

Environmental Microbiology

Functional Anatomy of Prokaryotic and Eukaryotic Cells

prepared by Prof. Bulent Içgen

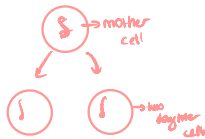
Prokaryotic Cells

- Comparing Prokaryotic and Eukaryotic Cells
 - Prokaryote comes from the Greek words for prenucleus.
 - Eukaryote comes from the Greek words for true nucleus.

Prokaryote

Eukaryote

- One circular chromosome, not in a membrane
- No histones (have histon-like proteins)
- No organelles
- Peptidoglycan cell walls
- Binary fission (reproduction)






- Paired chromosomes, in nuclear membrane → linear dna
- Histones
- Organelles
- Polysaccharide cell walls
- Mitotic spindle

Bacterial Cells

Morphology = cell shape

Major cell morphologies golden rule

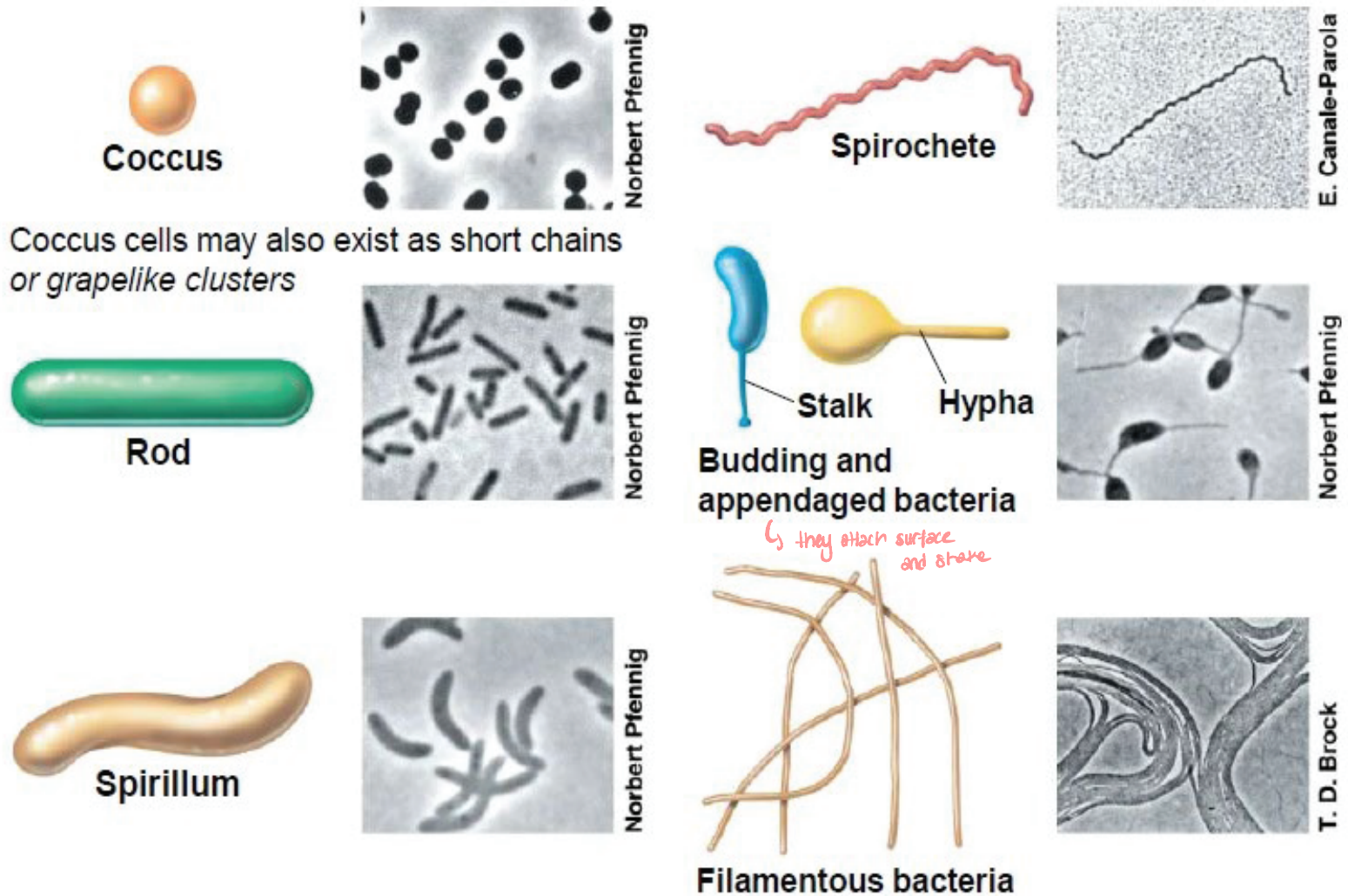
- Coccus (pl. cocci): spherical or ovoid 
- Rod (bacillus, pl. bacilli): cylindrical shape 
- Spirillum: spiral shape 

Cells with unusual shapes

- Spirochetes, appendaged bacteria, and filamentous bacteria
- Many variations on basic morphological types

Morphology

Figure 3.1 Representative cell morphologies of prokaryotes



Bacterial Cells

Morphology typically does not predict physiology¹, ecology, phylogeny², etc. of a prokaryotic cell

- **Selective forces** may be involved in setting the morphology
Optimization for nutrient uptake (small cells and those with high surface-to-volume ratio)
- **Swimming motility in viscous environments or near surfaces** (helical or spiral-shaped cells)
- **Gliding motility** (filamentous bacteria)

¹ functions and activities of living organisms and their parts

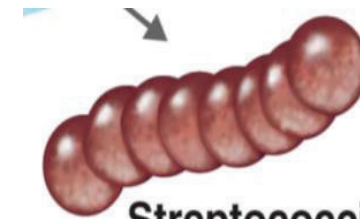
² the evolutionary history of a group of organisms

Coccus (cocci plural)

- **Cocci** means berries
- Typically round but can be oval
- When they reproduce/divide, the cells remain attached sometimes
- When two remain attached they are called diplococci
- Sometimes they form long chains of cells called streptococci...strep throat (*Streptococcus pyogenes*)
- Sometimes they form clusters called staphylococci... *Staphylococcus aureus*

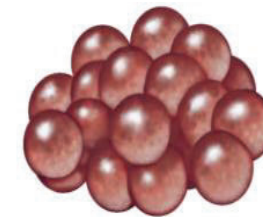


Diplococci



Streptococci

↳ *boğaz infeksiyonu*



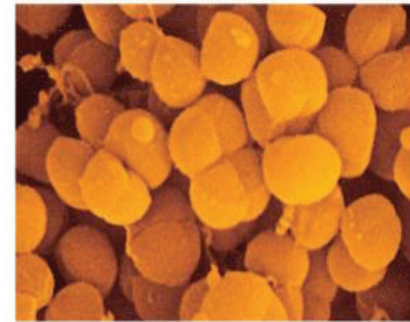
Staphylococci

↳ *stivik (Harab)*

Cocci – cont...

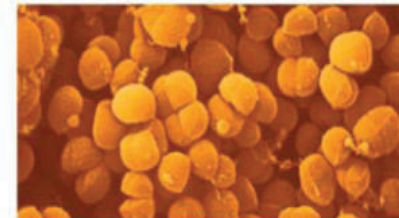
➤ Can also form groups of four cells called **tetrads**

- much less common
- can be difficult to determine microscopically



➤ Or form groups of 8 cells called **sarcinae**

- also fairly uncommon
- difficult to see microscopically



Bacillus (Bacilli pl.)

- Means little staffs
- Only divide across their short axis
- Exist as pairs called **diplobacilli**
- Or in chains called **streptobacilli**
- Some bacilli take on a more oval rod shape and are called **coccobacilli**



Diplobacilli



Streptobacilli



Coccobacillus



Spiral Bacteria

- Never straight, but don't always have a spiral appearance

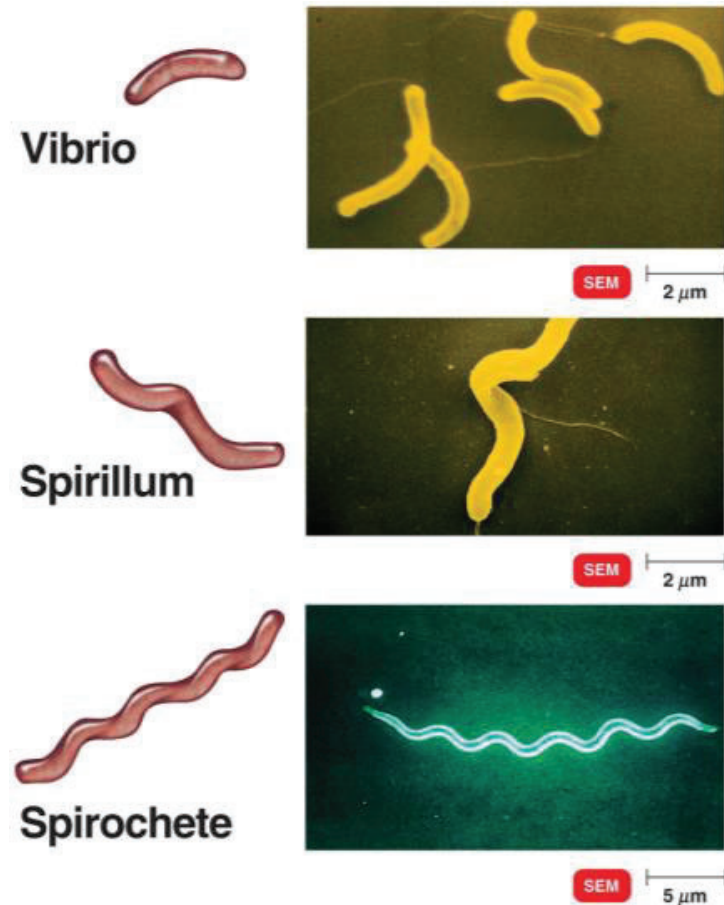
- ^{→ important} *Some are curved rods called **vibrio**

- Others are helical shaped called **spirilla** or **spirillum**

 - move via external flagella

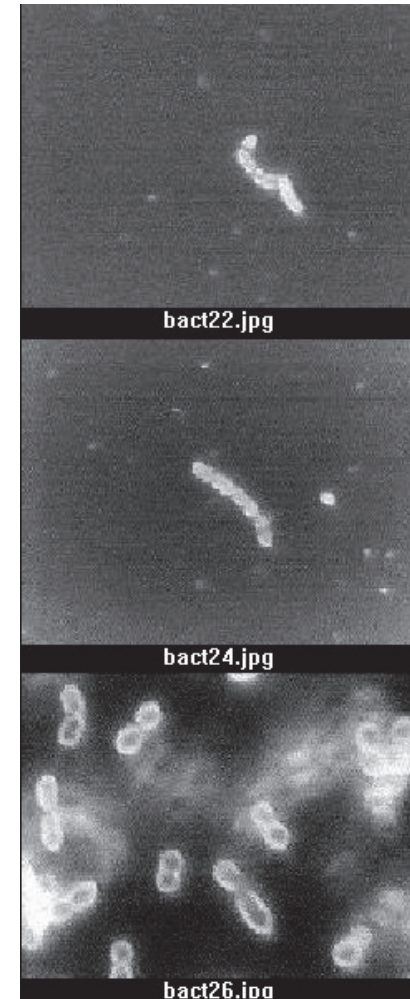
- Or they are helical and flexible and called **spirochete**

 - move via axial filaments that look like flagella but they are contained within a flexible external sheath
 - spirochete moves in snake-like fashion



Bacterial Cell Shape

- Most bacteria have a single shape and are hence referred to as **Monomorphic**
- Some can have different shapes depending on the environmental conditions they are exposed to and are hence called **Pleomorphic** → they can change their shape
 - *Corynebacterium*
 - *Rhizobium*

