Morphology of Bacteria

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Prokaryotic vs. Eukaryotic Cells

- Prokaryotic cells
  - No Nucleus
  - No Organelles
  - Cell Wall of peptidoglycan
  - Binary Fission
  - 1 circular chromosome
- Eukaryotic Cells
  - Nucleus
  - Organelles
  - If cell wall, Cellulose or chitin
  - Mitosis
  - Linear chromosomes

Size

- Size
  - Length 2u to 8u
  - Diameter 2u to .2u

Shape, and Arrangement

- Cocci:
  - Diplococci (Group of Two)
  - Streptococci (in chain)
  - Staphylococci (in grape like clusters)
  - Sarcinae (cube of eight)
  - Tatrad (Group of four)

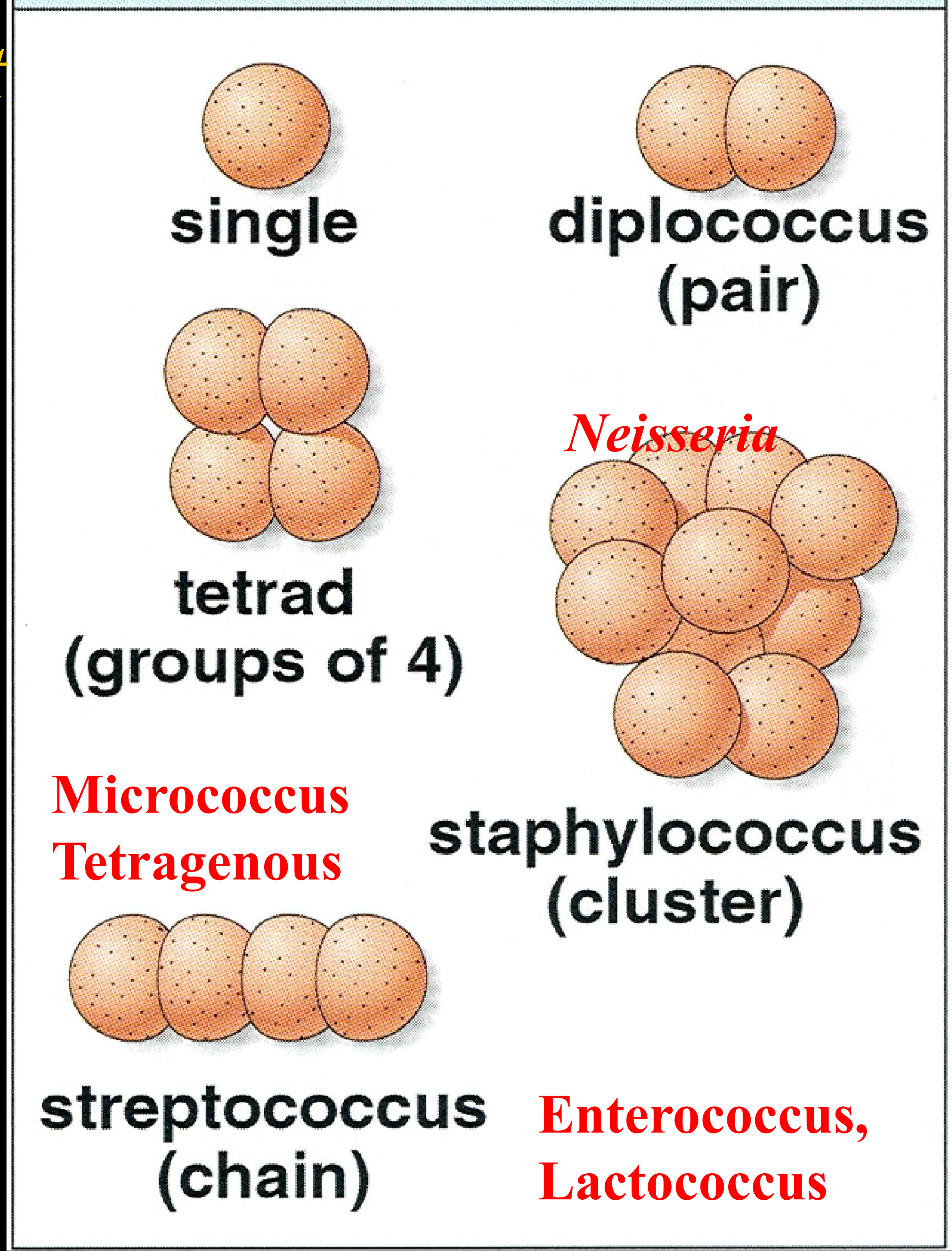
- Rods or Bacillus:
  - True bacilli/ Rods (Rod shaped)
  - Streptobacillus (in Chains)
  - Coccobacilli. (Oval Shaped)
  - Diplobacilli . (Group of two)
- Spirals:
  - Vibrio (curved or comma-shaped rods)
  - Spirillum (thick, rigid spiral)
  - Spirochete (thin, flexible spiral)

Cell Shape

- Peptidoglycan confers shape.
- Bacteria come in many sizes , shapes & arrangements

Arrangement

- Cocci
  - diplococci
  - streptococci
  - tetrads
  - sarcinae
  - staphylococci
- Bacilli
  - diplobacilli
  - streptobacilli
  - coccobacilli
- Spiral
  - vibrio
  - spirilla
  - spirochete



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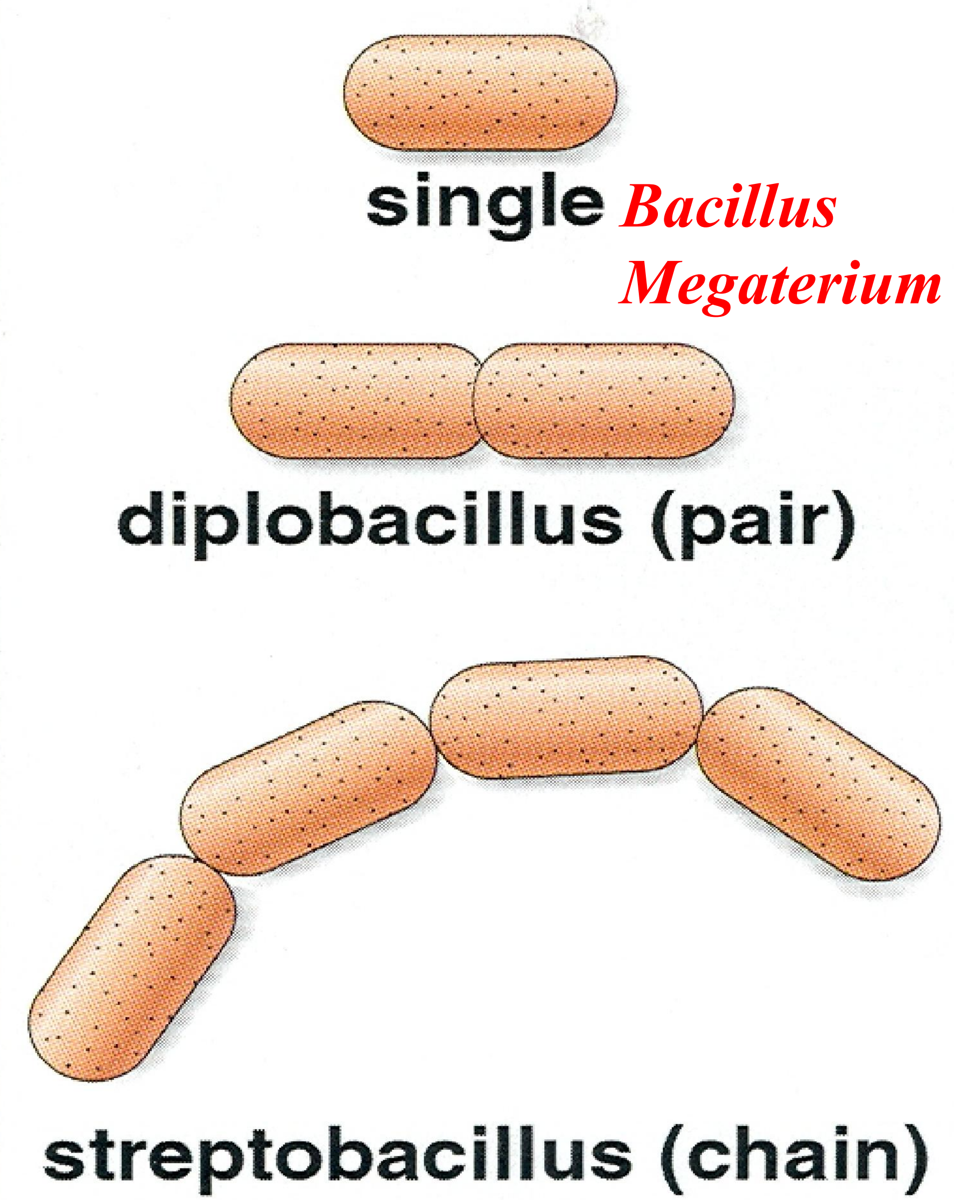

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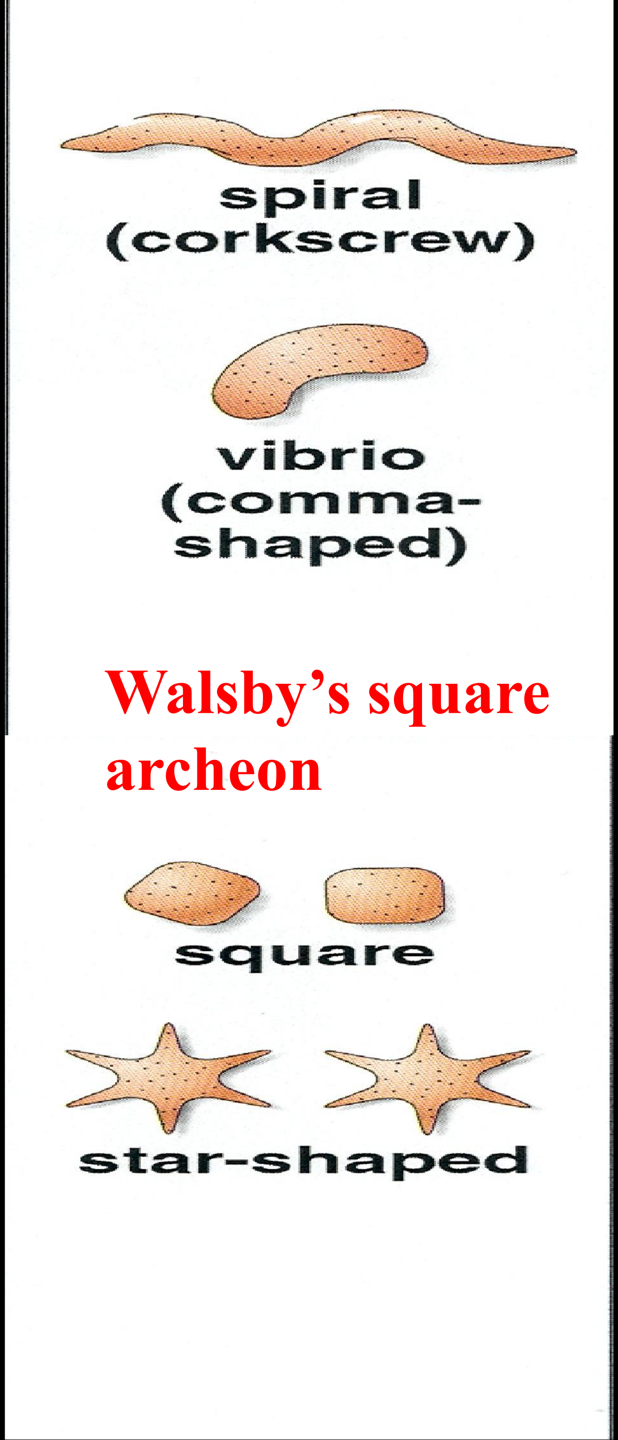
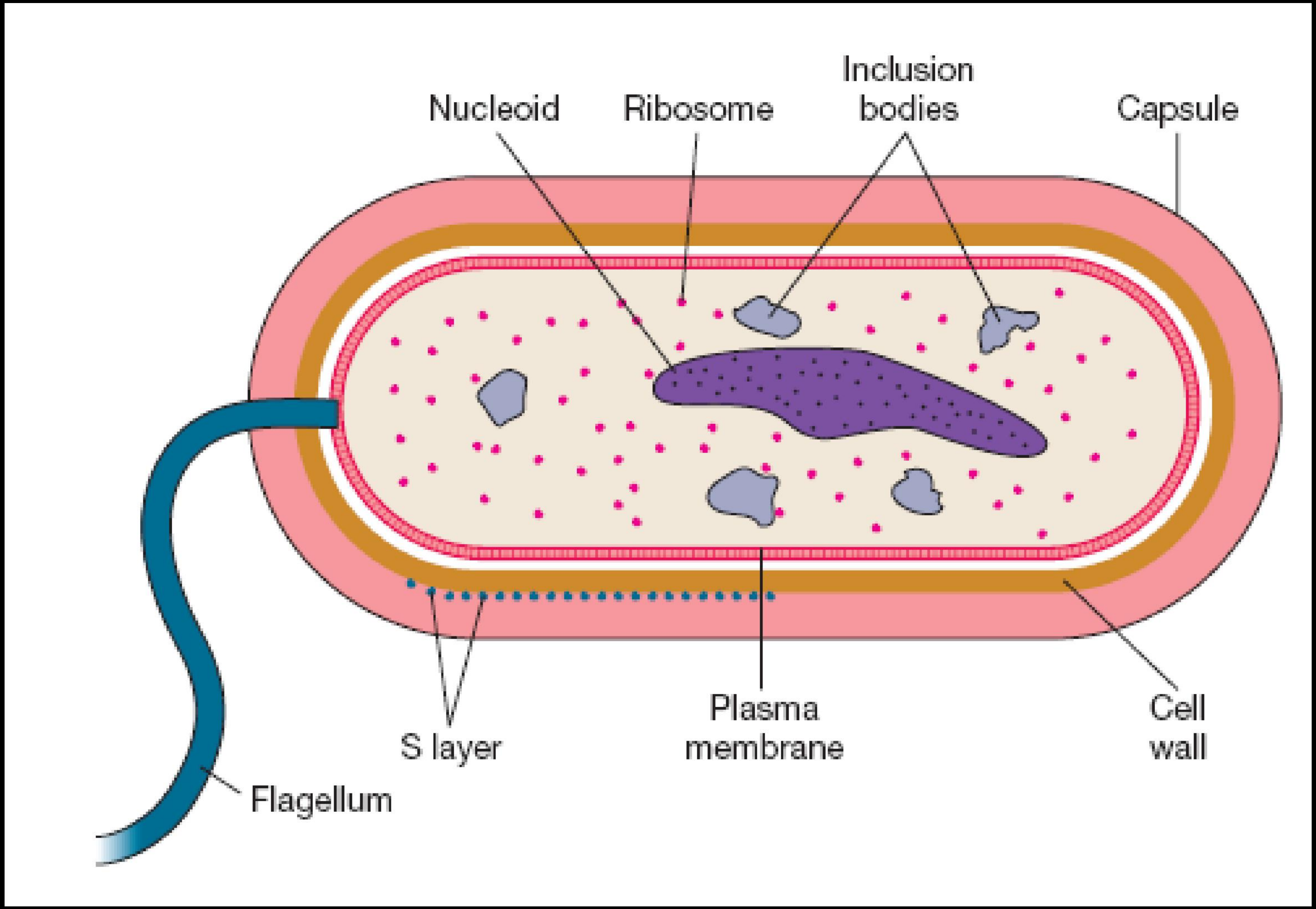


