An Overview of Procaryotic Cell Structure

- a wide variety of sizes, shapes, and cellular aggregation patterns
- simpler than eucaryotic cell structure
- unique structures not observed in eucaryotes

Size, Shape, and Arrangement

- 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
Size, Shape, and Arrangement

- bacilli (s., bacillus) – rods
  - coccobacilli – very short rods
  - vibrios – curved rods
- mycelium – network of long, multinucleate filaments

- spirilla (s., spirillum) – rigid helices
- spirochetes – flexible helices
- pleomorphic – organisms that are variable in shape

• largest – ≥50 μm in diameter
• smallest – 0.3 μm in diameter

Figure 3.3
Table 3.1 Functions of Prokaryotic Structures

<table>
<thead>
<tr>
<th>Structure</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma membrane</td>
<td>Selectively permeable barrier; mechanical</td>
</tr>
<tr>
<td></td>
<td>boundary of cell; nutrient and waste</td>
</tr>
<tr>
<td></td>
<td>transport; location of many metabolic</td>
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<tr>
<td></td>
<td>processes (respiration, photosynthesis),</td>
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<td></td>
<td>detection of environmental cues for</td>
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<tr>
<td></td>
<td>chemotherapy</td>
</tr>
<tr>
<td>Gas vacuole</td>
<td>Bacterio for floating in aquatic</td>
</tr>
<tr>
<td></td>
<td>environments</td>
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<tr>
<td>Ribosomes</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Inclusion bodies</td>
<td>Storage of carbon, phosphate, and other</td>
</tr>
<tr>
<td></td>
<td>nucleotides</td>
</tr>
<tr>
<td>Nucleoid</td>
<td>Localization of genetic material (DNA)</td>
</tr>
<tr>
<td>Peripheral space</td>
<td>Contains hydrolytic enzymes and binding</td>
</tr>
<tr>
<td></td>
<td>proteins for nutrient processing and uptake</td>
</tr>
<tr>
<td>Cell wall</td>
<td>Gives bacteria shape and protection from</td>
</tr>
<tr>
<td></td>
<td>hydrolytic solutions</td>
</tr>
<tr>
<td>Capsules and slime</td>
<td>Resistance to phageolysis, adherence to</td>
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<tr>
<td>layers</td>
<td>surfaces</td>
</tr>
<tr>
<td>Fimbriae and pili</td>
<td>Attachment to surfaces, bacterial motility</td>
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<tr>
<td>Flagella</td>
<td>Movement</td>
</tr>
<tr>
<td>Endospore</td>
<td>Survival under harsh environmental</td>
</tr>
<tr>
<td></td>
<td>conditions</td>
</tr>
</tbody>
</table>

Figure 3.4
Procaryotic Cell Membranes

- membranes are an absolute requirement for all living organisms
- plasma membrane encompasses the cytoplasm
- some procaryotes also have internal membrane systems

The Plasma Membrane

- contains lipids and proteins
  - lipids usually form a bilayer
  - proteins are embedded in or associated with lipids
- highly organized, asymmetric, flexible, and dynamic

The asymmetry of most membrane lipids

- polar ends
  - interact with water
  - hydrophilic
- nonpolar ends
  - insoluble in water
  - hydrophobic

Figure 3.5
Other membrane lipids

Figure 3.6

Membrane proteins

- peripheral proteins
  - loosely associated with the membrane and easily removed
- integral proteins
  - embedded within the membrane and not easily removed

Figure 3.7 Fluid mosaic model of membrane structure
Archaeal membranes

- composed of unique lipids
- some have a monolayer structure instead of a bilayer structure

Functions of the plasma membrane

- separation of cell from its environment
- selectively permeable barrier
  - some molecules are allowed to pass into or out of the cell
  - transport systems aid in movement of molecules

More functions...