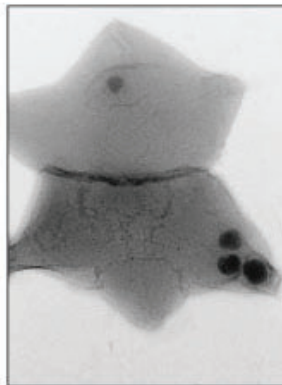


Bacterial Cell Shape

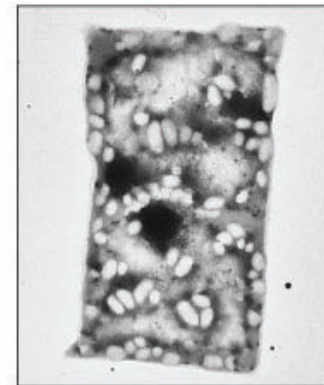
- Unusual shapes
 - Star-shaped *Stella*
 - Square *Haloarcula*
- Most bacteria are monomorphic
- A few are pleomorphic



(a) Star-shaped bacteria



(b) Rectangular bacteria



Cell Size and the Significance of Smallness

- Surface-to-Volume Ratios, Growth Rates, and Evolution
- Average size: $0.2 - 1.0 \mu\text{m} \times 2 - 8 \mu\text{m}$

Advantages to being small

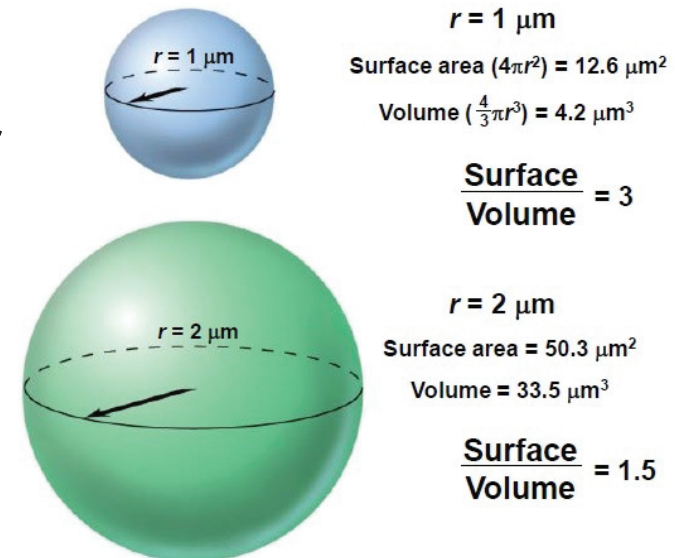
- Small cells have more surface area relative to cell volume than large cells (i.e., higher S/V)
- support greater nutrient exchange per unit cell volume
- tend to grow faster than larger cells

↳ because of ratio: ↓ transfer of the molecules easier

Lower Limits of Cell Size

- Cellular organisms $< 0.15 \mu\text{m}$ in diameter are unlikely
- Open oceans tend to contain small cells ($0.2 - 0.4 \mu\text{m}$ in diameter)

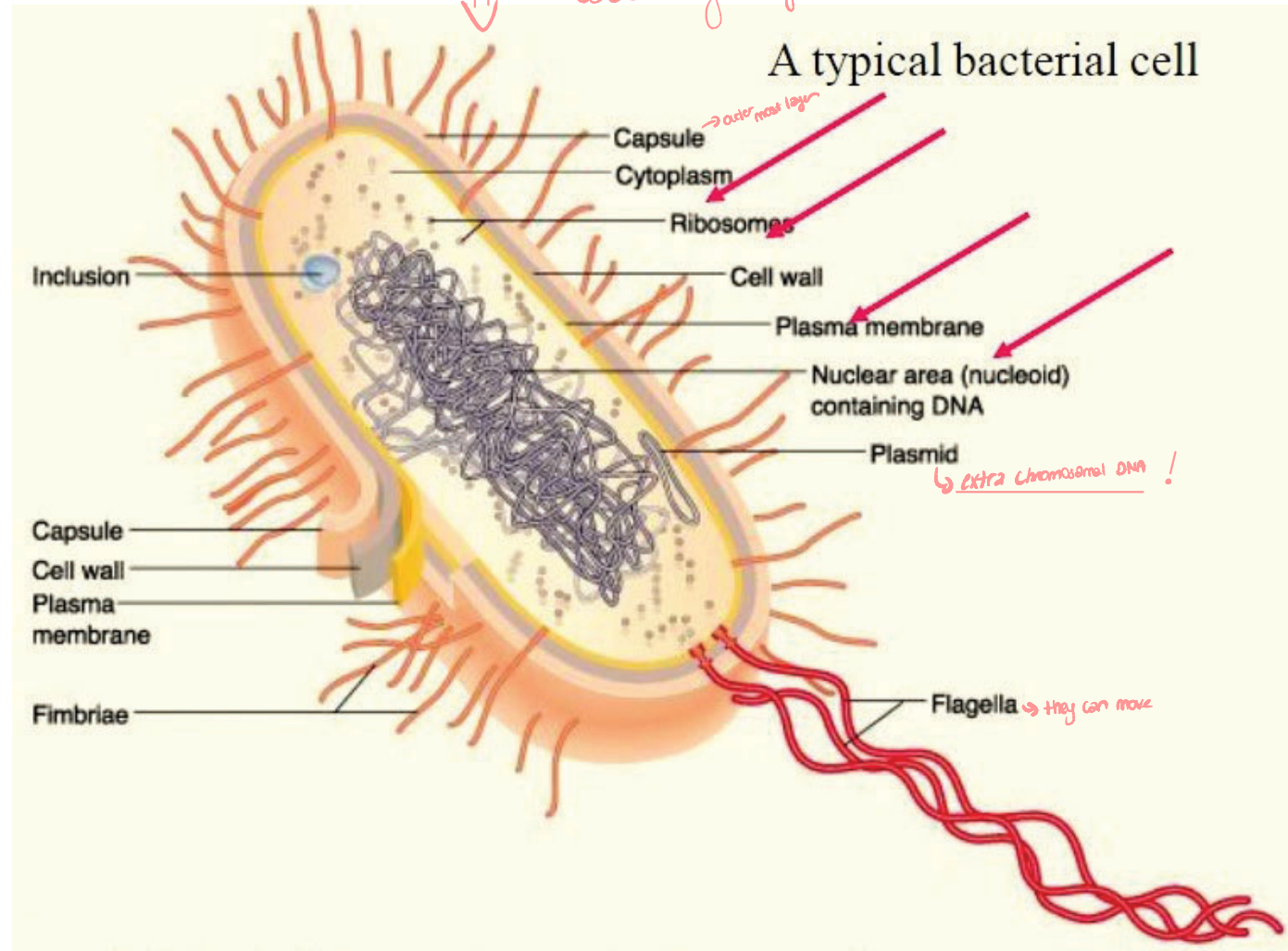
Surface area and volume relationships in cells



External Structures

Görseli
eaberk (yalıba pöer sinolda sermustu)

- Glycocalyx
- Flagella
- Axial filaments
- Fimbriae
- Pili



Glycocalyx

↓
outer most layer

→ general name
↓ capsule ↓ slime layer

- Outside cell wall
- Usually sticky
- A **capsule** is neatly organized
- A **slime layer** is unorganized & loose
- Extracellular polysaccharide allows cell to attach
- Capsules prevent phagocytosis

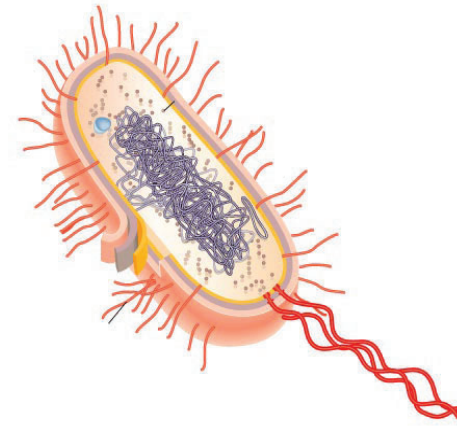
mostly pathogenic

olunc² ad capsule outer layer ⇒ smooth outer shell

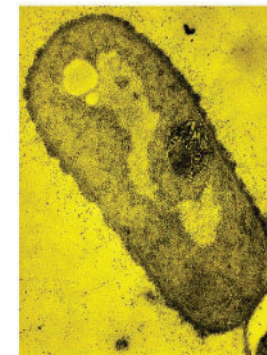
↳ rough

lysozymal resistance of deoxyr

(when the cell enter the body the antibodies attach + rem!)



(a)



(b)

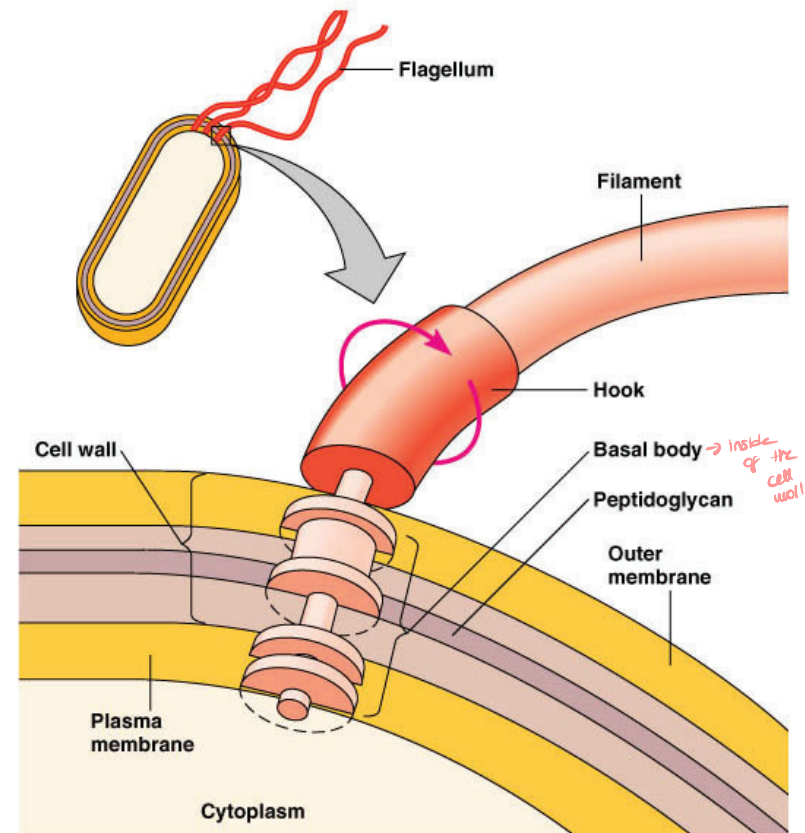
Flagella

↓
both
clockwise
and
counter clockwise

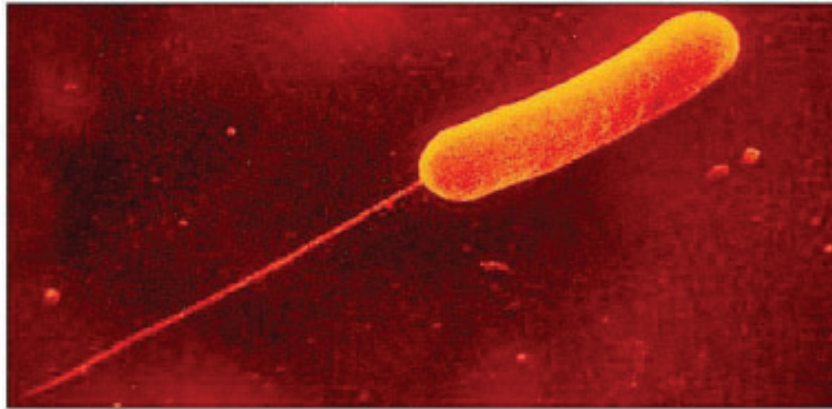
↳ bacteria have the ability to move

↳ they can survive longer
↓
they can go for the
nutrients.