Size

- Smallest (e.g., some members of the genus *Mycoplasma) are* about 0.3 um in diameter.
- Nanobacteria or ultramicrobacteria appear to range from around 0.2 m to less than 0.05 m in diameter.
- Smallest possible cell is about 0.14 to 0.2 um in diameter.
- *Escherichia coli, a bacillus of about* average size, is 1.1 to 1.5 m wide by 2.0 to 6.0 m long.
- Spirochetes occasionally reach 500 um in length.
- *Epulopiscium fishelsoni* grows as large as 600 by 80 um,

Prokaryotic Cell Structure



Prokaryotic Cell Structure

Table 3.1 Functions of Procaryotic Structures

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	Buoyancy for floating in aquatic environments
Ribosomes	Protein synthesis
Inclusion bodies	Storage of carbon, phosphate, and other substances
Nucleoid	Localization of genetic material (DNA)
Periplasmic space	Contains hydrolytic enzymes and binding proteins for nutrient processing and uptake
Cell wall	Gives bacteria shape and protection from lysis in dilute solutions
Capsules and slime layers	Resistance to phagocytosis, adherence to surfaces
Fimbriae and pili	Attachment to surfaces, bacterial mating
Flagella	Movement
Endospore	Survival under harsh environmental conditions

Cytoplasmic Membrane

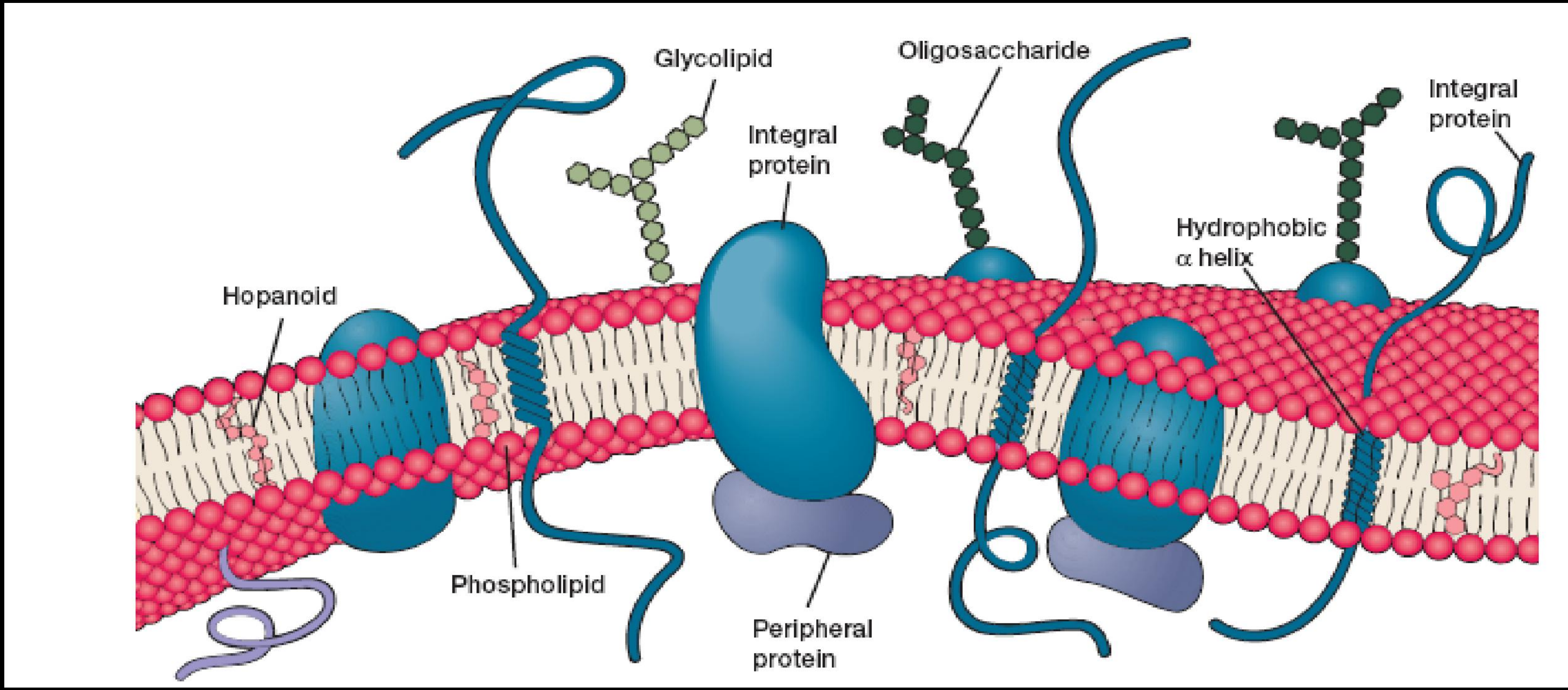
- Membrane that encloses cytoplasm called a plasma membrane
- In prokaryotes & eukaryotes, the membranes are quite similar Called a unit membrane

Cell Membrane (Plasma Membrane)

w Structural component

- double layer of phospholipids
- Proteins :**Peripheral proteins** are loosely connected to the membrane and can be easily removed. They are soluble in aqueous solutions and make up about 20 to 30% of total membrane protein.
- About 70 to 80% of membrane proteins are **integral proteins.**

fluid mosaic model



- Integral proteins (blue) floating in a lipid bilayer.
- Peripheral proteins (purple) are associated loosely with the inner membrane surface.
- Small spheres represent the hydrophilic ends of membrane phospholipidsand wiggly tails, the hydrophobic fatty acid chains. Other membrane lipids such as hopanoids (pink) may be present.

Functions of Cell Membrane

- 1. Selective barrier (selectively permeable)
- 2. Secretes exoenzymes
  - amylases
  - lipases
  - Peptidases
- 4. Enzymes for cell wall synthesis
- 5. If photosynthesis, enzymes are located on membranous structures called thylakoids.

Internal Membrane Systems

- Mesosomes are invaginations of the plasma membrane in the shape of vesicles, tubules or lamellae.
- In both gram positive and gram-negative bacteria.
- found next to septa or cross-walls in dividing bacteria and sometimes seem attached to the bacterial chromosome. Thus they may be involved in cell wall formation

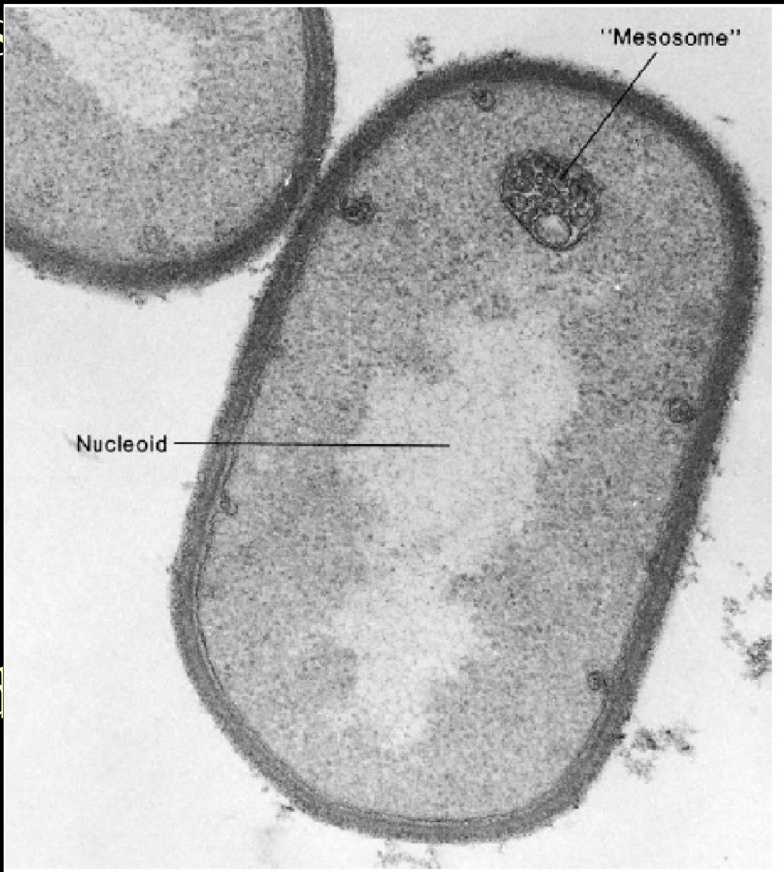
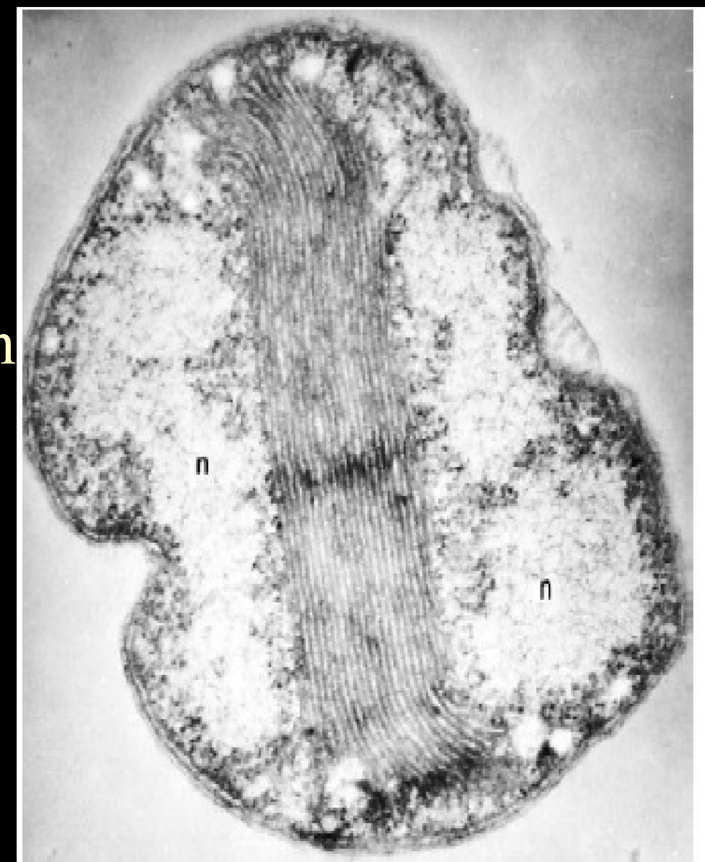


Figure 3.8 **Mesosome Structure.** *Bacillus fastidiosus* (×91,000). A large mesosome lies adjacent to the nucleoid.