- location of crucial metabolic processes
- detection of and response to chemicals in surroundings with the aid of special receptor molecules in the membrane
Internal Membrane Systems

- mesosomes
  - may be invaginations of the plasma membrane
- possible roles
  - cell wall formation during cell division
  - chromosome replication and distribution
  - secretory processes
- may be artifacts of chemical fixation process

Other internal membrane systems

- complex in-foldings of the plasma membrane
  - observed in many photosynthetic bacteria and in procaryotes with high respiratory activity
  - may be aggregates of spherical vesicles, flattened vesicles, or tubular membranes

The Cytoplasmic Matrix

- substance between membrane and nucleoid
- packed with ribosomes and inclusion bodies
- highly organized with respect to protein location
Inclusion Bodies

• 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

Organic inclusion bodies

• glycogen
  – polymer of glucose units
• poly-β-hydroxybutyrate (PHB)
  – polymers of β-hydroxybutyrate
Organic inclusion bodies

- cyanophycin granules
  - large polypeptides containing about equal quantities of arginine and aspartic acid
- carboxysomes
  - contain the enzyme ribulose-1,5-bisphosphate carboxylase

Organic inclusion bodies

- gas vacuoles
  - found in cyanobacteria and some other aquatic procaryotes
  - provide buoyancy
  - aggregates of hollow cylindrical structures called gas vesicles
Inorganic inclusion bodies

- polyphosphate granules
  - also called volutin granules and metachromatic granules
  - linear polymers of phosphates
- sulfur granules
- magnetosomes
  - contain iron in the form of magnetite
  - used to orient cells in magnetic fields
Ribosomes

- complex structures consisting of protein and RNA
- sites of protein synthesis
- smaller than eucaryotic ribosomes
  - procaryotic ribosomes ⇒ 70S
  - eucaryotic ribosomes ⇒ 80S
- $S = Svedburg$ unit
The Nucleoid

- irregularly shaped region
- location of chromosome – usually 1/cell
- not membrane-bound

In actively growing cells, the nucleoid has projections; these probably contain DNA being actively transcribed

Figure 3.14

The procaryotic chromosome

- a closed circular, double-stranded DNA molecule
- looped and coiled extensively
- nucleoid proteins probably aid in folding
  – nucleoid proteins differ from histones
Unusual nucleoids

- Some procaryotes have > 1 chromosome
- Some procaryotes have chromosomes composed of linear double-stranded DNA
- A few genera have membrane-delimited nucleoids

Plasmids

- Usually small, closed circular DNA molecules
- Exist and replicate independently of chromosome
- Not required for growth and reproduction
- May carry genes that confer selective advantage (e.g., drug resistance)

The Procaryotic Cell Wall

- Rigid structure that lies just outside the plasma membrane
**Functions of cell wall**

- provides characteristic shape to cell
- protects the cell from osmotic lysis
- may also contribute to pathogenicity
- may also protect cell from toxic substances

**Cell walls of Bacteria**

- Bacteria are divided into two major groups based on the response to Gram-stain procedure.
  - gram-positive bacteria stain purple
  - gram-negative bacteria stain pink
- staining reaction due to cell wall structure

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Figure 3.15
Periplasmic space

- gap between plasma membrane and cell wall (gram-positive bacteria) or between plasma membrane and outer membrane (gram-negative bacteria)
- periplasm
  - substance that occupies periplasmic space

Periplasmic enzymes

- found in periplasm of gram-negative bacteria
- some of their functions
  - nutrient acquisition
  - electron transport
  - peptidoglycan synthesis
  - modification of toxic compounds

Exoenzymes

- secreted by gram-positive bacteria
- perform many of the same functions that periplasmic enzymes do for gram-negative bacteria
Peptidoglycan Structure

- important component of both gram-positive and gram-negative bacteria
- polysaccharide formed from peptidoglycan subunits
- two alternating sugars form backbone
  - N-acetylglucosamine
  - N-acetylmuramic acid