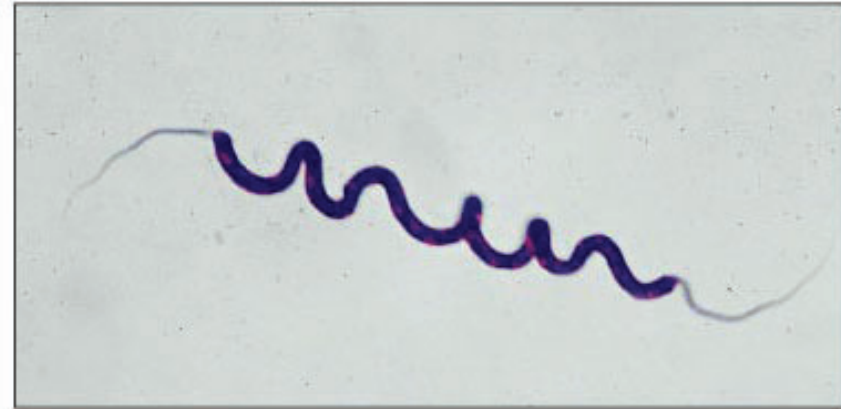
- Outside cell wall
- Made of chains of flagellin
- Contains **filament**, **hook** and **basal body**
- Filament attached to a protein hook
- Anchored to the wall and membrane by the basal body



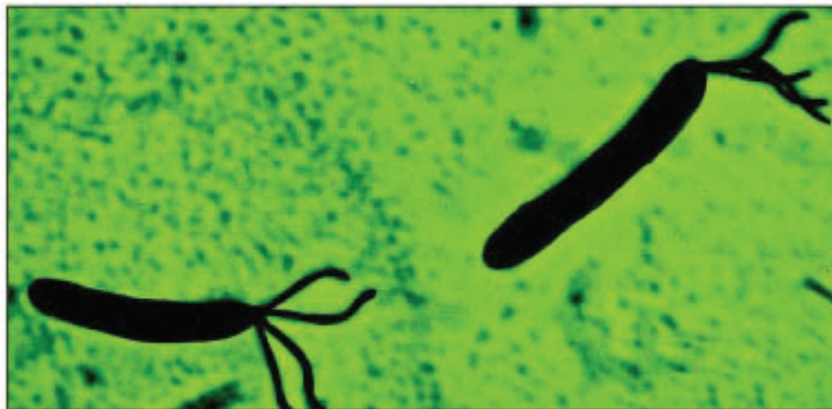
Flagella Arrangement



(a) Monotrichous



(b) Amphitrichous



(c) Lophotrichous



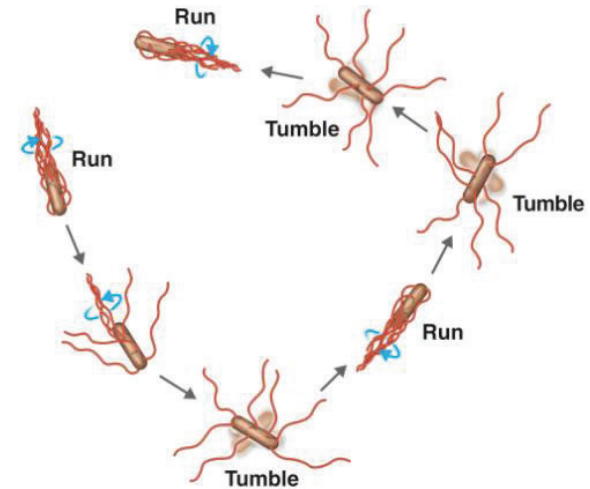
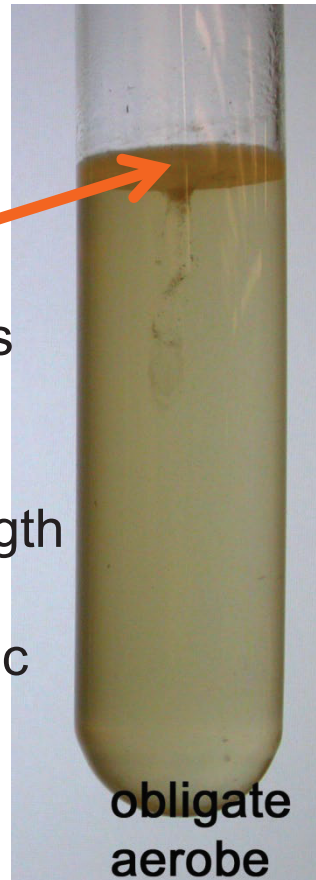
(d) Peritrichous

Cell Motility

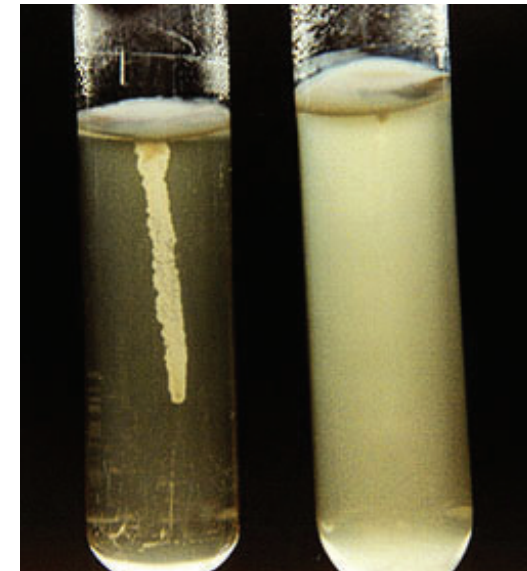
- Rotate flagella to **run** or **tumble**
- Move toward or away from stimuli (**taxis**)

↳ movement
↓ positive taxis (attraction)
↓ negative taxis (repulsion)

Chemotaxis: response to chemicals
Phototaxis: response to light
Aerotaxis: response to oxygen
Osmotaxis: response to ionic strength
Hydrotaxis: response to water
Magnetotaxis: response to magnetic field



(a) A bacterium running and tumbling. Notice that the direction of flagellar rotation (blue arrows) determines which of these movements occurs. Gray arrows indicate direction of movement of the microbe.



Axial Filaments

movement = motility = mobility

→ around the cell
not outside

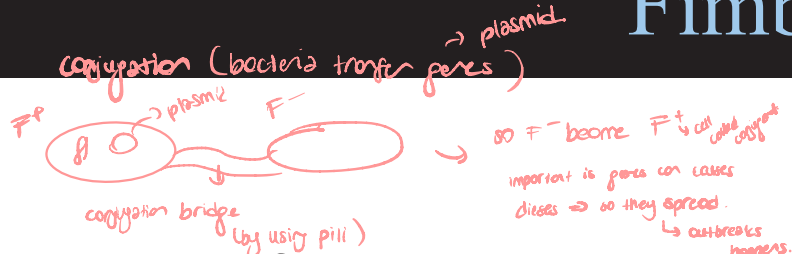
- Endoflagella
- In spirochetes
- Anchored at one end of a cell
- Rotation causes cell to move



(a)

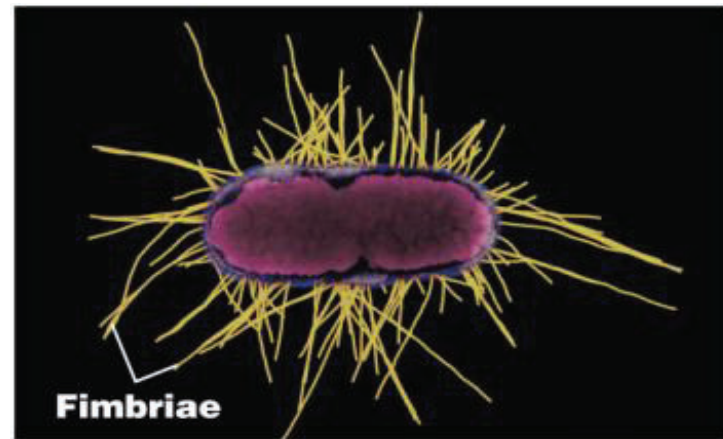
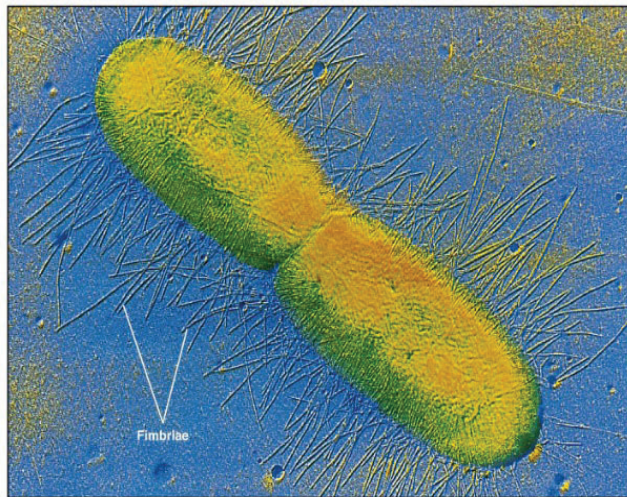
if plasmid attach to chromosomal dna cell called Hfr ^{high frequency recombination} → to this case Hfr → F⁻ → transfer is difficult → so F⁻ not becomes F⁺ but becomes F'
 → since chromosomal dna is large
 → not completely transferred → partially transferred
 → it has extra genes

Fimbriae & Pili



- Fimbriae filamentous structures allow attachment ^{→ shorter than flagella} to the surface. ^{for conjugation.}
- Pili are typically longer than fimbriae and are involved in motility ^{↳ but still shorter than flagella}
- However, many people use the terms interchangeably ^{↳ if they have pili F+} ^{↳ so pili attach two bacteria.} ^{↳ " " don't have pili F-}

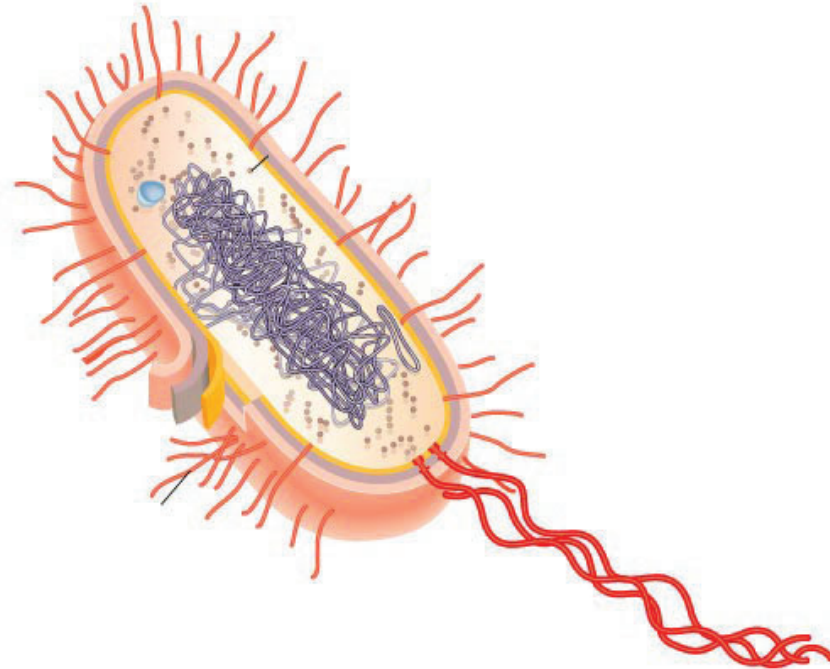
→ they can also clog pipes due biofilms
 → because of attachment they can make biofilm
 ↓
 gives them a resistant to antibiotics



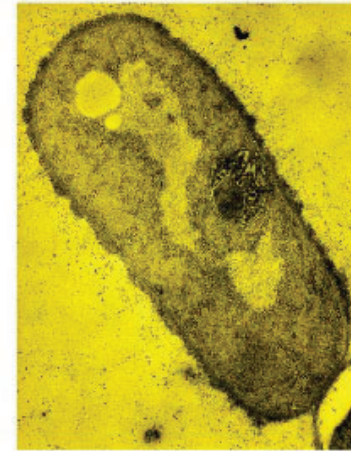
TEM 1 μm

Cell Wall ^{→ Gram(+)} } Gram(-) →

- Prevents osmotic lysis
- Made of peptidoglycan (in bacteria)



