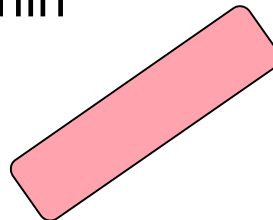


- Gram negative: thin peptidoglycan layer + outer membrane

Decolorized by alcohol (crystal violet is removed)

Counterstained with safranin

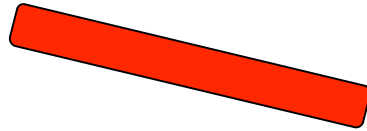
Ex. *Escherichia coli*



- Acid-fast: thin peptidoglycan + thick layer of lipids and waxes

Not decolorized by acid-alcohol (carbol fuchsin is retained)

Ex. *Mycobacterium tuberculosis*



Insight 4-2 figure

Cell membrane

- Separates interior of cell from external environment
- Bilayer of phospholipids and proteins
 - The hydrophobic, long-chain fatty acids restrict movement of ions and polar molecules into and out of cell

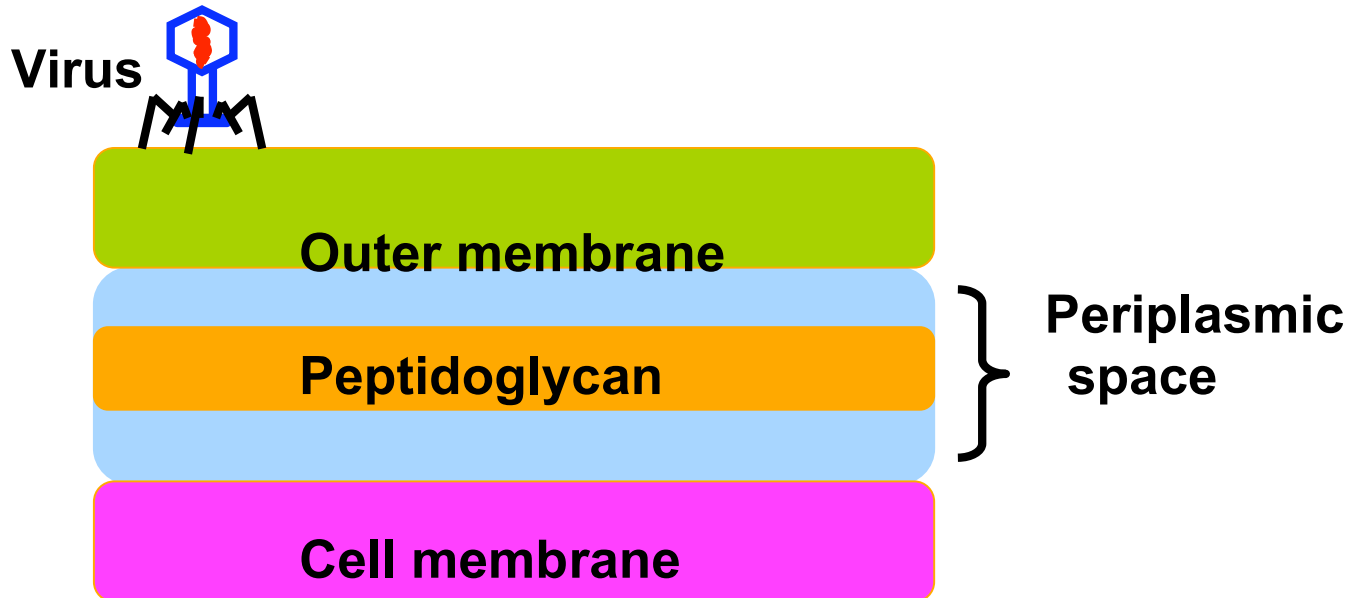
Ex. nutrients, inorganic ions, metabolic wastes and toxins

- Imbedded **transport proteins** move these substances through membrane
- Location where usable energy is captured (synthesis of ATP)