Internal Membrane Systems

- Many bacteria have internal membrane systems quite different from the mesosome.
- Plasma membrane infoldings can become extensive and complex in photosynthetic bacteria such as the cyanobacteria and purple bacteria or in bacteria with very high respiratory activity like the nitrifying bacteria. *They may be aggregates of spherical vesicles,* flattened vesicles, or tubular membranes.
- function may be to provide a larger membrane surface for greater metabolic activity.



The Cytoplasmic Matrix

- The cytoplasmic matrix is the substance lying between the plasma membrane and the nucleoid.
- The matrix is largely water (about 70% of bacterial mass is water).
- Often is packed with ribosomes and highly organized Specific proteins are positioned at particular sites such as the cell pole and the place where the bacterial cell will divide.
- Thus although bacteria may lack a true cytoskeleton, they do have a cytoskeleton likes FtsZ,MreB, cresentin proteins in their cytoplasmic matrix.
- The plasma membrane and everything within is called the protoplast; thus the cytoplasmic matrix is a major part of the protoplast.

Inclusion Bodies

- Granules of organic or inorganic material.
- Used for storage (e.g., carbon compounds, inorganic substances, and energy), and also reduce osmotic pressure by tying up molecules in particulate form.
- Not bounded by a membrane and lie free in the cytoplasm e.g. polyphosphate granules, cyanophycin granules, and some glycogen granules.
- Enclosed by a membrane about 2.0 to 4.0 nm thick, which is single-layered and not a typical bilayer membrane. E.g. poly--hydroxybutyrate granules, some glycogen and sulfur granules, carboxysomes, and gas vacuoles.

Inclusion Bodies

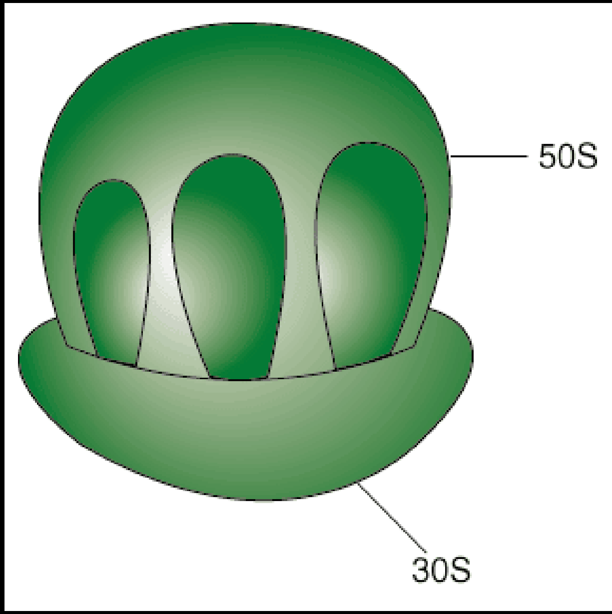
- Organic: glycogen & poly-B-hydroxy butyrate (PHB), are carbon storage reservoir providing material for energy and biosynthesis.
- Gas vacuole: aggregate of enormous numbers of small, hollow, cylindrical structures called **gas vesicles,** provide buoyancy, present in many photosynrhetic bacteria.
- Cynobacteria , photosynthetic bacteria two type
- Cynophycin granules: polypeptide containing arginine and aspartic acid equally.
- Carboxysome: polyhedral, contain enzyme Rubisco, enzyme for co2 fixation.

Inclusion Bodies

- Inorganic : two type
- Polyphosphate granules/volutin granules : storage reservoir for phosphate, known as metachromatic granules
- sulphur granules.
- Magnatosomes are used to orient in earth's magnetic field.

Ribosomes - *present in cytoplasmic matrix and attached to plasma membrane, made up of protein and RNA, site of protein synthesis.*

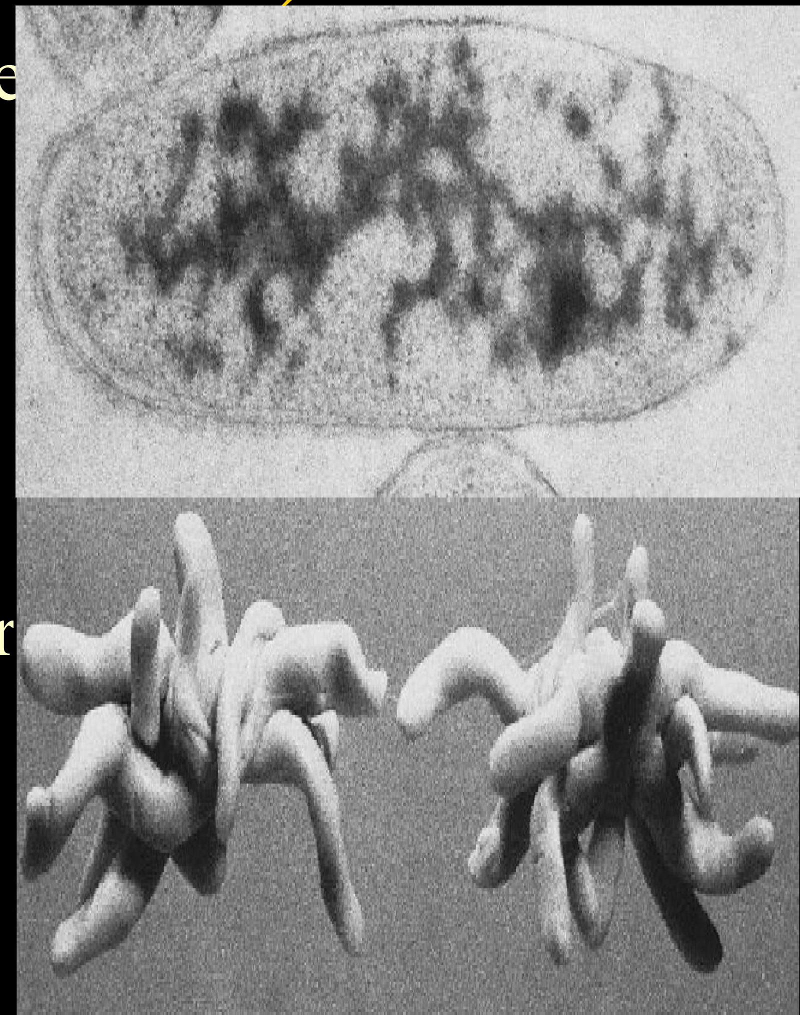
- Prokaryotic Ribosome
- 70 S
  - 50 S
  - 30 S



- Eukaryotic Ribosomes
- 80 S
  - 60 S
  - 40 S

Nuclear area (nucleoid)

- The procaryotic chromosome is located in an irregularly shaped region called the nucleoid.
- Prokaryotes contain a single circle of double-stranded DNA, but some have a linear DNA chromosome.
- *Vibrio cholerae have more than one* chromosome.
- composed of about 60% DNA, 30% RNA, and 10% protein by weight.



A section of actively growing *E. coli.* A model of two nucleoids in growing *E. coli cell*.

Plasmids

- Extrachromosomal material, < 30 genes.
- Double-stranded DNA molecules, usually circular, or linear that can exist and replicate independently of the chromosome or may be integrated with it (episomes).
- Plasmids are inherited during cell division and sometimes are lost, known as curing.

Type of plasmids

1. Conjugative plasmids (F factor): have genes for construction of pili & can transfer copies of plasmids to other during conjugation.
2. Resistance factor (R plasmid): have genes that code for enzymes capable of destroying or modifying antibiotics. Often resistance genes are within mobile genetic materials known as transposones.
3. Bacteriocin encoding plasmids: bacteriocins are bacterial proteins that destroy other bacteria.

Type of plasmids

Col plasmids contains genes for the synthesis of bacteriocins known as colicins.

3. Virulence plasmids: Encode factors that make their hosts more pathogenic. E.g. enterotoxigenic strains of E.coli cause traveler's diarrhea.

4. Metabolic plasmids: carry genes for the enzyme that degrade substances such as atomatic compounds (tolune), pesticides (2,4-dichlorophenoxyacetic acid) & sugars (Lactose).

Bacterial Cell Walls

- Layer outside the plasma membrane.
- **Functions:**
  - Determine shape of the cell
  - Protect cell from osmosis lysis.
  - Protect from toxic substance & pathogens.

Bacterial Cell Walls

Most have cell walls composed of **peptidoglycan**. Few lack a cell wall.

- Peptidoglycan outside p.membrane → protein + polysaccharide, also called **Murein**
- Peptidoglycan → Polymer of long chains of alternating sugars, **NAG and NAM** **&** A.A.
- NAG and NAM → held together by protein chains.

Bacterial Cell Walls

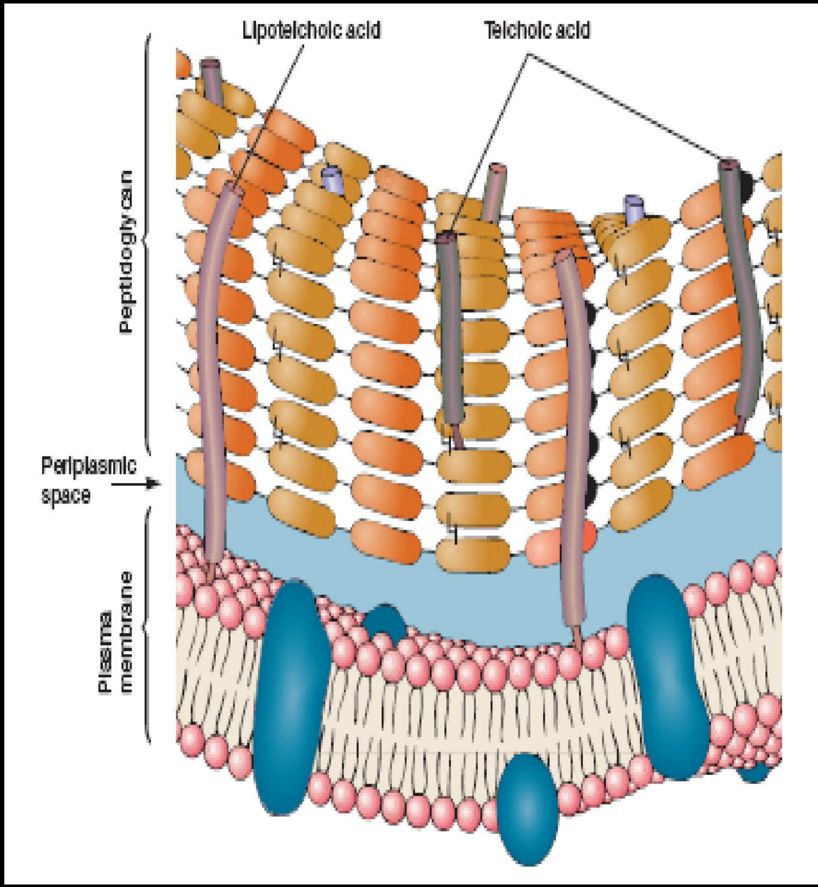
- Chains of NAG and NAM are attached to other chains by **tetrapeptide cross bridges**
- Tetrapeptide cross bridges → two amino acids are L-isomers and two are D-isomers
- Glycan and peptide linked to form a mesh-like structure

Bacterial Cell Walls

- Two basic types:
  - Gram Positive
  - Gram Negative

Gram Positive Cell Walls

- Relatively thick layer (20 to 80 nm) of peptidoglycan
- Contains unique polysaccharides called **techoic acid, lipotechioc acids.**
- Techoic Acid (-ve charge): polymer of Glycerol or Ribitol linked to a phosphate group.
- Lack discrete peplasmic space, have periplasm.
- Gram +ve : secrets exoenzyme



Gram Negative Cell Walls

- Have a only a thin layer of peptidoglycan bounded to either side of periplasmic space.
- Peptidoglycan mesh is only one to two layer thick (7 to 8 nm).
- Periplasmic space : greater in size.
- Outer membrane is linked to the cell by lipoprotein and adhession sites joining plasma membrane.
- Outer membrane contains Lipopolysaccharides consists of 3 parts
- 1. Lipid A 2. Core polysaccharide 3. O side chain

Gram Negative Cell Walls

Functions of LPS

- Bcz of the charged sugars and phosphate of core polysaccharide it contributes to –Ve charge of surface.
- Lipid A helps in stabilization of outer membrane structures.
- Helps in creating permeability barrier.
- Protect bacteria from host defense.
- Lipid A is toxic : LPS act as endotoxins.