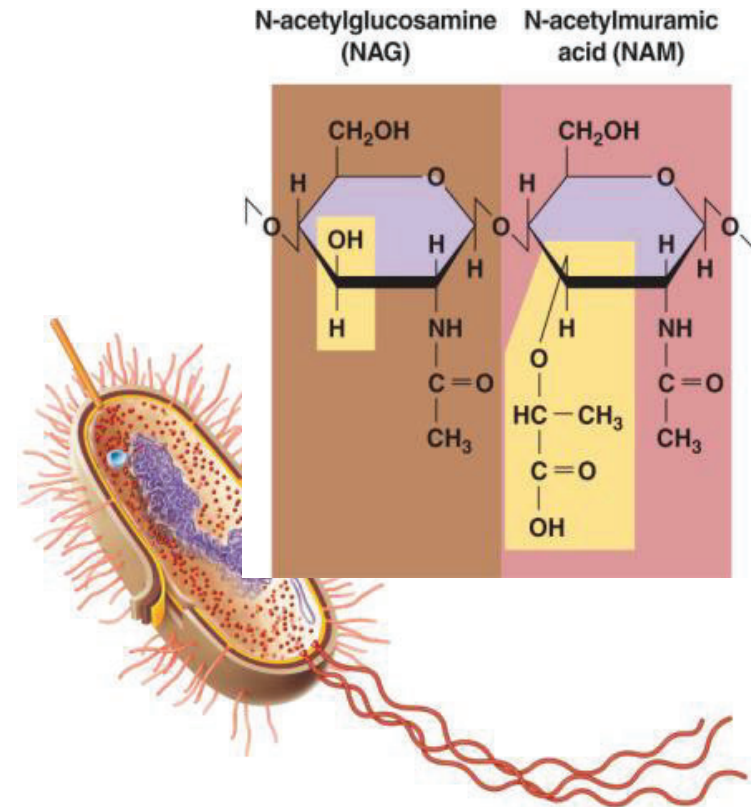
(a)



(b)

Bacterial Cell Wall

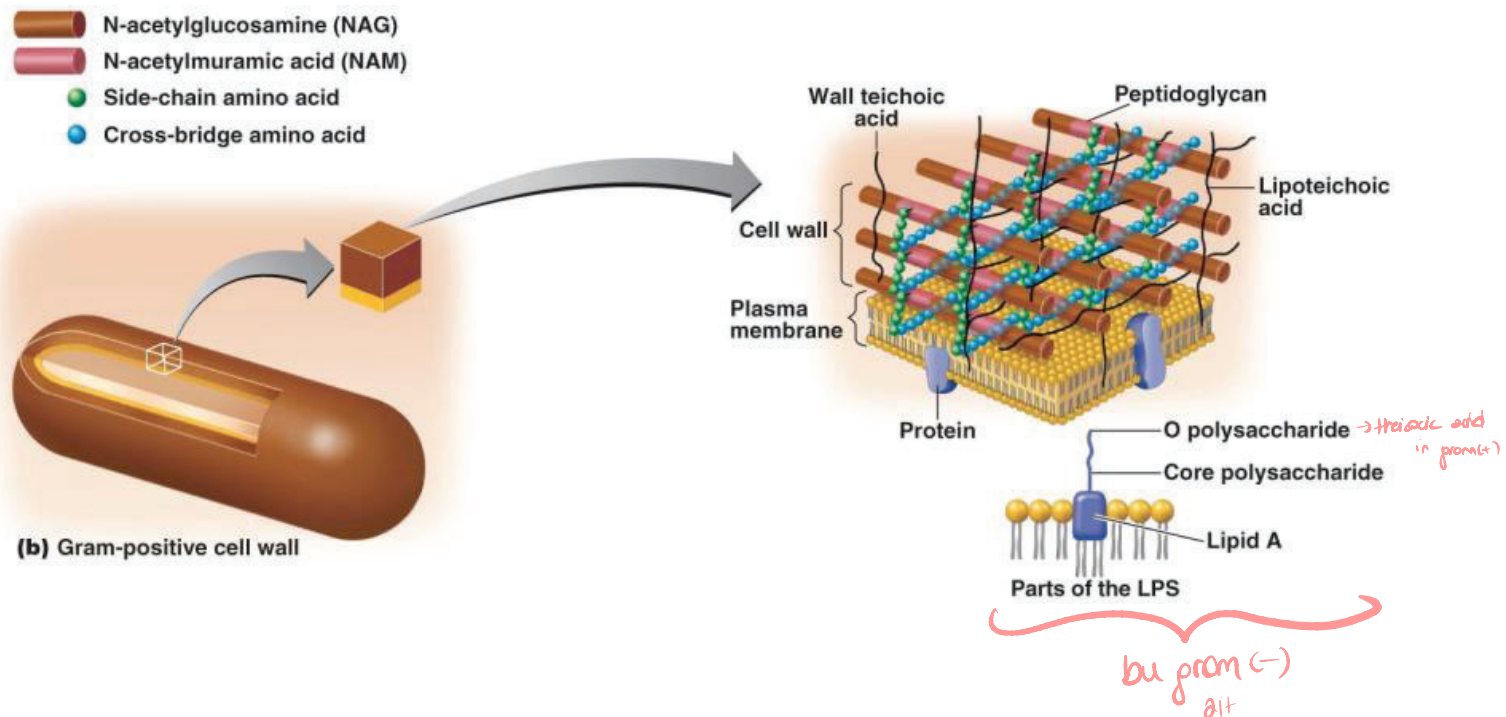
- Prevents osmotic lysis
- Made of **peptidoglycan (murein)** alone or in combination with other compounds
- Peptidoglycan is a polymer of disaccharide:
 - **N-acetylglucosamine (NAG)**
 - **N-acetylmuramic acid (NAM)**
- In Gram positives, peptidoglycan is laid down in rows like lattice-work
- Penicillin interferes with the linking of these rows



Gram-Positive Cell Walls

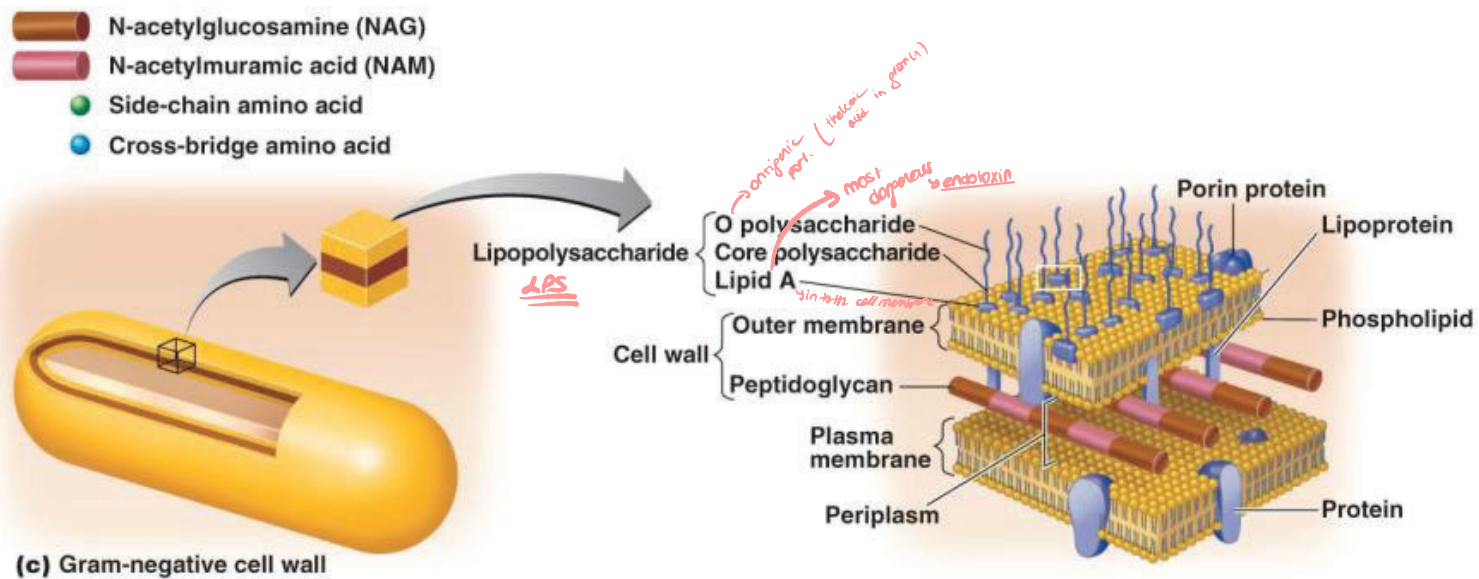
- Teichoic acids *→ difference btw from (-)*
 - lipoteichoic acid and wall teichoic acid linked to peptidoglycan layers
 - anchor peptidoglycan to plasma membrane

- Teichoic acids and Polysaccharides provide antigenic variation *→ means triple immune system*



Gram-Negative Cell Walls

- Peptidoglycan thin layer is bonded to lipoproteins in the outer lipid membrane...much more fragile cell wall but much more vicious bacteria due to outer membrane
- The space between the two lipid membranes is called the periplasm which is filled with fluid
- Penicillin Resistant but Tetracycline Sensitive

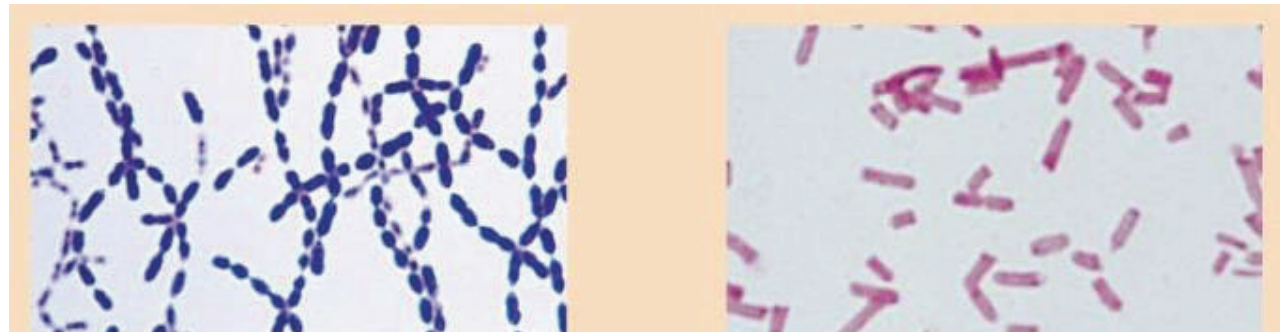


The Gram Stain Mechanism

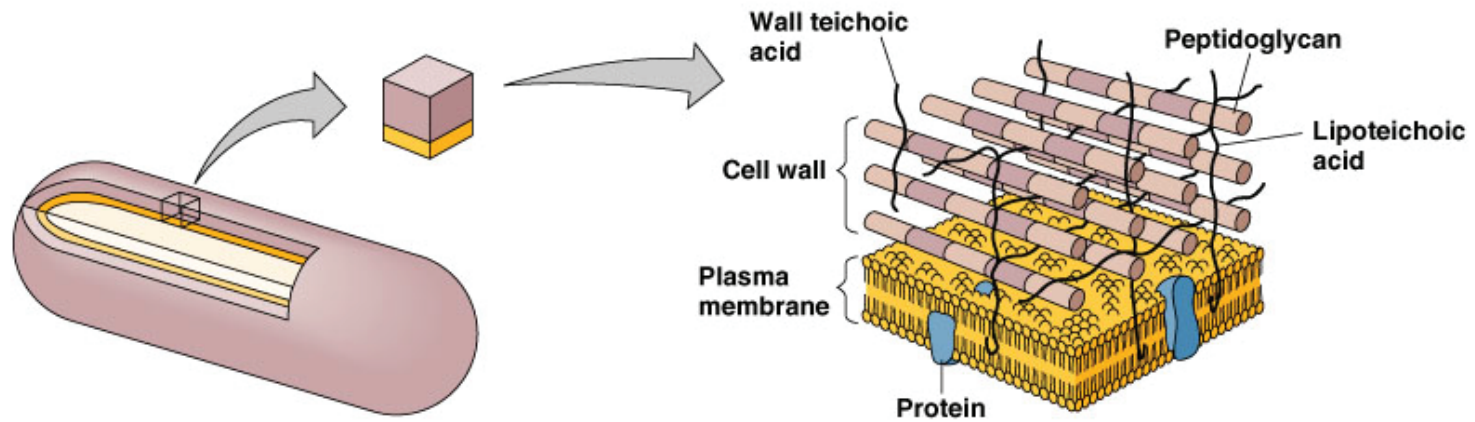
- Crystal violet-iodine crystals form in cell
- Gram-positive
 - alcohol dehydrates peptidoglycan
 - CV-I crystals do not leave
- Gram-negative
 - alcohol dissolves outer membrane & leaves holes in peptidoglycan
 - CV-I washes out
 - safranin can then stain it pink...pink can't be seen over CV in gram positives