Figure 4-16

Periplasmic space

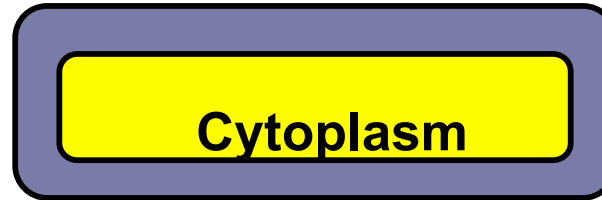
- **Region** between cell membrane and outer membrane of **Gram negative** bacteria
- Contains:
 - **Proteins** that help **transport substances** into the cell
 - **Enzymes** that:
 - **break down** large **food** molecules
 - **protect cell** from **invasion** by **viruses**
 - **protect cell** by **destroying antibiotics**



Cytoplasm

- **Interior** contents of cell (i.e. within the cell membrane)
Dense gelatinous solution of sugars, amino acids, and salts

80% Water



20% Dissolved or suspended substances

- Proteins (enzymes, etc.)
- Carbohydrates
- Organic acids
- Nucleotides
Ex. ATP
- Nucleic acids (DNA and RNA)
- Inorganic ions
Ex. K^+ , Na^+ , Cl^- , HPO_4^- , NH_4^+ , Mg^{++} , Ca^{++}

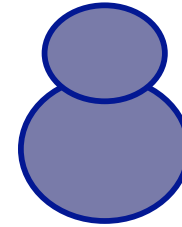
➤ Most metabolic reactions occur in the cytoplasm

Cytoplasmic structures

- **All** prokaryotic cells

Ribosomes

- Site of protein synthesis
- Composed of **RNA** and **proteins**
- Made of 60% ribosomal RNA and 40% protein
- Consist of two subunits: large and small
- Prokaryotic differ from eukaryotic ribosomes in size and number of proteins
- Present in all cells



○

Figure 4-18 Prokaryotic ribosome

Chromosome (1 per cell, usually)

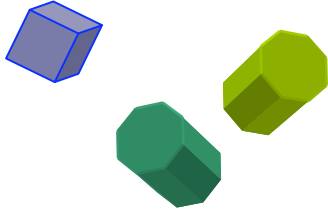
- Large circular molecule of DNA
- Storage of genetic information

Figure 4-17

- Plasmids
 - Small circular, double-stranded DNA
 - Free or integrated into the chromosome
 - Duplicated and passed on to offspring
 - Not essential to bacterial growth and metabolism
 - May encode antibiotic resistance, tolerance to toxic metals, enzymes, and toxins
 - Used in genetic engineering - readily manipulated and transferred from cell to cell

Some prokaryotic cells

- **Storage granules** Polymers that store energy and nutrients



Ex. polyphosphate, glycogen,
polyhydroxybutyrate

- **Magnetic particles** Orientation of aquatic bacteria
- **Gas-filled vacuoles** Flotation of aquatic bacteria
- **Internal membranes**

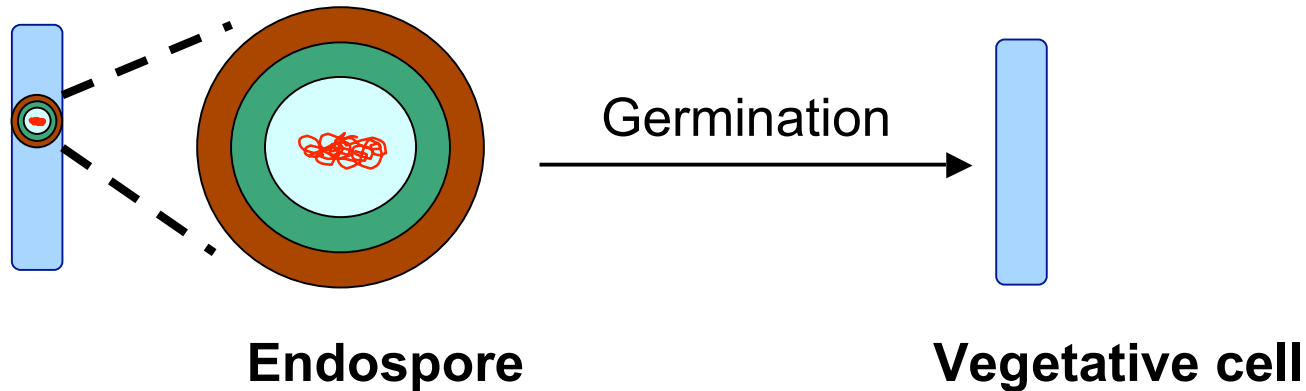
Ex. Photosynthetic and methane oxidizing bacteria