Porin proteins allow the passage of molecules smaller than 600 to 700 Daltons.

Gram Negative Cell Walls

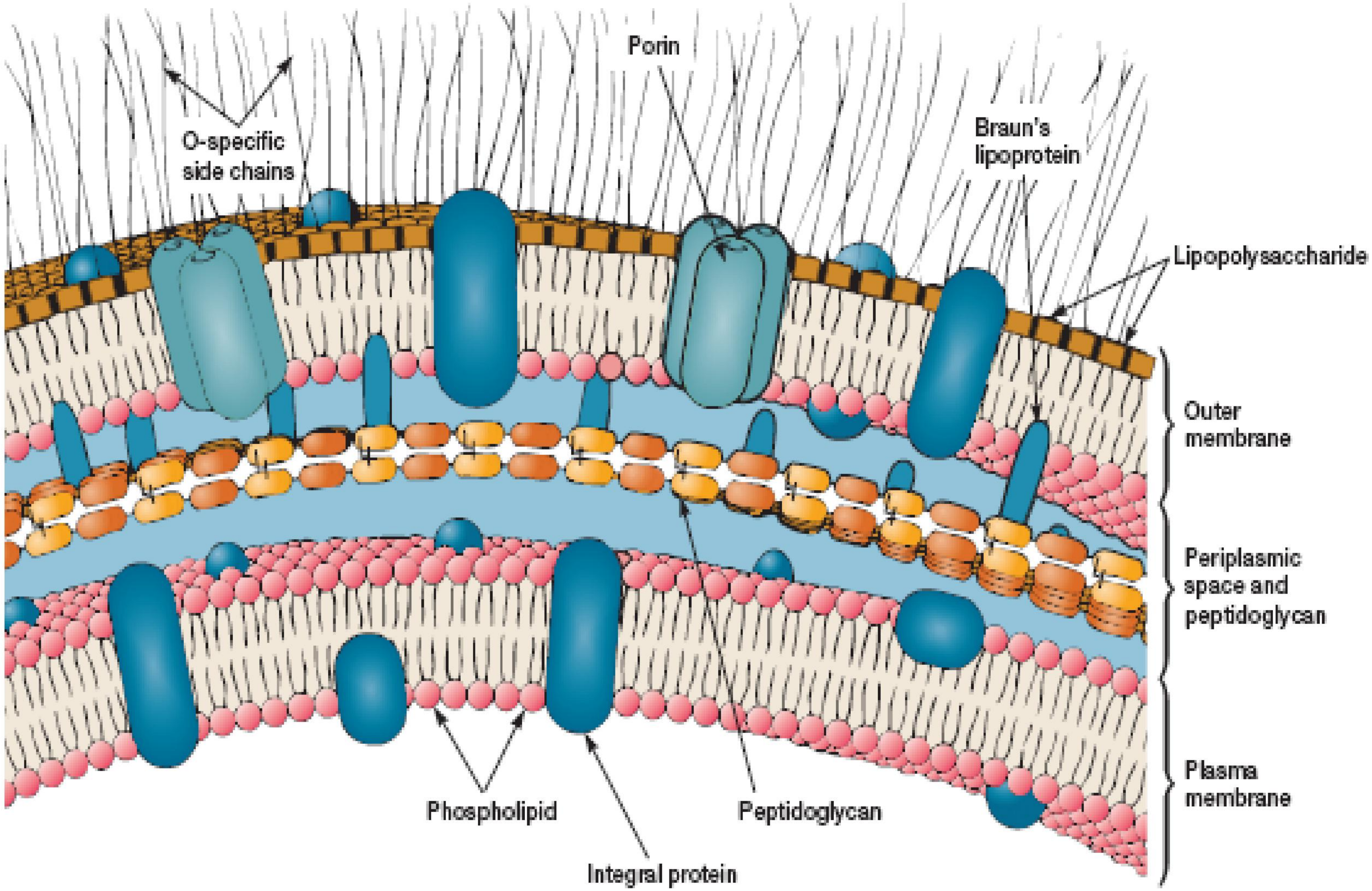


Figure 3.23 The Gram-Negative Envelope.

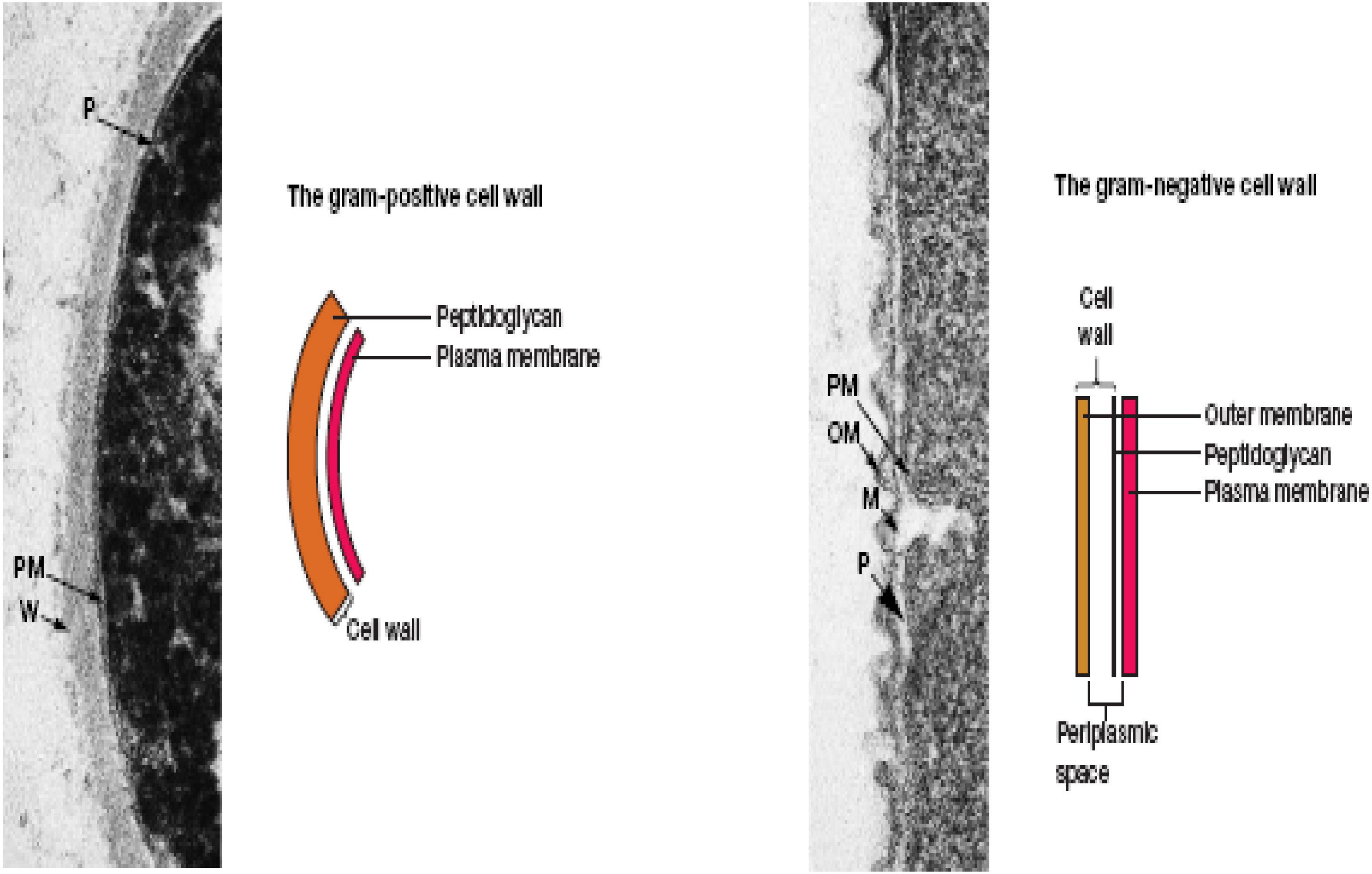


Figure 3.15 Gram-Positive and Gram-Negative Cell Walls. The gram-positive envelope is from *Bacillus licheniformis* (left), and the gram-negative micrograph is of *Aquaspirillum serpens* (right). M; peptidoglycan or murein layer; OM, outer membrane; PM, plasma membrane; P, periplasmic space; W, gram-positive peptidoglycan wall.

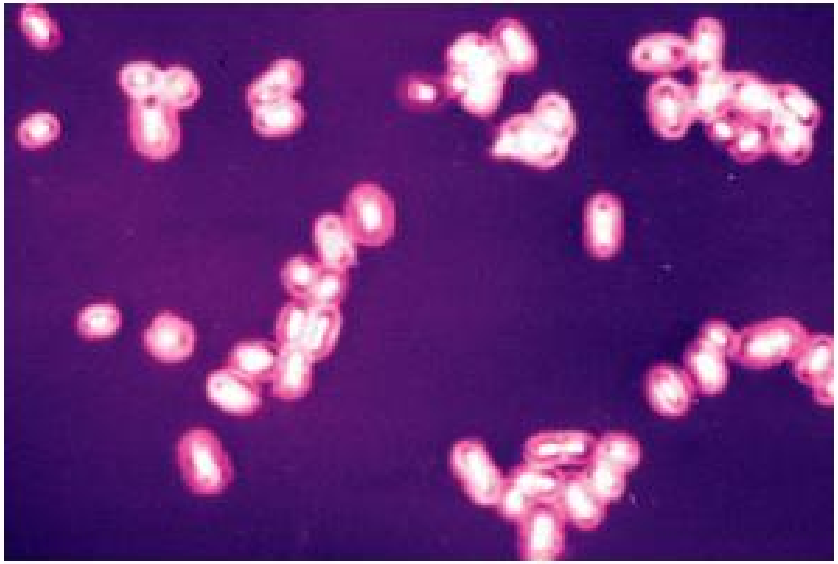
Archaeal Cell Walls

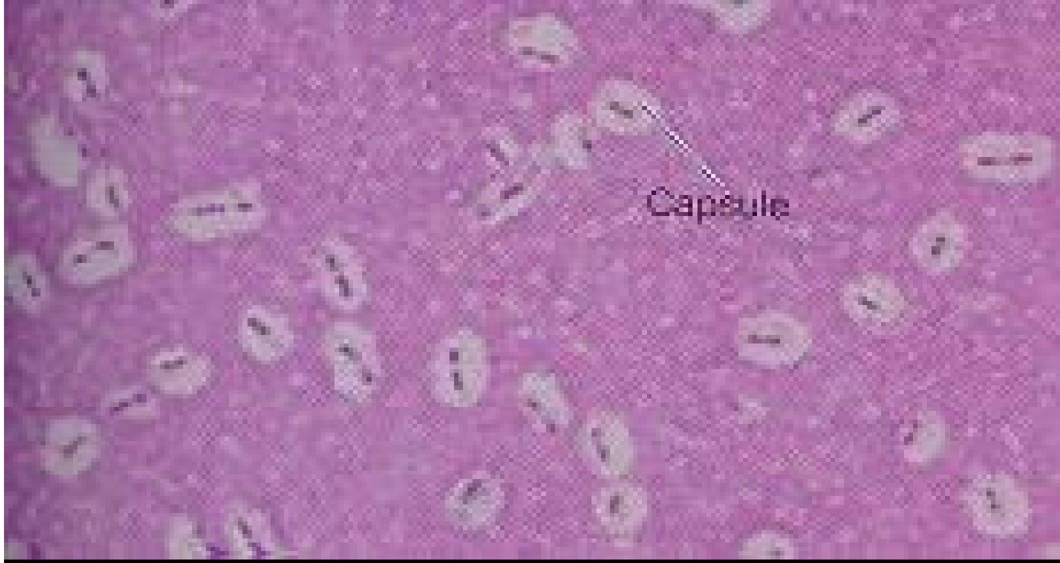
- Do not have peptidoglycan
- Cell Walls consists of complex heteropolysaccharides.
- E.g. Methanobacterium contains pseudomurein, a peptidoglycan that has L-Amino acids instead of D-Amino acids, N-acetyltalosaminuroic acids instead of NAM and B (1-3) glycosidic bonds instead of B (1-4) glycosidic bonds.
- Cytoplasmic membrane is also different