Positive = purple

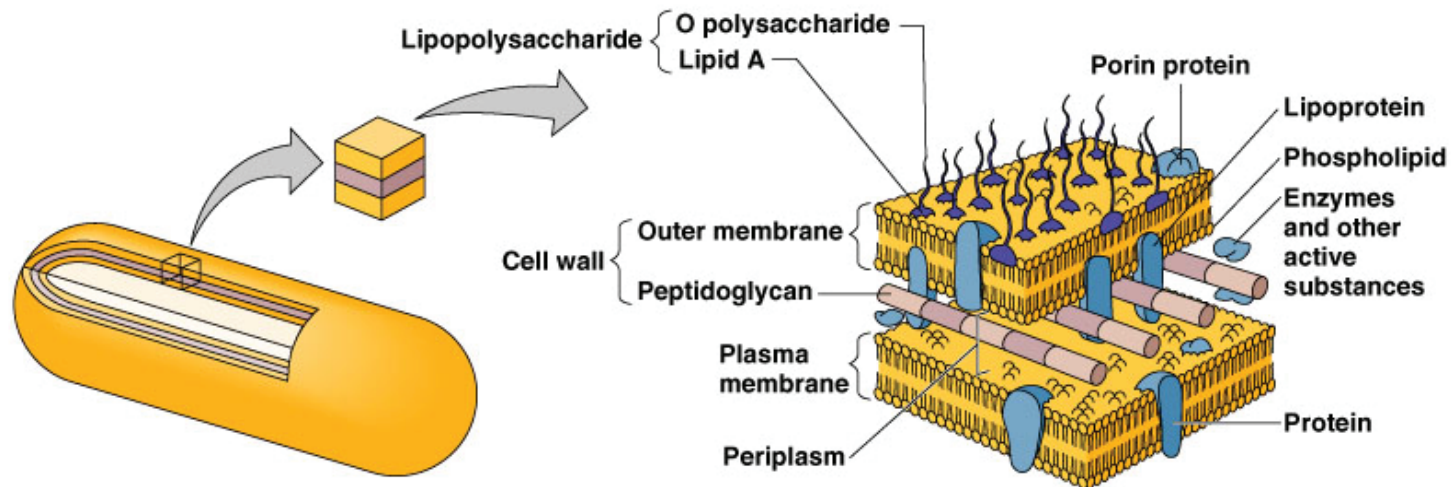
Negative = red



Gram - versus Gram + Cell Walls



(b) Gram-positive cell wall



(c) Gram-negative cell wall

Gram-Positive Cell Walls

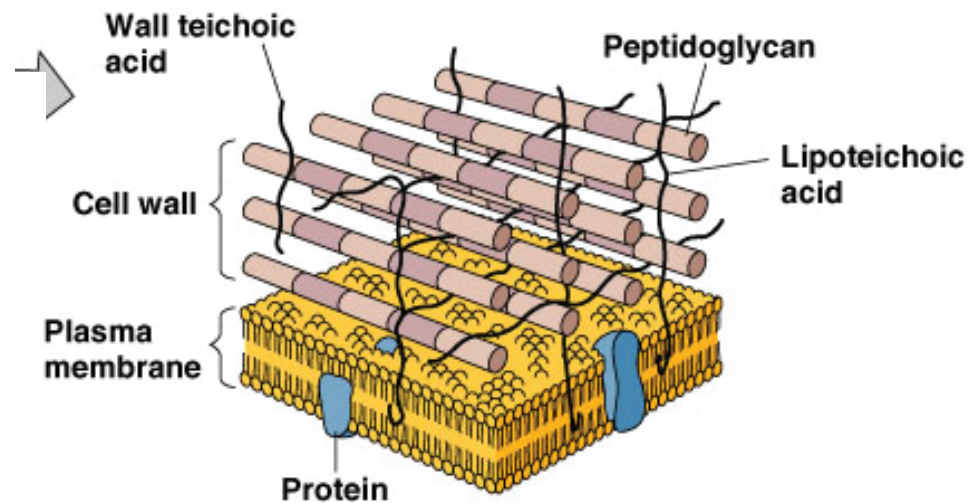
Gram-Negative Cell Walls

- Thick peptidoglycan
- Teichoic acids
- In acid-fast cells, contains mycolic acid

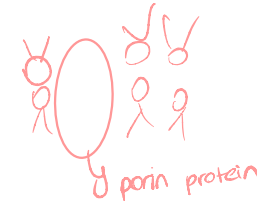
- Thin peptidoglycan
- No teichoic acids
- Outer membrane

Gram-Positive Cell Walls

- Teichoic acids:
 - Lipoteichoic acid links to plasma membrane
 - Wall teichoic acid links to peptidoglycan
- May regulate movement of cations
- Teichoic acids provide antigenic variation

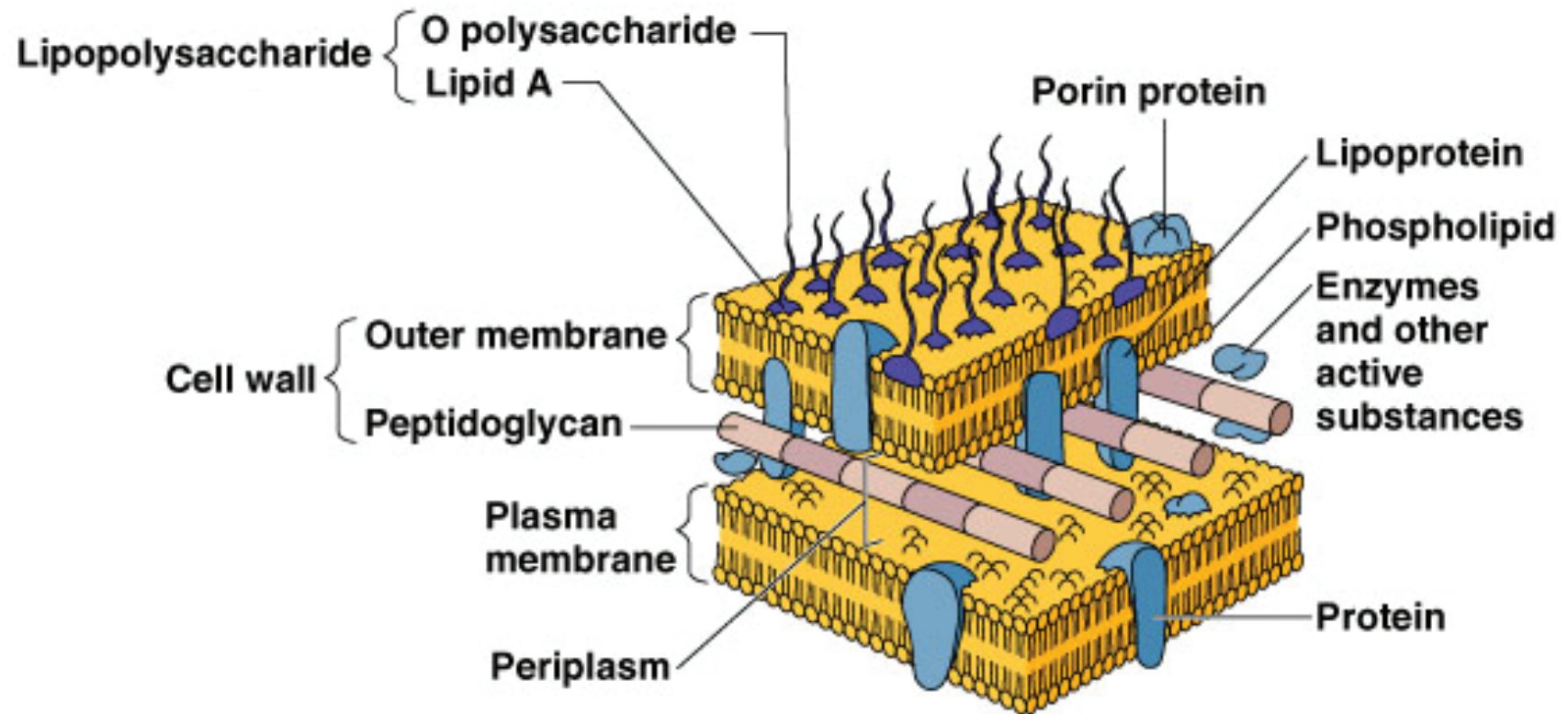


Gram-Negative Outer Membrane



- Lipopolysaccharides, lipoproteins, phospholipids.
- Forms the periplasm between the outer membrane and the plasma membrane.
- Protection from phagocytes, complement, antibiotics.
- O polysaccharide antigen, e.g., *E. coli* O157:H7.
- Lipid A is an endotoxin.
- Porins (proteins) form channels through membrane

Gram-Negative Outer Membrane



Gram Stain Mechanism

- Crystal violet-iodine crystals form in cell
- Gram-positive
 - Alcohol dehydrates peptidoglycan
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 - Alcohol dissolves outer membrane and leaves holes in peptidoglycan
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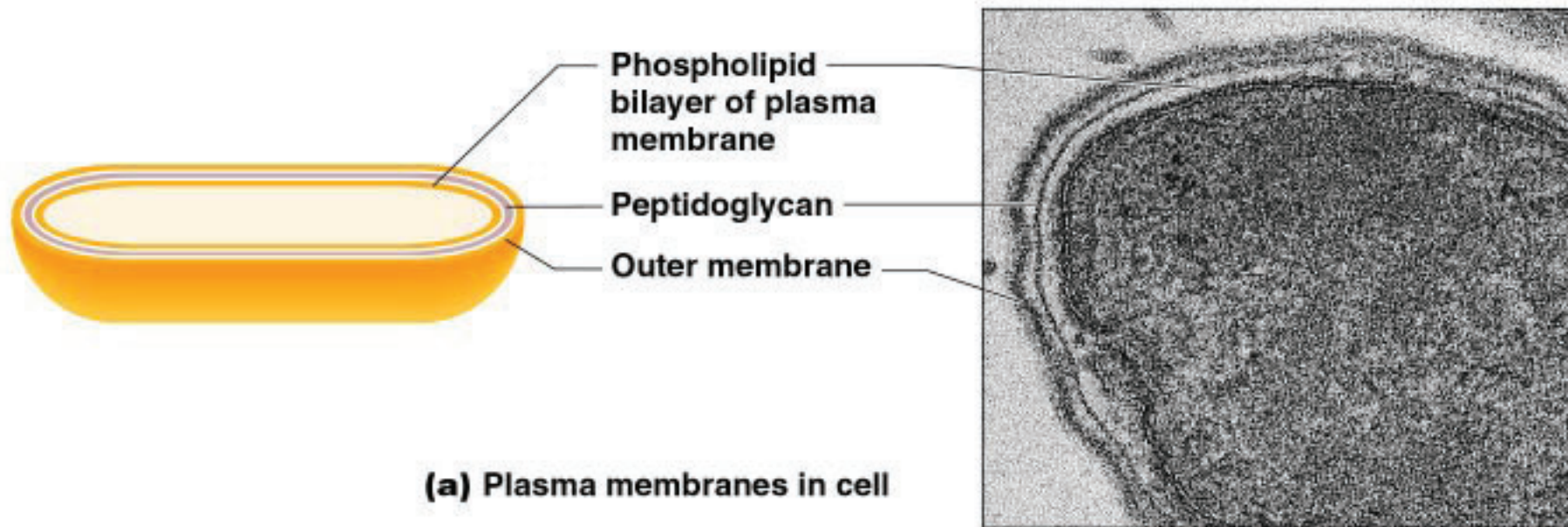
Atypical Cell Walls