Figure 4-19

Endospore Resting stage of some **Gram positive** bacteria

Environment **Unfavorable**

Favorable



- **Forms inside cell** when environment is **unfavorable** for **growth**
Ex. Lack of moisture or nutrients, acidic pH, heat
--Helps cell **survive** harsh conditions
- Contains chromosome (DNA) surrounded by **thick protective layers** of peptidoglycan and protein
- Resistance linked to high levels of calcium and dipicolinic acid
- Metabolically **inactive (dehydrated)**

- **Germinates** and becomes an active **vegetative cell** when conditions are favorable for growth
- Longevity verges on immortality, 250 million years
- Resistant to ordinary cleaning methods and boiling
Pressurized steam at 120°C for 20-30 minutes will destroy.
- Species of ***Bacillus*** and ***Clostridium*** are the main endospore formers

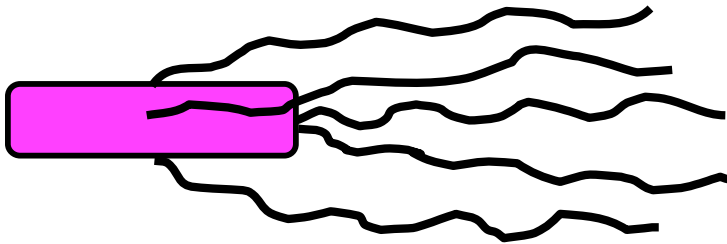
Ex. The majority of spore-forming bacteria are relatively harmless.

<i>Bacillus anthracis</i>	Spores aid survival in dry soil
<i>Clostridium botulinum</i>	Survival of high temp. during canning of food
<i>C. tetani</i>	Tetanus (lockjaw), germinate in dead tissue
<i>C. perfringens</i>	Gas gangrene, germinate in dead tissue

Figure 4-22

External structures

- **Flagellum** Long, whip-like; for **motility**
 - **One or more** may be present at **ends** or **all over surface**
 - Allow cells to move toward or away from environmental stimuli (Ex. nutrients, light, O₂)



Flagella

- 3 parts:
 - **Filament** – long, thin, helical structure composed of protein **Flagellin**
 - **Hook** – curved sheath
 - **Basal body** – stack of rings firmly anchored in cell wall
- Rotates 360°

Figure 4-2

Flagellar Arrangements

1. Monotrichous – single flagellum at one end
2. Lophotrichous – small bunches emerging from the same site
3. Amphitrichous – flagella at both ends of cell
4. Peritrichous – flagella dispersed over surface of cell; slowest

Figure 4-3

Flagellar Responses

Guide bacteria in a direction in response to external stimulus:

Chemical stimuli – **chemotaxis**; positive and negative

Light stimuli – **phototaxis**

Signal sets flagella into rotary motion clockwise or

counterclockwise:

Counterclockwise – results in smooth linear direction – **run**

Clockwise – **tumbles**

Figure 4-4

Figure 4-5

Periplasmic Flagella

- Internal flagella, enclosed in the space between the outer sheath and the cell wall peptidoglycan
- Produce cellular motility by contracting and imparting twisting or flexing motion

Figure 4-6

Fimbriae (Figure 4-7)

- Fine, proteinaceous, hairlike bristles emerging from the cell surface
- Function in adhesion to other cells and surfaces
- Important for some pathogens