Components External to the Cell Wall

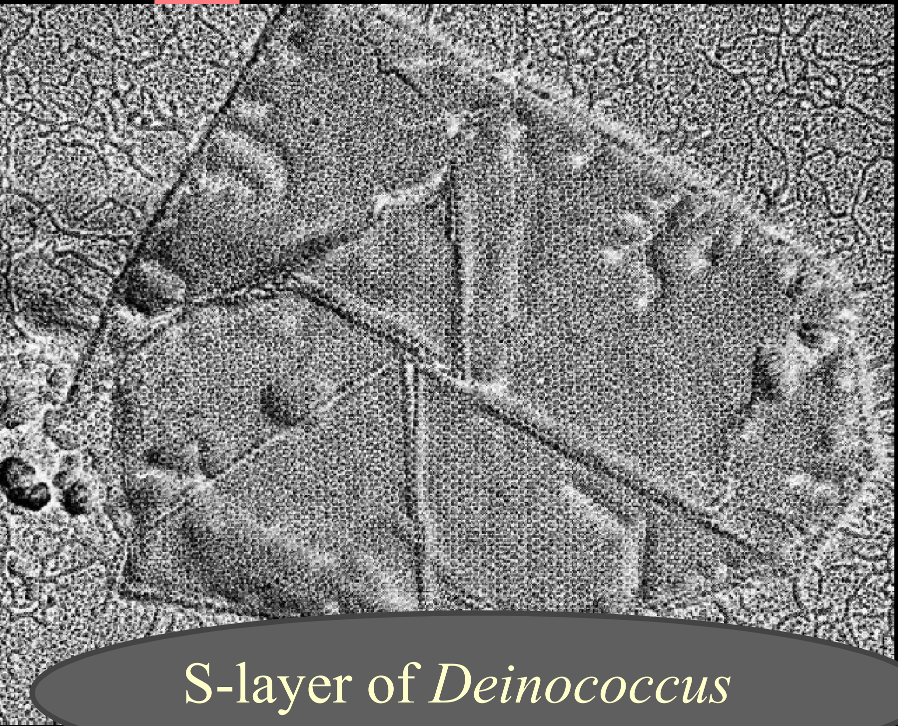
- Layer Of Material Outside Cell Wall
- 1. Capsule
  - if the layer is well organized and firmly attached to cell wall
- 2. Slime Layer
  - if the layer is unorganized and loosely attached to cell wall.
- 3. Glycocalyx

  if the layer consist of network of plysaccharide.
- Bacillus anthracis has a capsule of poly-D-glutamic acid.





Klebsiella pneumoniae



S-layer of *Deinococcus radiodurans*

Many gram-positive and gram-negative bacteria have a regularly structured layer called an **S-layer on their surface.**

pattern like floor tiles

composed of protein or glycoprotein.

In gram-negative bacteria

the S-layer adheres directly to the outer membrane.

it is associated with peptidoglycan surface in gram-positive bacteria.

Functions of Capsules

- 1. Contribute to Virulence of bacteria by preventing phagocytosis by WBC's

  A. *Streptococcus pneumoniae*

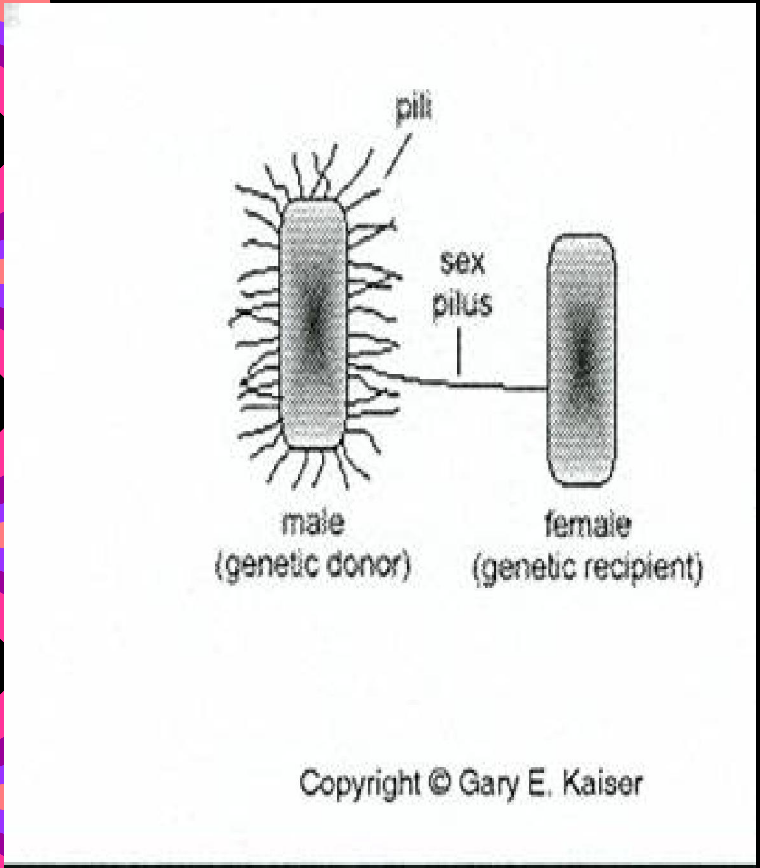
  B. *Bacillus anthracis*

- 2.Prevents drying out or dessication
- 3. Allows bacteria to adhere to various surfaces
  - *Streptococcus mutans* - enamel on teeth to cause dental carries
  - *Klebseilla pneumoniae* - attaches to respiratory tract

Pili

- Straight hair like projections made of protein pilins
- May be short or several cell lengths long. Main function is attachment→ each type of bacteria attach to sp. surfaces
- Present in virtually all Gm(-), absent in many Gm(+).

Sex Pili



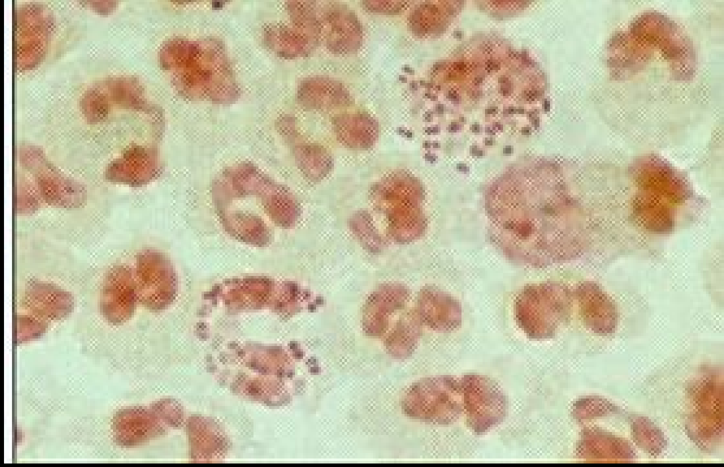
- 1-10 in number,
- Larger than fimbriae,
- Determined by conjugative plamids
- Required for conjugation
- Attaches one bacterial cell to another during mating

Fimbriae

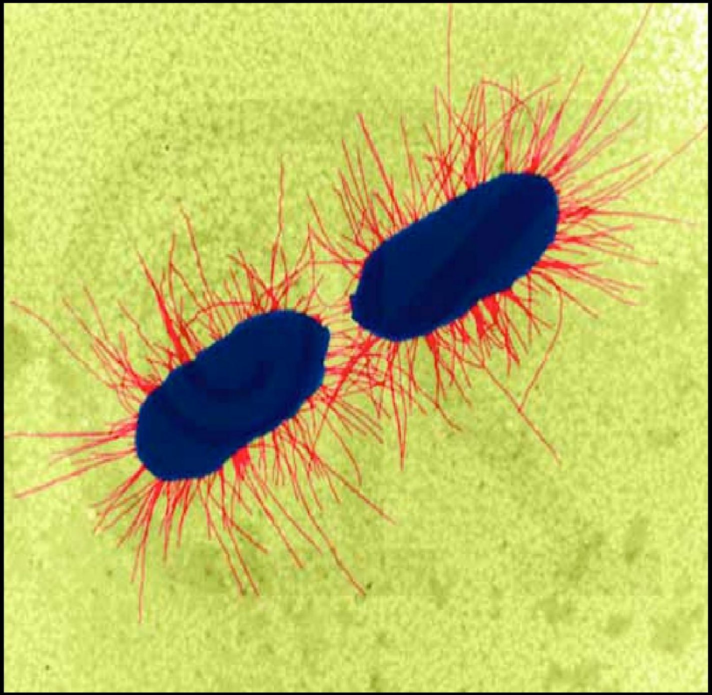
- Filamentous appendages that are shorter, finer, hairlike, thinner, straighter and more numerous than flagella

- Found mostly in Gram (-) Bacteria

- Used for attachment and also required for twitching motility of P.aeruginosa and E.coli, N.gonorrhoea.



Neisseria gonorrhoeae



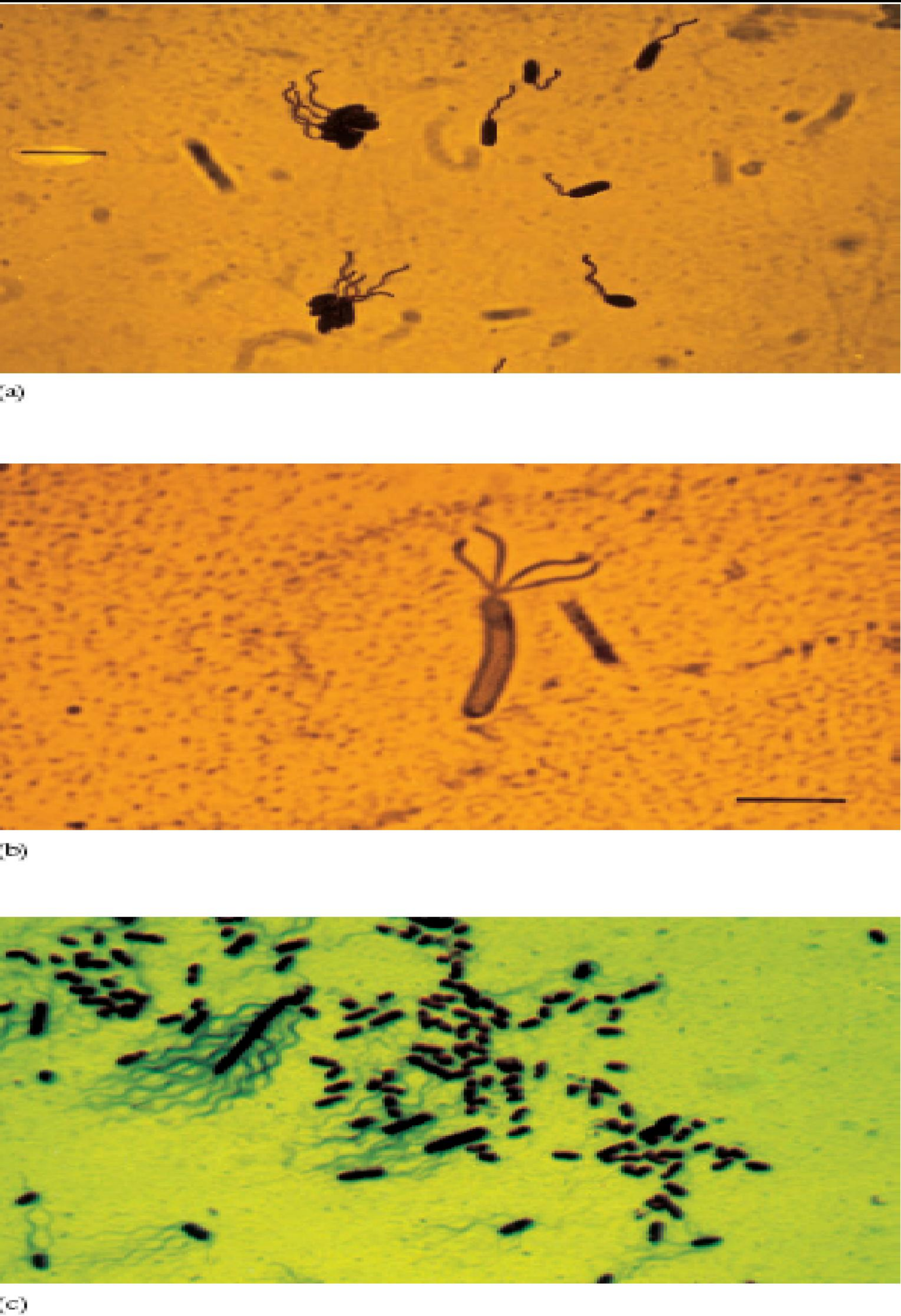
E. Coli (pathogenic)

Flagella

- Thread like structures that extend from the surface of the envelope
- Function→ Locomotion, allow bacteria to seek favorable conditions.

Flagella Arrangement

- Monotrichous: Single flagellum at one pole.
- Amphitrichous: Single flagellum at each pole.
- Lopotrichous: Two or more at one or both poles.
- Peritrichous: Flagella all over the surface.