- Mycoplasmas → they don't have cell walls
 - Lack cell walls
 - Sterols in plasma membrane
- Archaea → methanospira!
 - Wall-less, or
 - Walls of pseudomurein (lack NAM and D amino acids)

Damage to Cell Walls

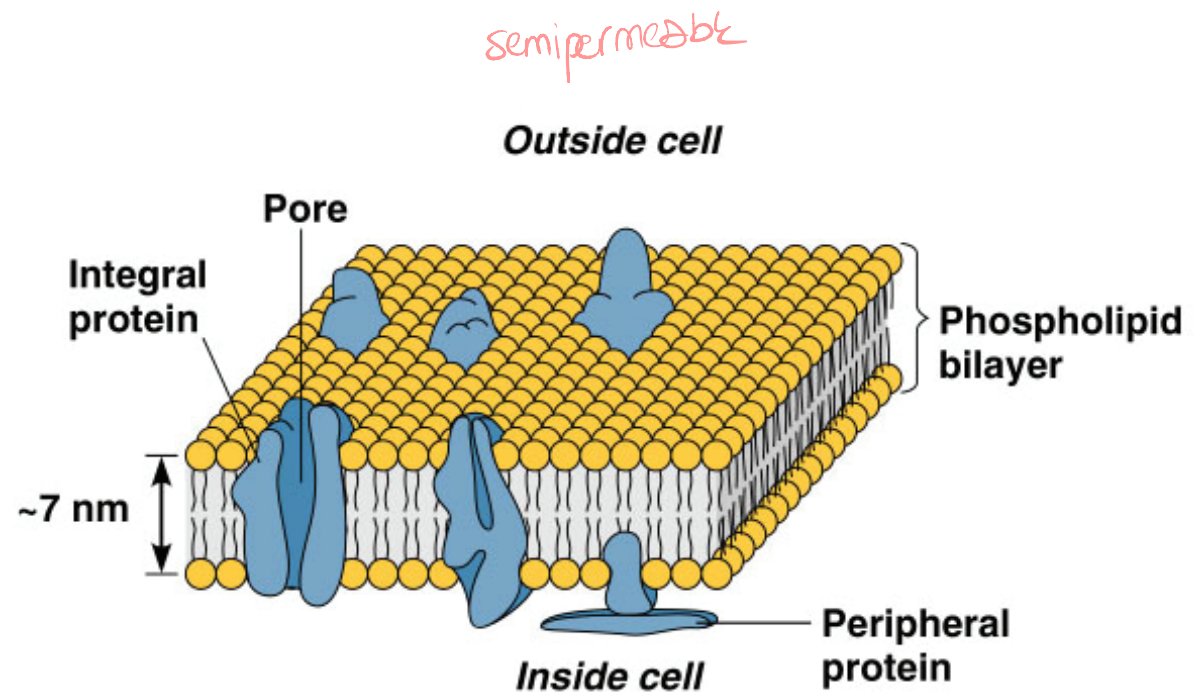
- Lysozyme digests disaccharide in peptidoglycan.
- Penicillin inhibits peptide bridges in peptidoglycan.
- Protoplast is a wall-less cell.
- Spheroplast is a wall-less Gram-negative cell.
- L forms are wall-less cells that swell into irregular shapes.
- Protoplasts and spheroplasts are susceptible to osmotic lysis.

Plasma Membrane



Plasma Membrane

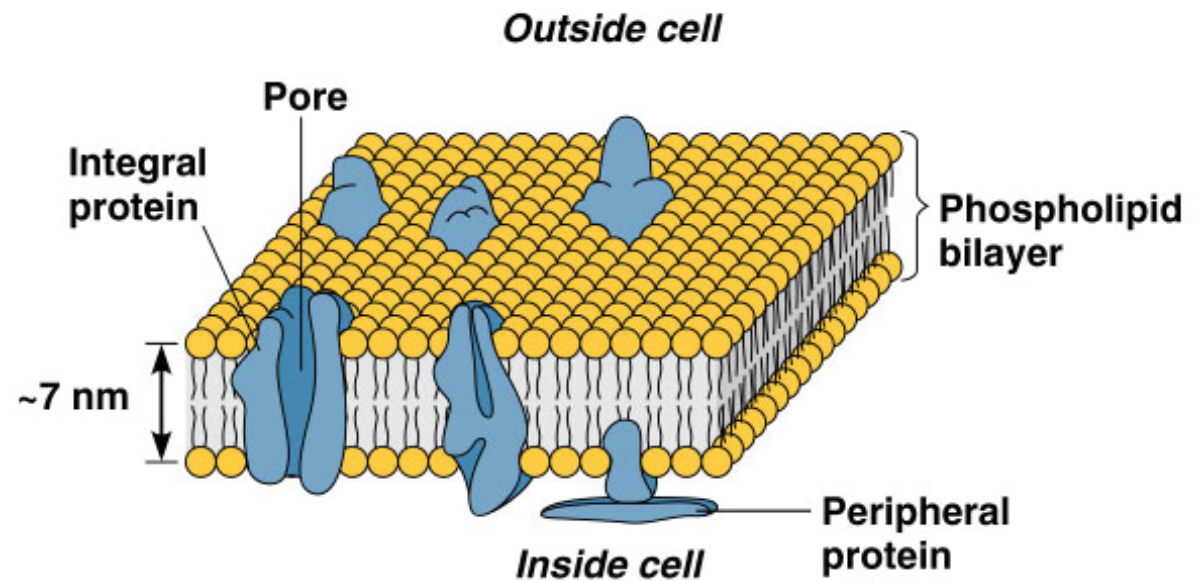
- Phospholipid bilayer
- Peripheral proteins
- Integral proteins
- Transmembrane proteins



(b) Phospholipid bilayer of membrane

Fluid Mosaic Model

- Membrane is as viscous as olive oil.
- Proteins move to function
- Phospholipids rotate and move laterally



(b) Phospholipid bilayer of membrane

Plasma Membrane

- Selective permeability allows passage of some molecules
- Enzymes for ATP production
- Photosynthetic pigments on foldings called chromatophores or thylakoids
- Damage to the membrane by alcohols, quaternary ammonium (detergents) and polymyxin antibiotics causes leakage of cell contents.

Movement Through Membranes

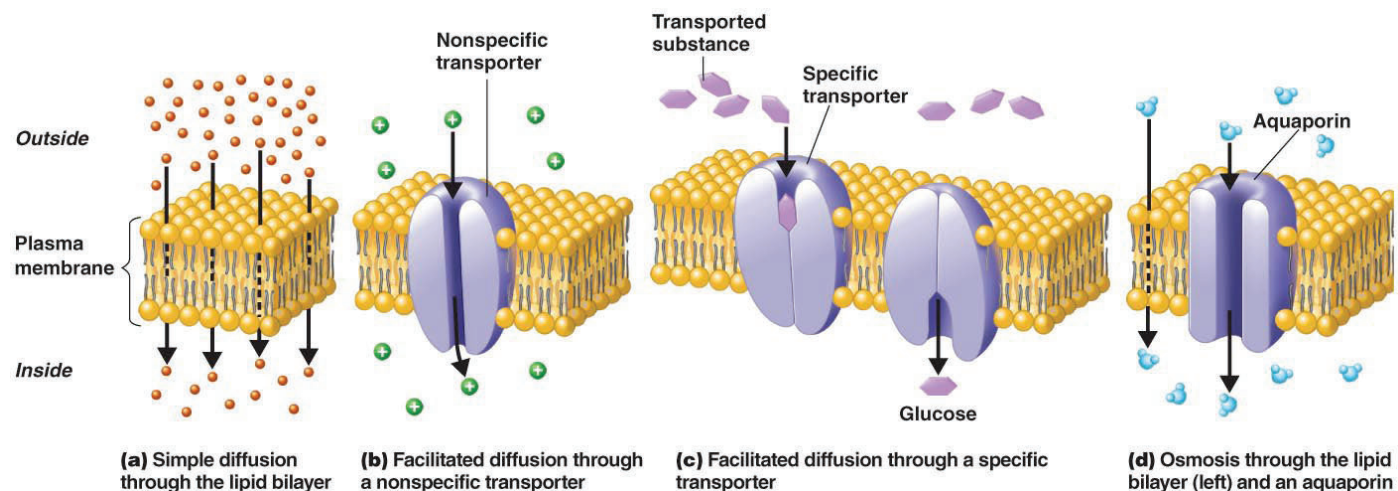
Passive vs. Active Processes:

Passive diffusion requires no energy

- move molecules from an area of higher concentration to lower concentration
- two types: simple and facilitated: simple diffusion, movement of a solute from an area of high concentration to an area of low concentration, facilitative diffusion, solute combines with a transporter protein in the membrane.

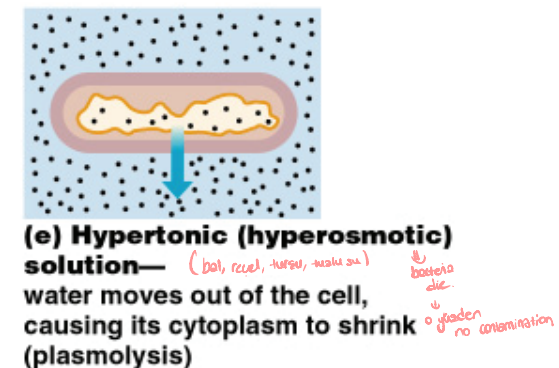
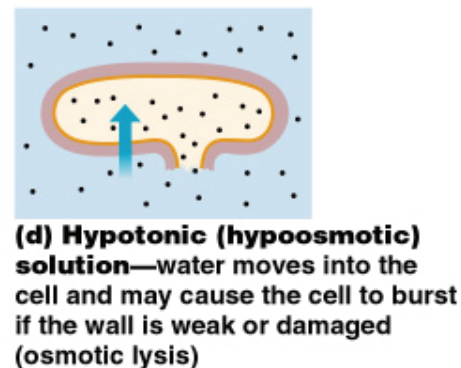
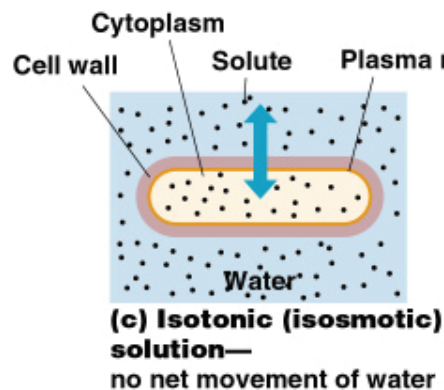
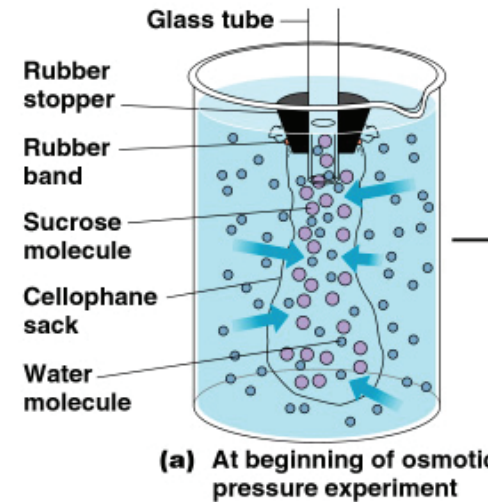
Active transport requires energy

- often used to move molecules against a concentration gradient (ex. Na^+ , K^+ , Ca^{2+} , Cl^- , amino acids & simple sugars). Active transport of substances requires a transporter protein and ATP. Group translocation of substances requires a transporter protein and PEP.