Pili (Figure 4-8)

- Rigid tubular structure made of **pilin** protein
- Found only in gram-negative cells
- **Conjugation**: transfer of DNA between cells

Glycocalyx

Capsule Gelatinous layer surrounding cells (polysaccharide or polypeptide)

- Protects some pathogens from attack by immune system



• **Slime layer** Thinner than capsule

- Attaches cells to surfaces

Ex. rocks in stream, teeth, catheters, artificial joints

- Involved in formation of **biofilms**

-Provides a protective microenvironment

-May be composed of several different microorganisms

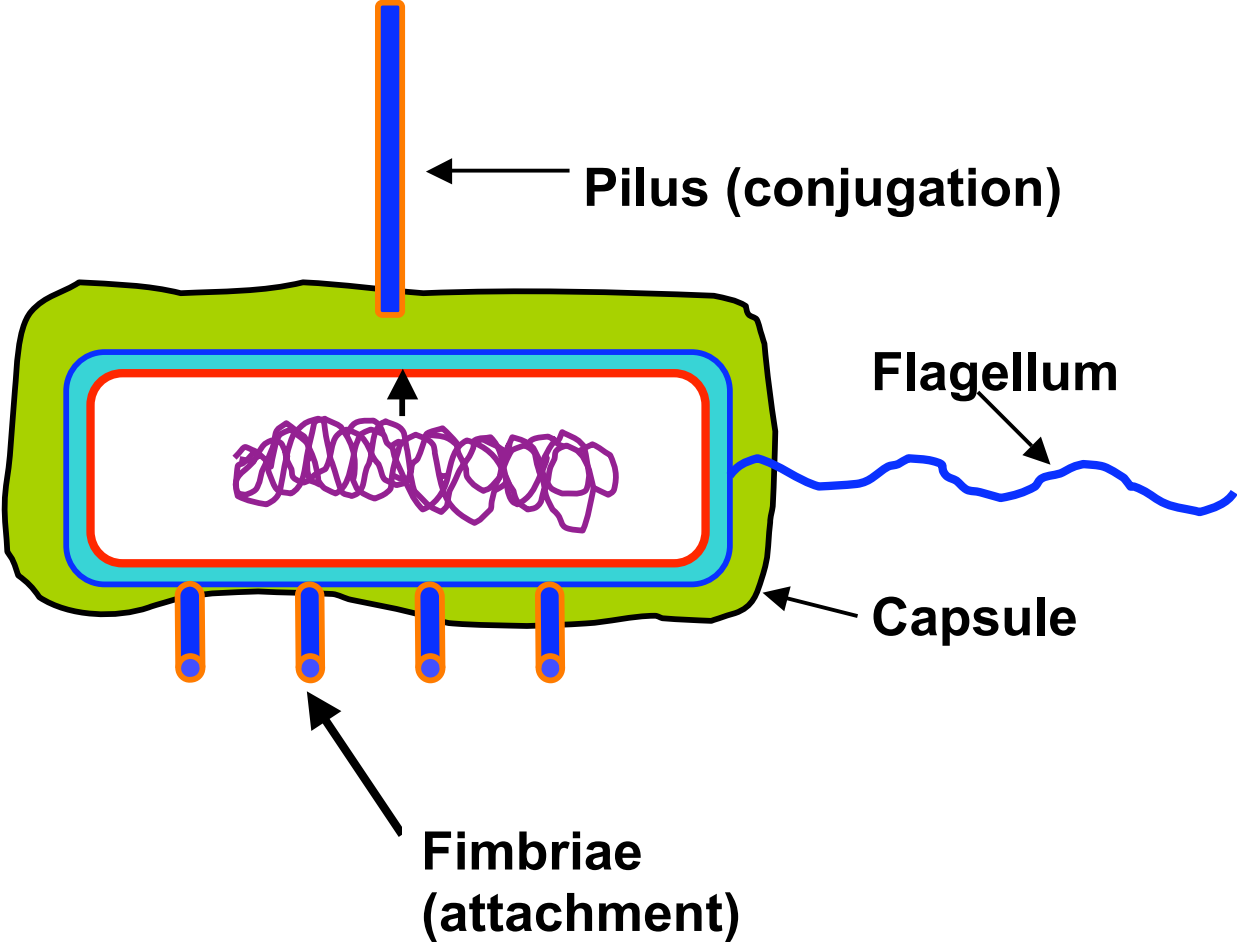
Biofilm on a catheter

<http://webs.wichita.edu/mschneegurt/biol103/lecture22/lecture22.html>

***Staphylococcus aureus* biofilm of the surface of a catheter**

http://en.wikipedia.org/wiki/Image:Staphylococcus_aureus_biofilm_01.jpg

Prokaryotic cell external structures



A. Taxonomy

- The science of organizing, classifying and naming
- Linnaeus introduced a system for naming species of living organisms called **binomial nomenclature**
- Each organism is given 2 names
 1. First name: Genus
 2. Second name: specific epithet

Genus + specific epithet = species

-Species names are *italicized* or underlined

Staphylococcus aureus Staphylococcus aureus

Related organisms or organisms with similar characteristics are grouped together and have the same genus name

Ex.

Escherichia coli } **Gram negative**, non spore-forming rods
Escherichia blattae }



Different characteristics, distantly related

Bacillus anthracis } **Gram positive**, spore-forming rods
Bacillus popillae }

- **Species** – a collection of bacterial cells which share an **overall similar pattern of traits** in contrast to other bacteria whose pattern differs significantly