Examples of various patterns of flagellation as seen in the light microscope.

(a) Monotrichous polar (*Pseudomonas*).

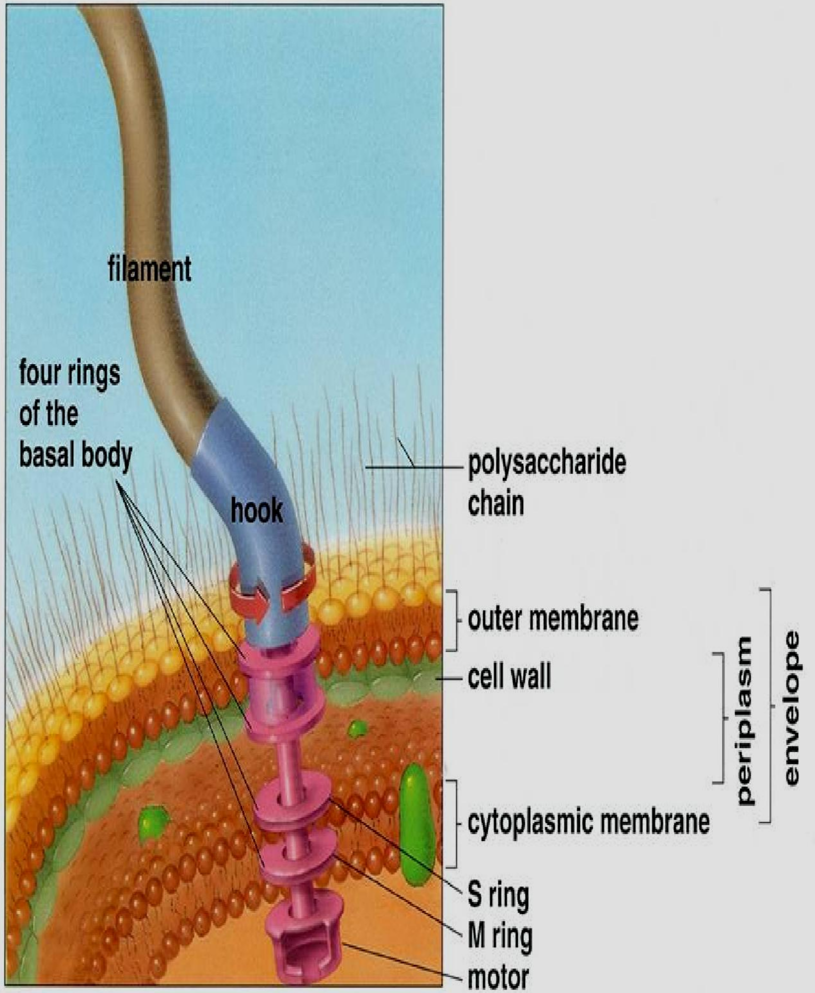
(b) Lophotrichous (Spirillum).

(c) Peritrichous

Flagella Structure

Three distinct parts

- Filament: longest portion, flagellin protein arranged in chains & forms a helix around a hollow core.
- Sheath surround bacteria.
- V.Cholera has LPS sheath
- Hook: short thickened bent region, act as a joint.

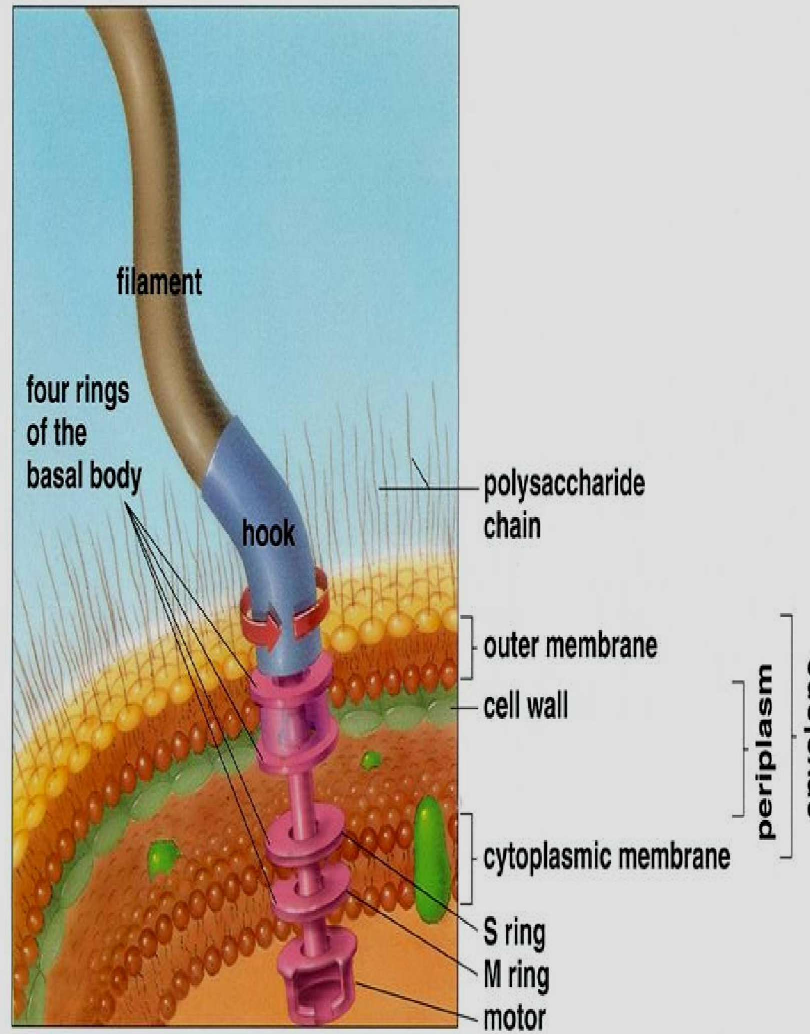


The flagellum of a Gram-negative bacterium

Flagella Structure

Three distinct parts:

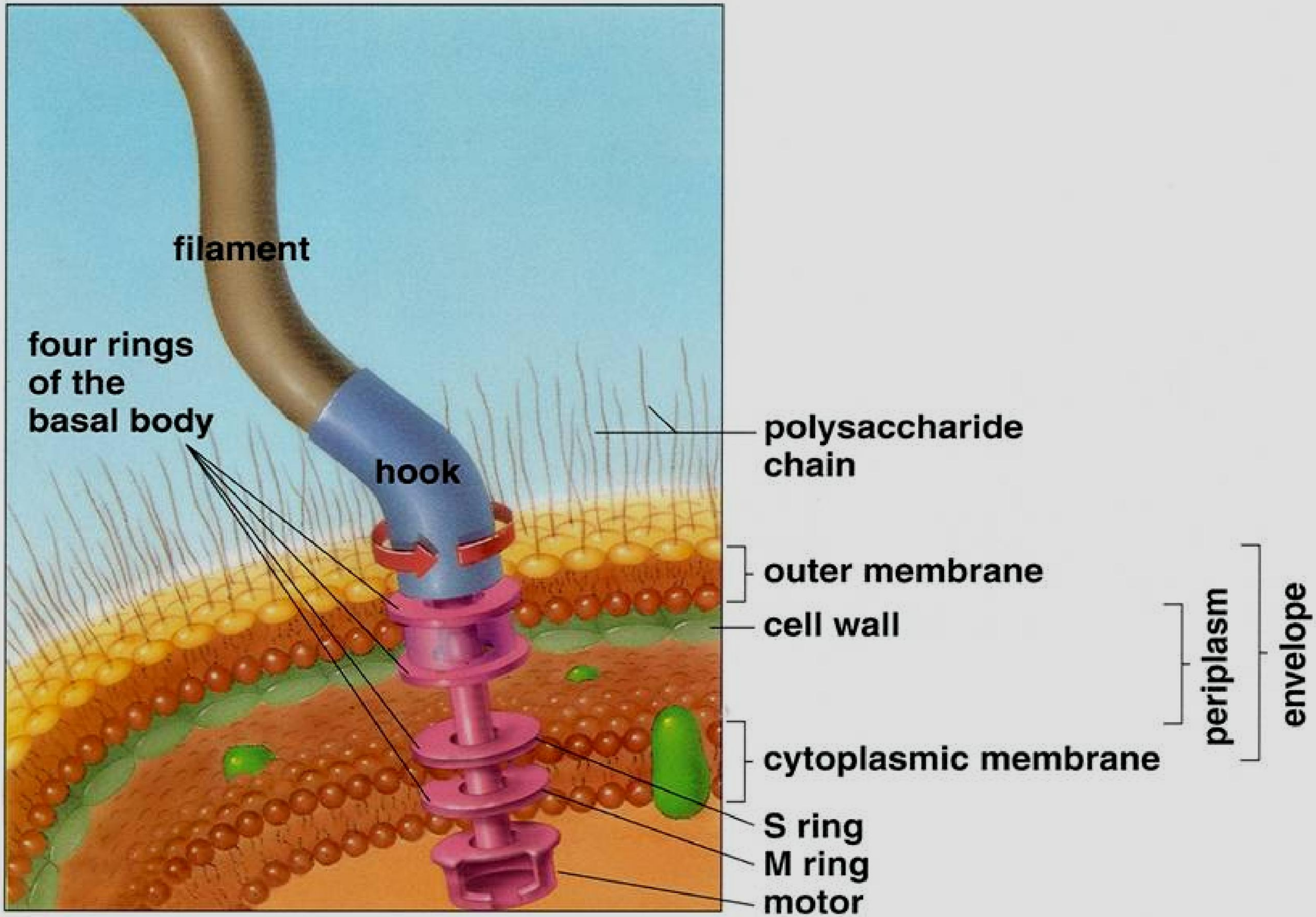
- Basal body→ complex part of flagellum.
- Gram –ve :contains four rings L,P,S,M.
- Gram +ve :contains two rings M,P.



The flagellum of a Gram-negative bacterium

Mechanism of flagellar movement

- The filament is in the shape of a rigid helix, and the bacterium moves when this helix rotates.
- Flagella act just like propellers on a boat.
- Bacterial mutants with straight flagella or abnormally long hook regions (polyhook mutants) cannot swim.
- When bacteria are tethered to a glass slide using antibodies to filament or hook proteins, the cell body rotates rapidly about the stationary flagellum.



The flagellum of a Gram-negative bacterium

Mechanism of flagellar movement

- If polystyrene-latex beads are attached to flagella, the beads spin about the flagellar axis due to flagellar rotation.
- Flagellar motor can rotate very rapidly *E. coli motor rotates 270 RPS; Vibrio alginolyticus* : 1,100 RPS.
- The direction of flagellar rotation determines the nature of bacterial movement.
- Monotrichous, polar flagella rotate counterclockwise during normal forward movement, whereas the cell itself rotates slowly clockwise.
- The rotating helical flagellar filament thrusts the cell forward in a run with the flagellum trailing behind.
- Bacteria stop and tumble randomly by reversing the direction of the flagellar movement.