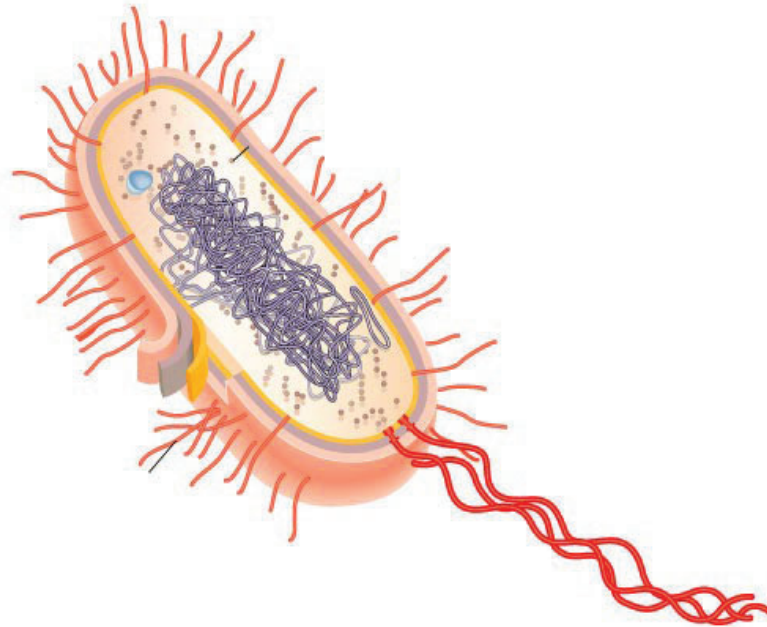
Movement Across Membranes

- **Osmosis**
 - Movement of water across a selectively permeable membrane from an area of high water concentration to an area of lower water.
- **Osmotic pressure**
 - The pressure needed to stop the movement of water across the membrane.

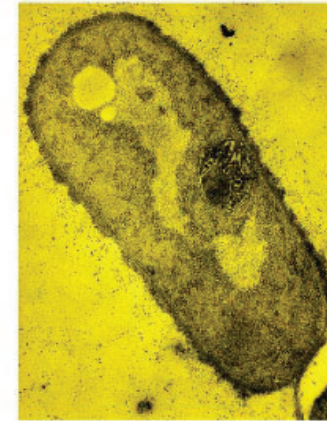


Cytoplasm

- Cytoplasm is the substance inside the plasma membrane



(a)



(b)

Bacterial Cell Components

- Cytoplasm is similar to eukaryotic except that DNA is found there in the nucleoid region
- DNA replication enzymes are found on the inside of the plasma membrane
- Bacteria have additional genetic information stored in plasmids (5-100 genes)
- Plasmids are small circular double-stranded DNA molecules
 - believed to contain genes involved in antibiotic resistance, tolerance to toxic metals, the production of toxins and synthesis of certain enzymes
 - not crucial for survival though...can be removed
 - used in biotechnology to genetically modify organisms

Bacterial Cell Components

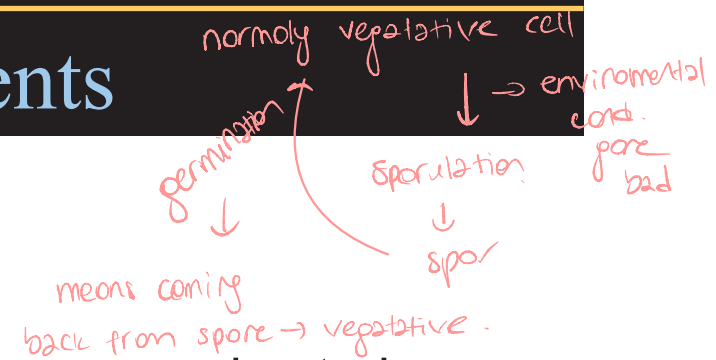
- Contain ribosomes
- Function: protein synthesis
- Size: 70S vs. 80S in eukaryotes
 - large (50S) and small (30S) subunits
- Several antibiotics inhibit protein synthesis by interfering with the subunits
- Streptomycin & gentamicin affect the small subunit
- Erythromycin & chloramphenicol affect large subunit
- Bacterial specificity

Bacterial Cell Components

- Have no vacuoles but have reserve deposits called Inclusions (or Granules) within the cytoplasm
- Store molecules in inclusion bodies so compounds don't affect osmotic gradients
- Since sometimes species specific, they can be used to help identify
 - metachromatic granules (aka volutin) characteristic of *Corynebacterium diphtheria*
 - lipid inclusions found in *Mycobacterium*, *Bacillus*, *Azotobacter*
 - sulfur inclusions found in *Thiobacillus* (sulfur bacteria)
 - other inclusions: polysaccharide granules, carboxysomes and magnetosomes

Bacterial Cell Components

resting cells → no way to kill them



- Endospores are specialized cells formed by particular gram+ bacteria when essential nutrients are depleted
 - considered resting cells
 - *Clostridium* & *Bacillus*
- Highly durable – dehydrated with a thickened cell wall and additional outer lipid layer
- Can survive extreme heat, lack of water and exposure to many toxic chemicals
- Do not carry out metabolic reactions until **Germination**

Nuclear Area

3 ways to transfer genes in cells
1- Conjugation
2- Transformation
3- Transduction

naked dna environment why? ⇒ Because bacteria get lysis

Third way Transduction

Third mechanism is proper when viruses infect to bacteria, naked dna transfer from the virus to bacteria eventually cell lysis, then millions of viruses (viruses) get released to environment.

Single cells become free
↓
Other cells can take that
↳ transformation process
↳ second mechanism (first one is conjugation)

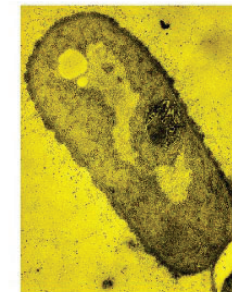
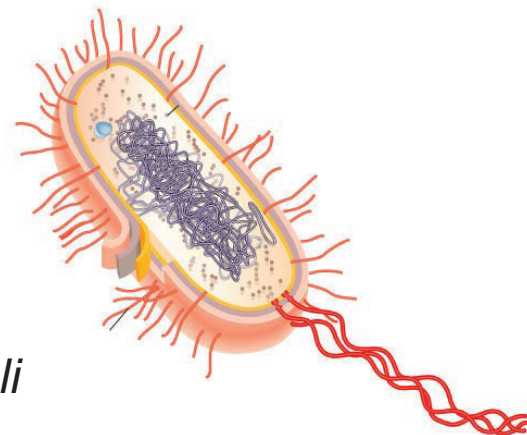
- Nuclear area (nucleoid) Genome
- A cell's full complement of genes
- Prokaryotic cells generally have a single, circular DNA molecule called a chromosome
- DNA aggregates to form the nucleoid region
- Prokaryotes also may have small amounts of extra-chromosomal DNA called plasmids that confer special properties (e.g., antibiotic resistance)

- **Escherichia coli Genome**

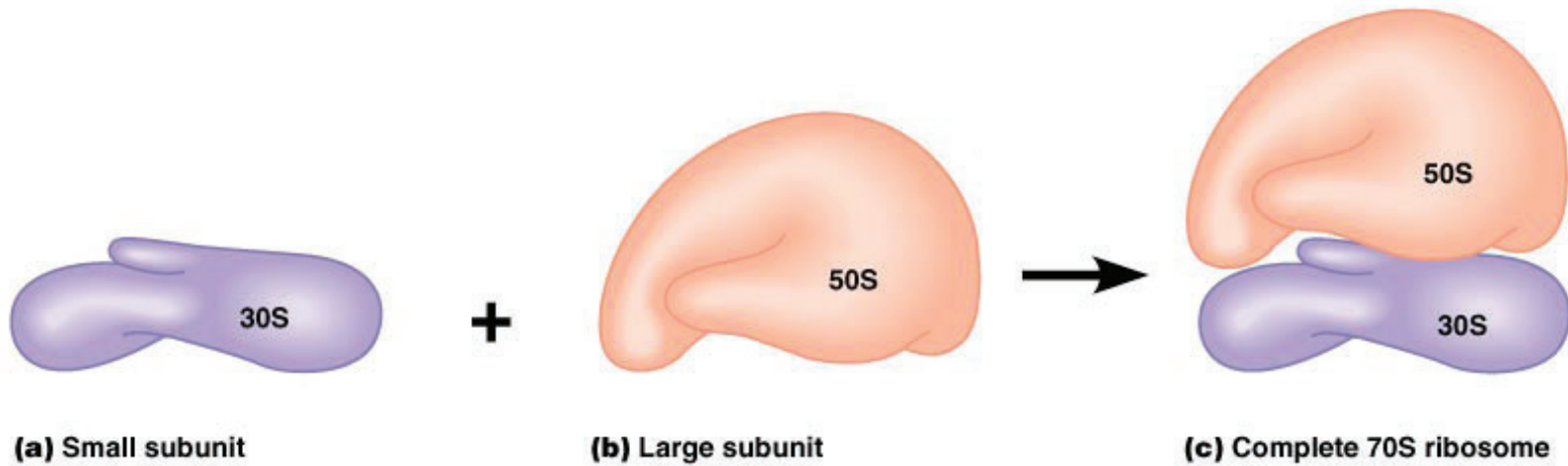
- 4.64 million base pairs (bp)
- 4,300 genes
- 1,900 different kinds of protein
- 2.4 million protein molecules

- **Human Cell**

- 1,000 x more DNA per cell than *E. coli*
- 7 x more genes than *E. coli*



Ribosomes



Inclusions

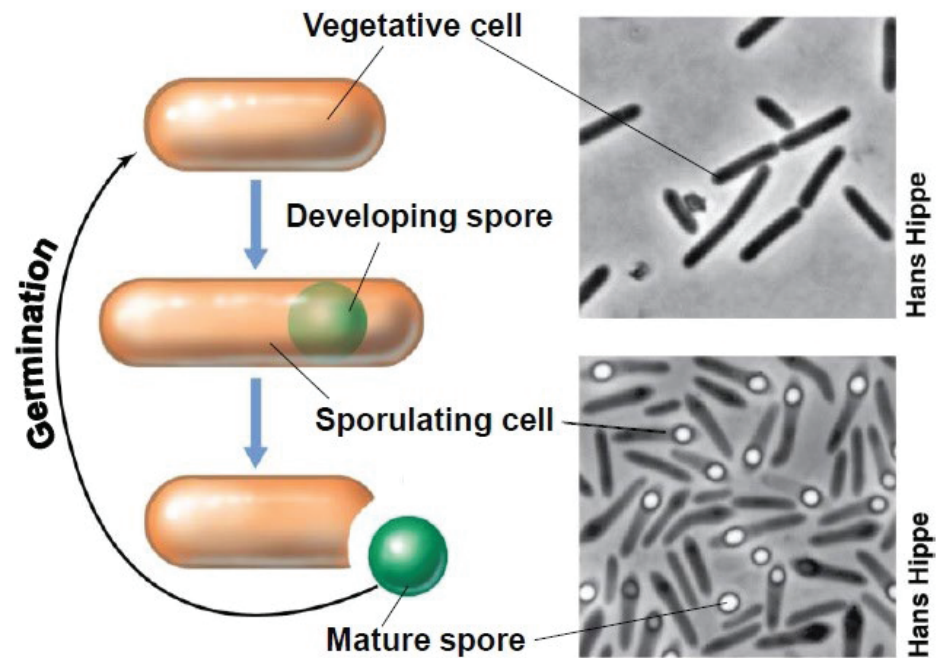
- Metachromatic granules (volutin)
- Polysaccharide granules
- Lipid inclusions
- Sulfur granules
- Carboxysomes
- Gas vacuoles
- Magnetosomes
- Phosphate reserves
- Energy reserves
- Energy reserves
- Energy reserves
- Ribulose 1,5-diphosphate carboxylase for CO₂ fixation
- Protein covered cylinders
- Iron oxide (destroys H₂O₂)