- **Strain** or **variety** – a culture derived from a single parent that differs in **structure** or **metabolism** from other cultures of that species (biovars, morphovars)
- **Type** – a subspecies that can show differences in antigenic makeup (serotype or serovar), susceptibility to bacterial viruses (phage type) and in pathogenicity (pathotype)

discovered *Escherichia coli* in 1885

Major Taxonomic Groups of Bacteria

- **Domain Archaea** – primitive, adapted to extreme habitats and modes of nutrition
- **Domain Bacteria:**
 - **Phylum Proteobacteria** – Gram-negative cell walls
 - **Phylum Firmicutes** – mainly gram-positive with low G + C content
 - **Phylum Actinobacteria** – Gram-positive with high G + C content

King Phillip Came Over For Grape Soda

Figure 4-27 Universal phylogenetic tree

The Other Prokaryotes

- Constitute third Domain Archaea
- Seem more closely related to Domain Eukarya than to bacteria
- Contain unique genetic sequences in their rRNA
- Have unique membrane lipids and cell wall construction
- Live in the most extreme habitats in nature, extremophiles
- Adapted to heat, salt, acid pH, pressure, and atmosphere
Includes: methane producers, hyperthermophiles, extreme halophiles, and sulfur reducers

Table 4-5

Characteristics used to classify bacteria

1. Morphology

Size, shape, external structures (pili, flagella, capsules)

Endospores: presence or absence, location in cell

2. Staining

Gram positive, **Gram negative**, **Acid-fast**

3. Nutrition

Carbon and energy sources, nitrogen sources

Special requirements (Ex. vitamins, blood)

4. Physiology

Aerobic, anaerobic, pH and temp. preferences

Salt tolerance or requirement

5. Biochemistry

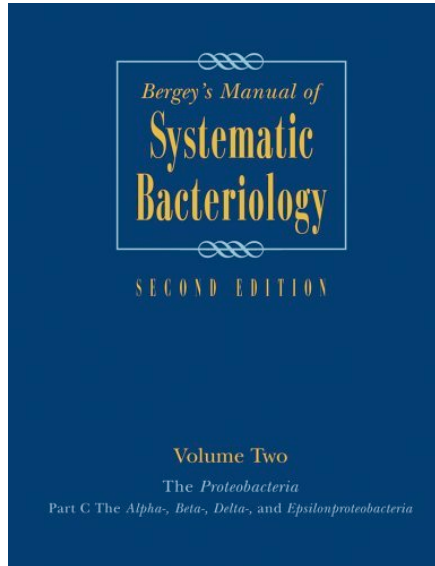
Presence of specific enzymes

Ex. catalase: $2 \text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2\text{H}_2\text{O}$