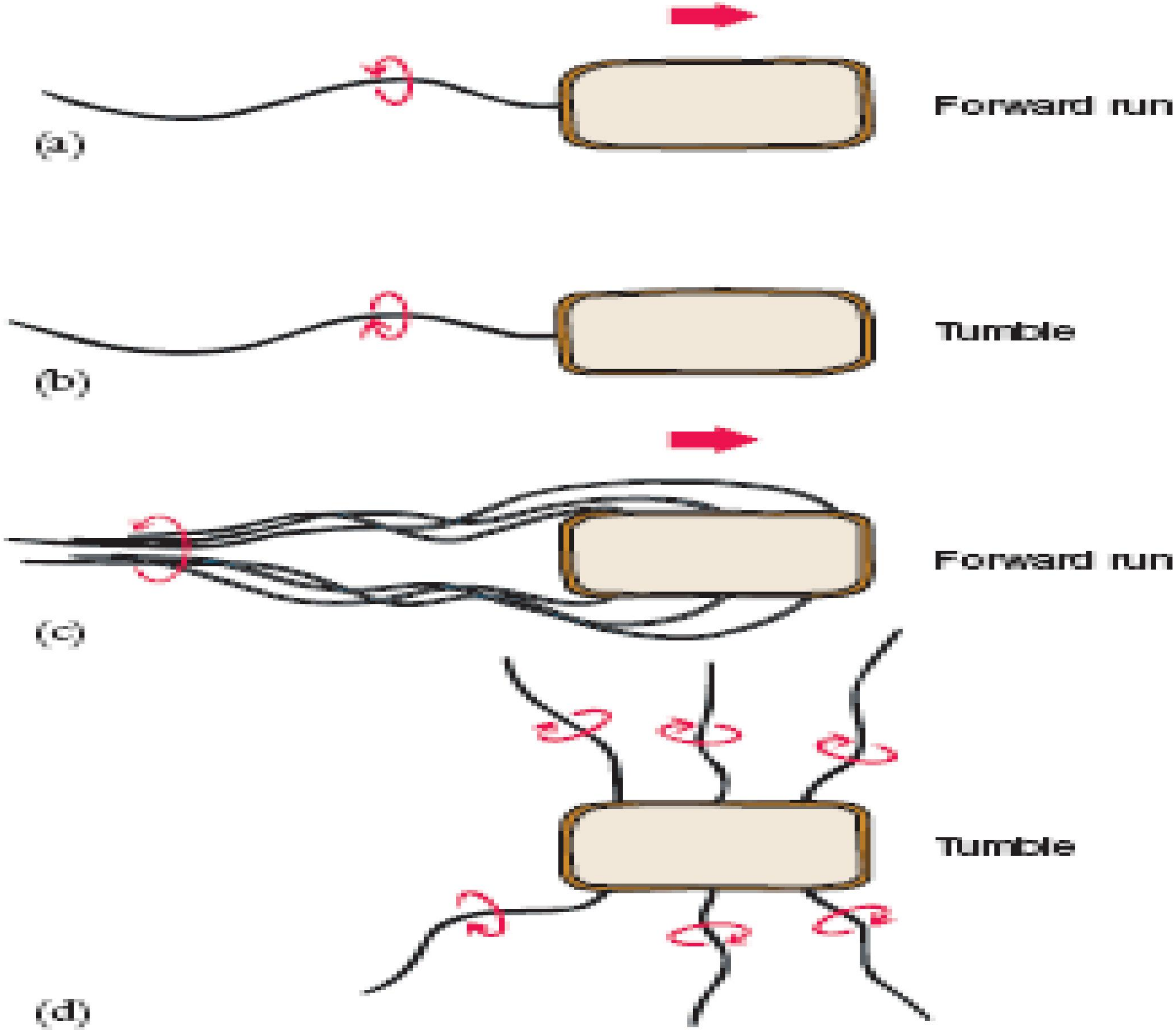


Figure 3.35 **Flagellar Motility.** The relationship of flagellar rotation to bacterial movement. Parts (a) and (b) describe the motion of monotrichous, polar bacteria. Parts (c) and (d) illustrate the movements of peritrichous organisms.

Motility

- Spirochetes: Spinning motility : by Axial filament.
- Spiroplasma : Swimming motility : by Kinks.
- Cynobacteria, Myxobacteria : gliding motility.
- Almost all **Spiral** bacteria are **motile**
- About 1/2 of **Bacilli** are **motile**
- Almost all **Cocci** are **non-motile**

Chemotaxis

- Bacteria do not always swim aimlessly but are attracted by such nutrients as sugars and amino acids, and are repelled by many harmful substances and bacterial waste products.
- Bacteria also can respond to other environmental cues such as temperature, light, oxygen, osmotic pressure and gravity.
- Chemotaxis → bacteria sense certain chemicals and move toward nutrients or away from toxins

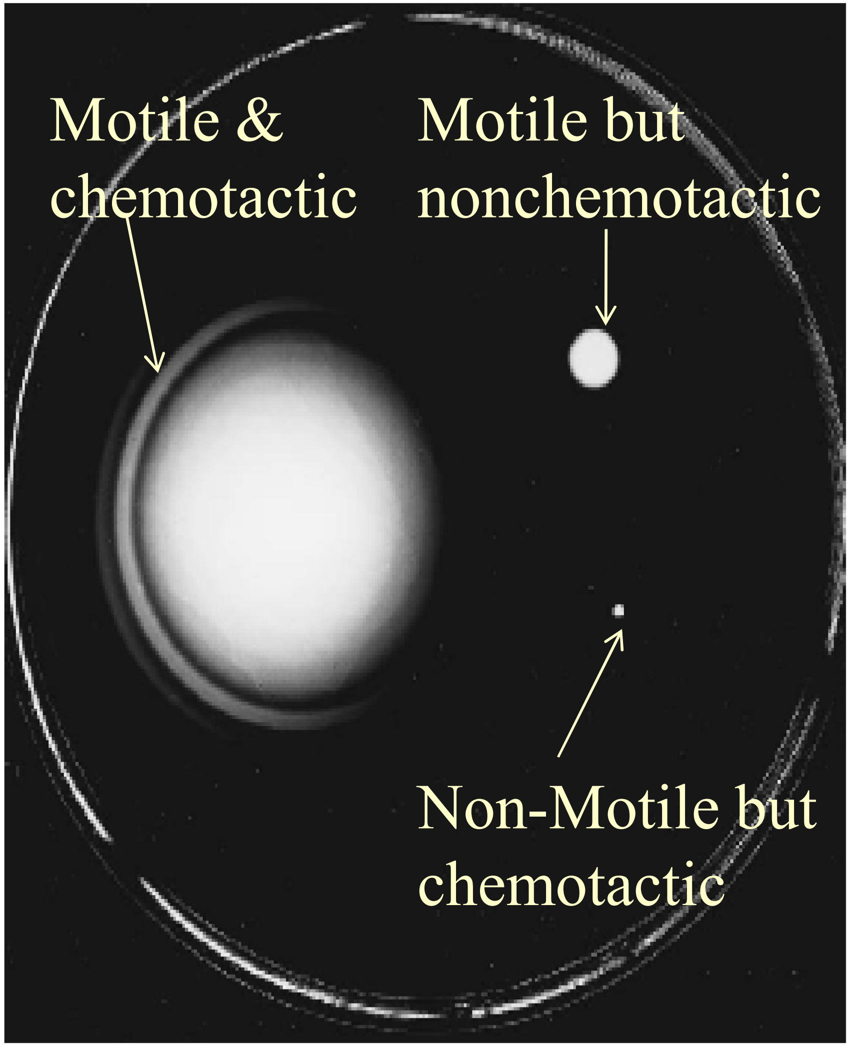


Figure 3.37 Positive Bacterial Chemotaxis. Chemotaxis can be demonstrated on an agar plate that contains various nutrients. Positive chemotaxis by *Escherichia coli* on the left. The outer ring is composed of bacteria consuming serine. The second ring was formed by *E. coli* consuming aspartate, a less powerful attractant. The upper right colony is composed of motile, but nonchemotactic mutants. The bottom right colony is formed by nonmotile bacteria.

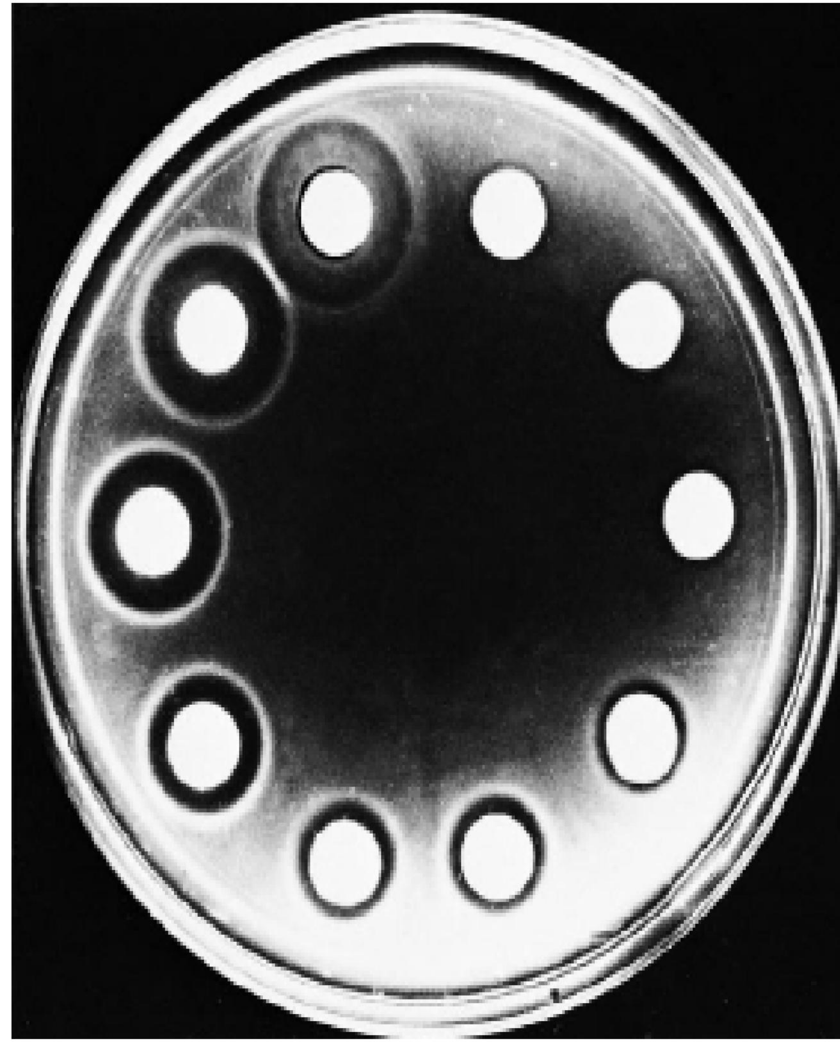
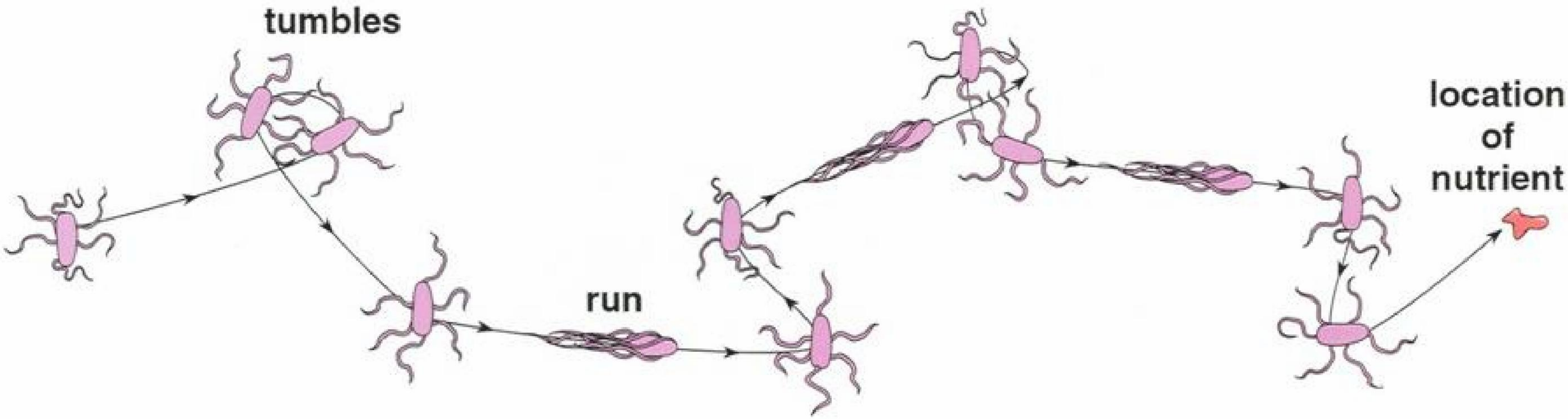


Figure 3.38 Negative Bacterial Chemotaxis. Negative chemotaxis by *E. coli* in response to the repellent acetate. The bright disks are plugs of concentrated agar containing acetate that have been placed in dilute agar inoculated with *E. coli*. Acetate concentration increases from zero at the top right to 3 M at top left. Note the increasing size of bacteria-free zones with increasing acetate. The bacteria have migrated for 30 minutes.

Chemotaxis

- Attractants and repellants are detected by chemoreceptors.
- Protein + chemical : signals
- These chemoreceptor proteins are located in the periplasmic space or the plasmamembrane.

Chemotaxis



Endospores – a special resistant dormant structure, formed under periods of environmental stress

- Only found in Gram (+) Bacteria
- *Bacillus*
  - *Bacillus cereus*
  - *Bacillus anthracis*
- *Clostridium*
  - *Clostridium tetani*
  - *Clostridium botulinum*
  - *Clostridium perfringens*

Endospores

- Extremely resistant to heat, cold, chemicals, lack of water, ultraviolet radiation, gamma radiation, chemical disinfectants.
- In fact, some endospores have remained viable for around 1,00,000 years, and actinomycete spores have been recovered alive after burial in the mud for 7,500 years.
- Most vegetative bacterial cells are killed at temps. above 70 C (160 F)
  - Endospores can survivein boiling water for several hours (some for as long as 20 hours)

- Spores are impermeable to most stains, so seen as colorless areas in bacteria treated with methylene blue and other simple stains.
- special spore stains are used .
- *Spore position* in the mother cell or sporangium frequently differs among species.