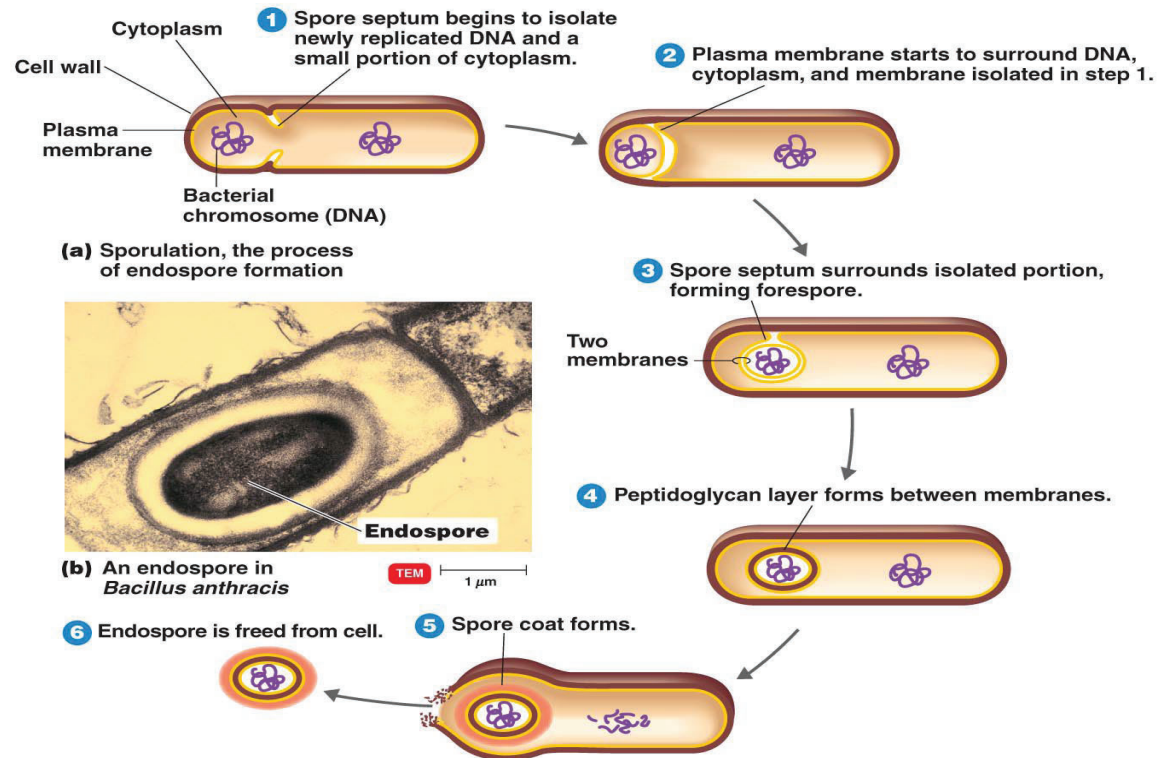
Endospores

- Resting cells
- Resistant to desiccation, heat, chemicals
- *Bacillus*, *Clostridium*
- **Sporulation**: Endospore formation
- **Germination**: Return to vegetative state

Figure 3.33 The life cycle of an endospore-forming bacterium.

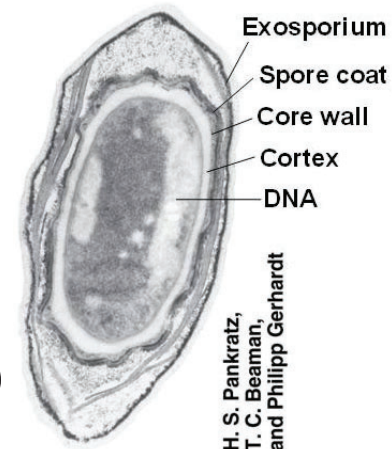


Sporulation (Sporogenesis)

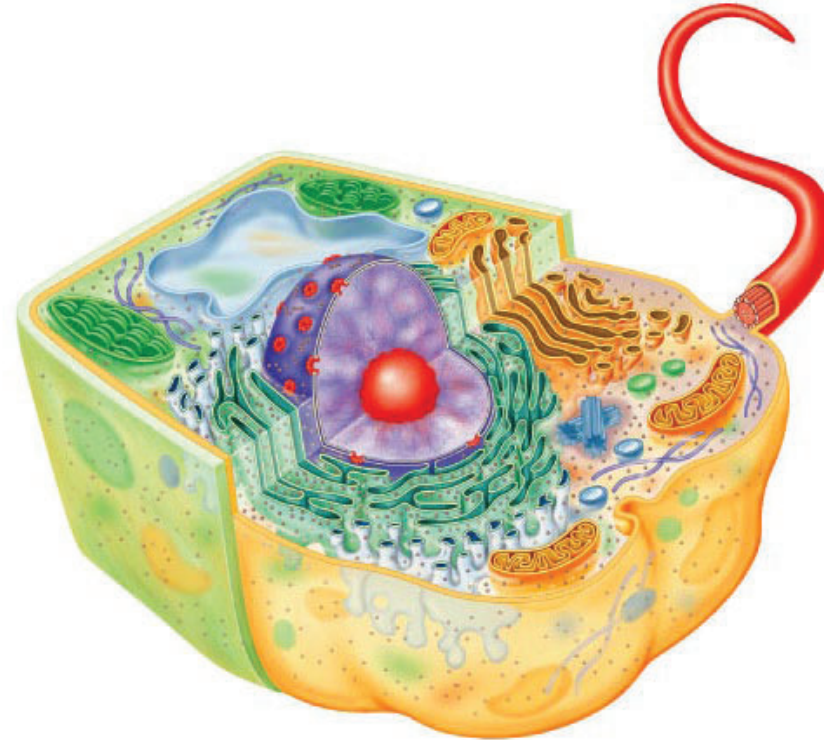


Endospore Structure

- Contains dipicolinic acid
- Enriched in Ca^{2+}
- Core contains small acid-soluble proteins (SASPs)



Eukaryotic Cells



- Comparing Prokaryotic and Eukaryotic Cells
 - Prokaryote comes from the Greek words for pre-nucleus.
 - Eukaryote comes from the Greek words for true nucleus.

Cell Wall

- Cell wall
 - Plants, algae, fungi
 - Carbohydrates
- Cellulose, chitin, glucan, mannan
- Glycocalyx
 - Carbohydrates extending from animal plasma membrane
 - Bonded to proteins and lipids in membrane

Plasma Membrane

- Phospholipid bilayer
- Peripheral proteins
- Integral proteins
- Transmembrane proteins
- Sterols
- Glycocalyx carbohydrates

Plasma Membrane

- Selective permeability allows passage of some molecules
- Simple diffusion
- Facilitative diffusion
- Osmosis
- Active transport
- Endocytosis
 - Phagocytosis: Pseudopods extend and engulf particles
 - Pinocytosis: Membrane folds inward bringing in fluid and dissolved substances

Organelles

- Membrane-bound:
 - Nucleus Contains chromosomes
 - ER Transport network
 - Golgi complex Membrane formation and secretion
 - Lysosome Digestive enzymes
 - Vacuole Brings food into cells and provides support
 - Mitochondrion Cellular respiration
 - Chloroplast Photosynthesis
 - Peroxisome Oxidation of fatty acids; destroys H_2O_2

Ribosomes

By iconu sinovab

pelicey
↳ 16s 18s

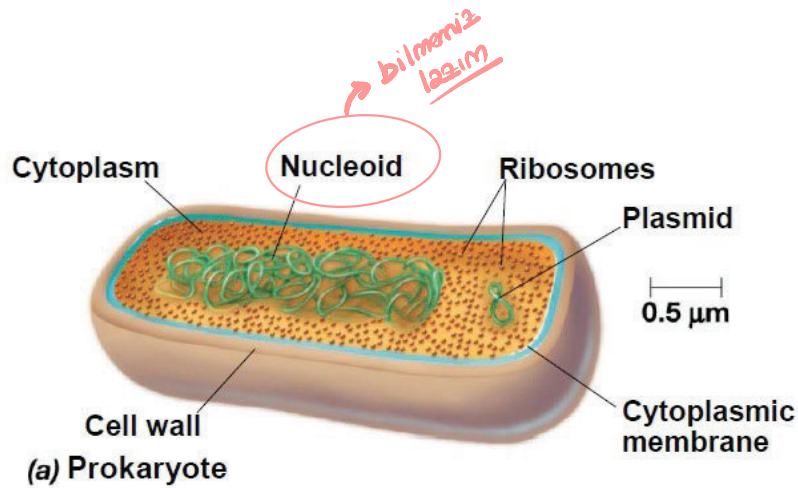
universal primitor de
dohil.

- 80S (40S & 60S)
 - Membrane-bound
 - Free
- 70S (30S & 50S)
 - In chloroplasts and mitochondria

Attached to ER

In cytoplasm

Prokaryote versus Eukaryote

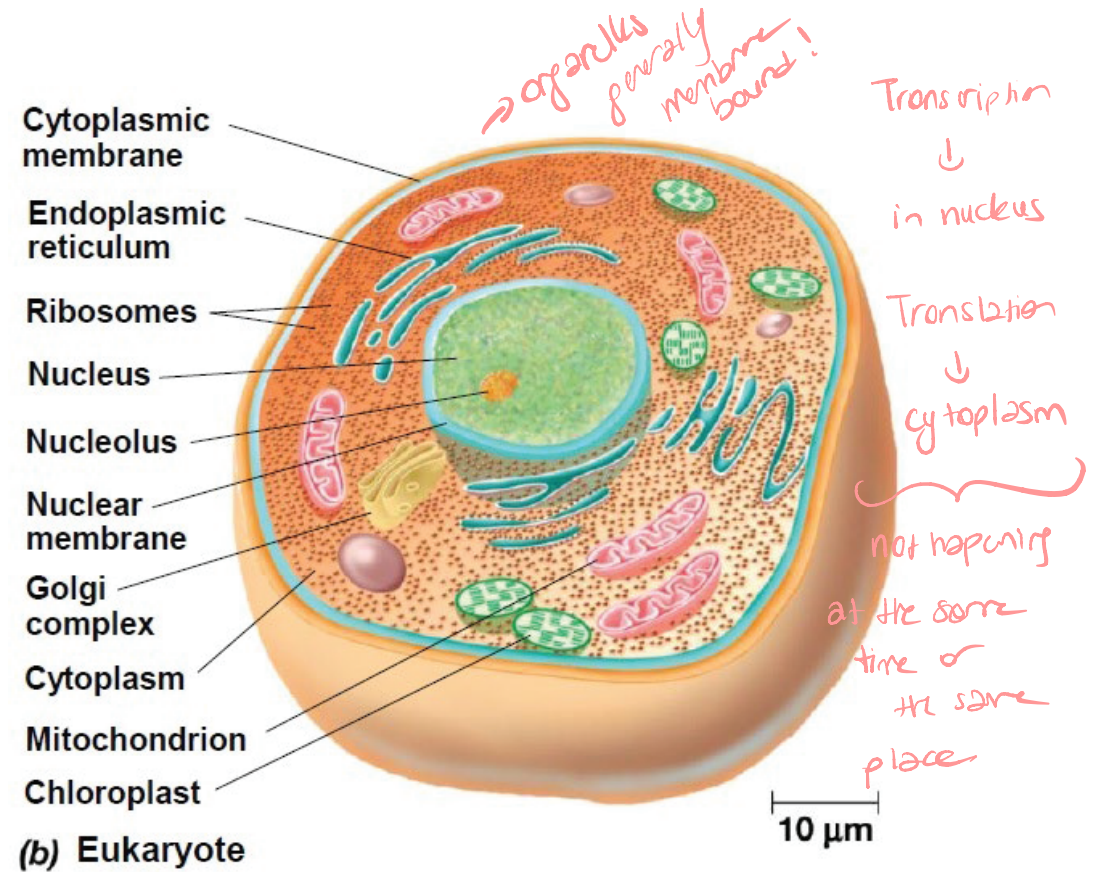


bilaminar

\downarrow
 maybe sometimes we have capsule
 and some have flagella \rightarrow if they
 are mobile.

DNA
 \downarrow
 mRNA
 \downarrow
 protein

Transcription and translation coupled
 at the same time
 at the same place



Endosymbiotic Theory → Eukaryotic cells evolved from prokaryotic cells.