6. Genetics

Sequences of DNA bases (A, T, G, C)

Bergey's Manual



- David H. Bergey (Editor)
 - American bacteriologist (1860-1937)
- Authoritative source for bacterial taxonomy
- Gives **scientific name** and **characteristics** of most known bacteria
- Bacteria grouped into **33** different **sections** of the manual
- Organisms in a section have **similar morphological** and **biochemical characteristics**

Sections of Bergy's Manual containing medically important bacteria

Gram negatives

Section 1. Spirochetes: Gram negative, corkscrew shaped

Treponema Syphilis, gum disease

Borrelia Lyme disease

Section 2. Helical: Gram negative

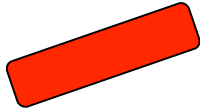
H. pylori

Campylobacter Abortions in cattle. food poisoning

Helicobacter Stomach ulcers

Section 4. Gram-negative aerobic rods and cocci

Pseudomonas Usually not pathogenic



Causes opportunistic infections

Ex. severe burn wounds

Neisseria Gonorrhea, meningitis (inflammation of the membrane covering the brain and spinal cord)



Brucella Brucellosis in humans

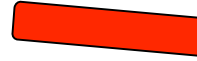


Abortions in cattle, swine and dogs

Section 5. Facultatively* Anaerobic, Gram negative, rods

Escherichia

Enteritis



Salmonella

Enteritis

Yersinia

Bubonic plague

Vibrio

Cholera

* Can grow with or without O₂

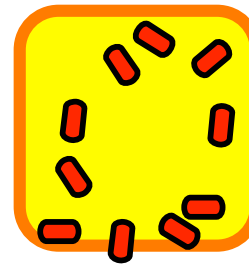
Section 8. Anaerobic Gram negative cocci

Veillonella Tooth abscesses and gum disease

Section 9. Obligate intracellular parasites

Rickettsia Rocky Mtn. spotted fever

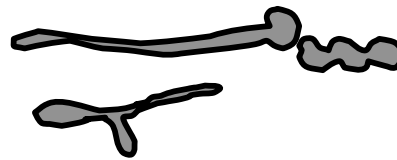
Chlamydia Eye infections, pneumonia,
genital tract (an STD)



Host cell

Bacteria without a cell wall

Section 10. Mycoplasmas Lack cell walls, shape is pleomorphic



Mycoplasma Atypical pneumonia

Gram positives

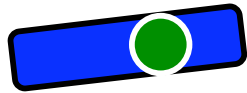
Section 12. Gram positive cocci



Streptococcus Strep. throat, pneumonia, dental plaque

Staphylococcus Skin abscesses

Section 13. Endospore-forming Gram positive rods and cocci

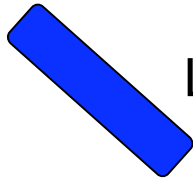


Bacillus Anthrax: cattle, sheep and humans

Clostridium Tetanus and food poisoning (botulism)

Section 14. Nonsporing Gram positive rods

Listeria



Listeriosis

Food-borne infection
(meningitis, septicemia,
abortion, stillbirth)

Section 15. Nonsporing Gram positive irregular rods

Corynebacterium (club shape)



Diphtheria

Actinomyces (branched filaments) Jaw abscesses



Corynebacterium diphtheriae

Dark regions are polyphosphate inclusions

Section 16. Mycobacteria Acid fast

Mycobacterium Tuberculosis, leprosy

Section 29. Streptomyces Gram positive, filamentous, spore-forming

- No pathogens, produce **antibiotics** used to treat infections

Streptomyces Produces streptomycin