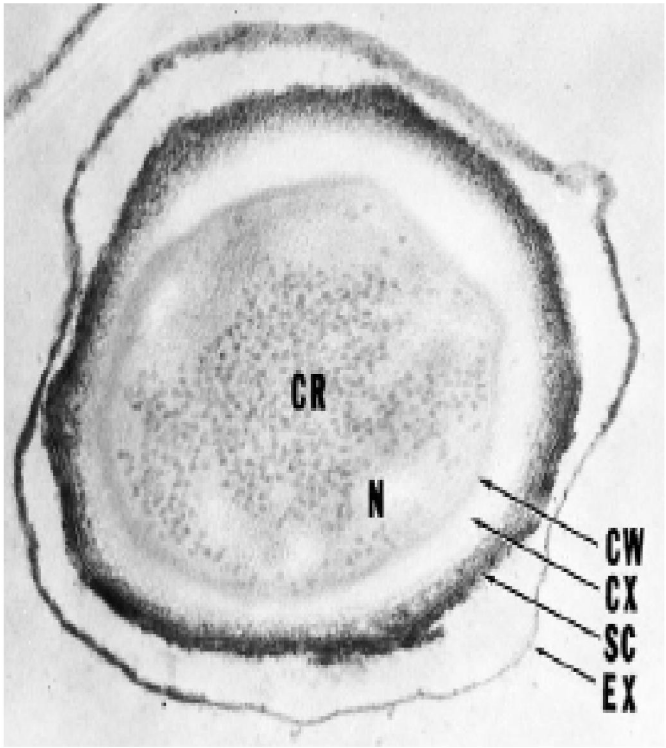


Figure 3.41 Endospore Structure. *Bacillus anthracis* endospore (×151,000). Note the following structures: exosporium, EX; spore coat, SC; cortex, CX; core wall, CW; and the protoplast or core with its nucleoid, N, and ribosomes, CR.

- Spores may be centrally located, close to one end (subterminal), or definitely terminal.
- surrounded by a thin, delicate covering called the **exosporium.**
- Spore Coat lies beneath the exosporium, is composed of several protein layers, and may be fairly thick, impermeable & responsible for the spore's resistance to chemicals.

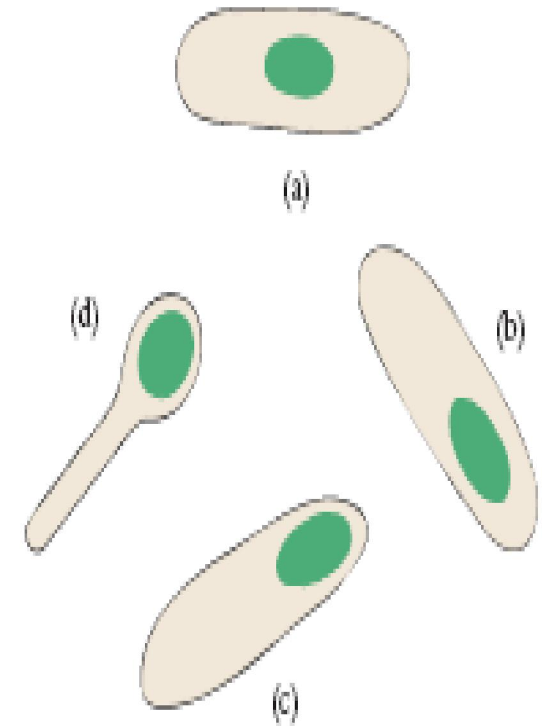


Figure 3.40 Examples of Endospore Location and Size. (a) Central spore. (b) Subterminal spore. (c) Terminal spore. (d) Terminal spore with swollen sporangium.

- The cortex rests beneath the spore coat, made of a peptidoglycan that is less cross-linked than that in vegetative cells.
- The spore cell wall is inside the cortex & surrounds the protoplast or core.
- The Spore core has the normal cell structures such as ribosomes and a nucleoid, but is metabolically inactive.

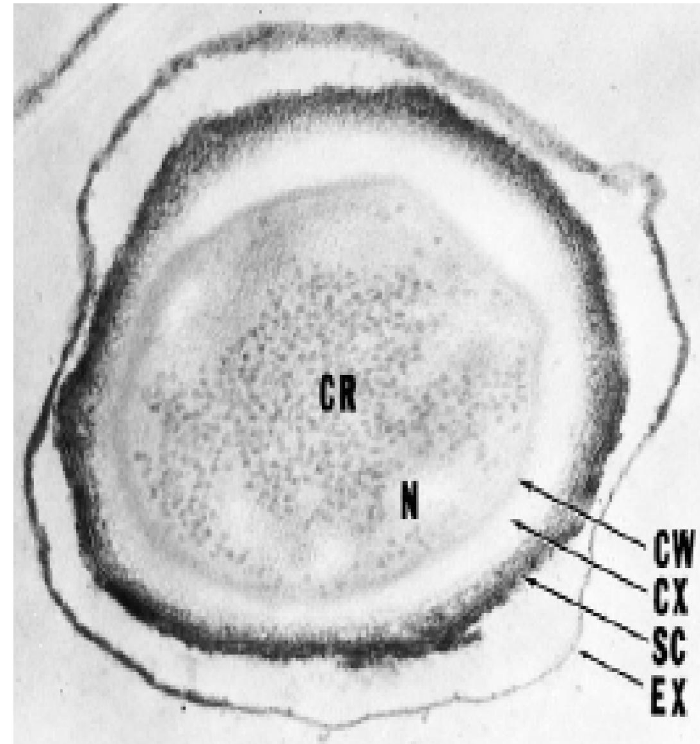


Figure 3.41 **Endospore Structure.** *Bacillus anthracis* endospore (×151,000). Note the following structures: exosporium, EX; spore coat, SC; cortex, CX; core wall, CW; and the protoplast or core with its nucleoid, N, and ribosomes, CR.

- Endospore heat resistance probably is due to several factors: calcium-dipicolinate and small acid-soluble protein stabilization of DNA, protoplast dehydration the spore coat, DNA repair enzyme, the greater stability of cell proteins in bacteria adapted to growth at high temperatures and others.

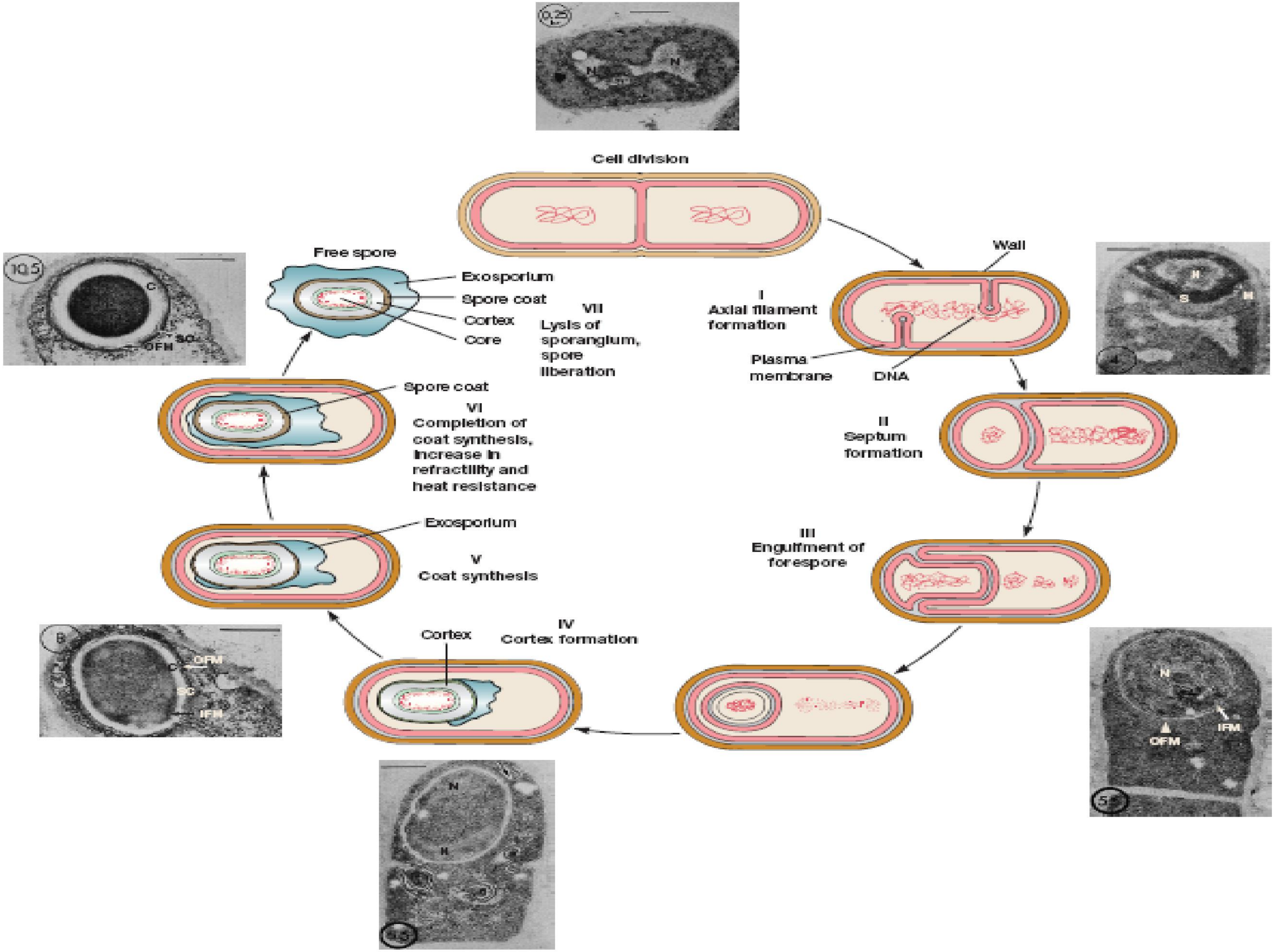


Figure 3.43 **Endospore Formation: Life cycle of *Bacillus megaterium*.** The stages are indicated by Roman numerals. The circled numbers in the photographs refer to the hours from the end of the logarithmic phase of growth: 0.25 h—a typical vegetative cell; 4 h—stage II cell, septation; 5.5 h—stage III cell, engulfment; 6.5 h—stage IV cell, cortex formation; 8 h—stage V cell, coat formation; 10.5 h—stage VI cell, mature spore in sporangium. Abbreviations used: C, cortex; IFM and OFM, inner and outer forespore membranes; M, mesosome; N, nucleoid; S, septum; SC, spore coats. Bars = 0.5 mm.

Germination of Spore

- 1. Activation: prepare spore for germination & results from treatment like heating.
- 2. Germination: breaking of the spore dormant state, by swelling, rupture or absorption of spore coat, loss of resistance to heat & other stresses and increase in metabolic activity.
- 3. Out growth : spore protoplast makes new components, emerges from the spore coat and develops again in to an active bacterium.

Prokaryotes vs. Eukaryotes

Table 4.2 Comparison of Procaryotic and Eucaryotic Cells

Property	Procaryotes	Eucaryotes
Organization of Genetic Material		
True membrane-bound nucleus	Absent	Present
DNA complexed with histones	No	Yes
Number of chromosomes	One[a]	More than one
Introns in genes	Rare	Common
Nucleolus	Absent	Present
Mitosis occurs	No	Yes
Genetic Recombination	Partial, unidirectional transfer of DNA	Meiosis and fusion of gametes
Mitochondria	Absent	Present
Chloroplasts	Absent	Present
Plasma Membrane with Sterols	Usually no[b]	Yes
Flagella	Submicrosopic in size; composed of one fiber	Microscopic in size; membrane bound; usually 20 microtubules in 9 + 2 pattern
Endoplasmic Reticulum	Absent	Present
Golgi Apparatus	Absent	Present
Cell Walls	Usually chemically complex with peptidoglycan[c]	Chemically simpler and lacking peptidoglycan
Differences in Simpler Organelles		
Ribosomes	70S	80S (except in mitochondria and chloroplasts)
Lysosomes and peroxisomes	Absent	Present
Microtubules	Absent or rare	Present
Cytoskeleton	May be absent	Present
Differentiation	Rudimentary	Tissues and organs

Prokaryotes vs. Eukaryotes

- Structural Difference
- Chemical Difference
- Size Difference

Structural Difference

- Prokaryotes
  - Have organelles but are not membrane bound
  - Have irregular area containing DNA
- Eukaryotes
  - Membrane bound organelles
  - Defined nucleus

Chemical Difference

- Prokaryotes
  - Cell Wall composed of peptidoglycan
- Eukaryotes
  - Do not contain peptidoglycan in the cell walls

Size Difference

- Prokaryotes
  - High surface area relative to volume- easier to take in nutrients and excrete wastes
  - multiply rapidly
- Eukaryotes
  - About 10x larger than prokaryotes

Thank you