*Figure 3.16*

Some amino acids are not observed in proteins

*Figure 3.18*
Gram-Positive Cell Walls

- composed primarily of peptidoglycan
- may also contain large amounts of teichoic acids
- some gram-positive bacteria have layer of proteins on surface of peptidoglycan
Gram-Negative Cell Walls

- consist of a thin layer of peptidoglycan surrounded by an outer membrane
- outer membrane composed of lipids, lipoproteins, and lipopolysaccharide (LPS)
- no teichoic acids
Important connections

- Braun’s lipoproteins connect outer membrane to peptidoglycan
- Adhesion sites
  - sites of direct contact (possibly true membrane fusions) between plasma membrane and outer membrane
  - substances may move directly into cell through adhesion sites

Lipopolysaccharides (LPSs)

- consist of three parts
  - lipid A
  - core polysaccharide
  - O side chain (O antigen)

Figure 3.25
Importance of LPS

• protection from host defenses (O antigen)
• contributes to negative charge on cell surface (core polysaccharide)
• helps stabilize outer membrane structure (lipid A)
• can act as an exotoxin (lipid A)

Other characteristics of outer membrane

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

The Mechanism of Gram Staining

• thought to involve constriction of the thick peptidoglycan layer of gram-positive cells
  – constriction prevents loss of crystal violet during decolorization step
• thinner peptidoglycan layer of gram-negative bacteria does not prevent loss of crystal violet
The Cell Wall and Osmotic Protection

- osmosis
  - movement of water across selectively permeable membrane from dilute solutions to more concentrated solutions
- cells are often in hypotonic solutions
  \[ \text{solute}_{\text{outside cell}} < \text{solute}_{\text{inside cell}} \]

The Cell Wall and Osmotic Protection

- osmotic lysis
  - can occur when cells are in hypotonic solutions
  - movement of water into cell causes swelling and lysis due to osmotic pressure
- cell wall protects against osmotic lysis

Cell walls do not protect against plasmolysis

- plasmolysis
  - occurs when cells are in hypertonic solutions
    \[ \text{solute}_{\text{outside cell}} > \text{solute}_{\text{inside cell}} \]
  - water moves out of cell causing cytoplasm to shrivel and pull away from cell wall
Practical importance of plasmolysis and osmotic lysis

• plasmolysis
  – useful in food preservation
  – e.g., dried foods and jellies
• osmotic lysis
  – basis of lysozyme and penicillin action

Figure 3.26

• protoplast – cell completely lacking cell wall
• spheroplast – cell with some cell wall remaining

Archaeal cell walls

• lack peptidoglycan
• can be composed of proteins, glycoproteins, or polysaccharides
Protein Secretion in Procaryotes

• numerous protein secretion pathways have been identified
• four major pathways are:
  – Sec-dependent pathway
  – type II pathway
  – type I (ABC) protein secretion pathway
  – type III protein secretion pathway

Sec-Dependent Pathway

• also called general secretion pathway
• translocates proteins from cytoplasm across or into plasma membrane
• secreted proteins synthesized as preproteins having amino-terminal signal peptide
  – signal peptide delays protein folding
  – chaperone proteins keep preproteins unfolded
• translocon transfers protein and removes signal peptide

Figure 3.27a
**Type II Protein Secretion Pathway**
- transports proteins from periplasmic across outer membrane
- observed in some gram-negative bacteria, including some pathogens
- complex systems consisting of up to 12-14 proteins
  - most are integral membrane proteins

**Type I Protein Secretion Pathway**
- also called ABC protein secretion pathway
- transports proteins from cytoplasm across both plasma membrane and outer membrane
- secreted proteins have C-terminal secretion signals
- proteins that comprise type I systems form channels through membranes
- translocation driven by both ATP hydrolysis and proton motive force

![Figure 3.27b](image.png)
Type III Protein Secretion Pathway

- secretes virulence factors of gram-negative bacteria from cytoplasm, across both plasma membrane and outer membrane, and into host cell
- some type III secretion machinery is needle-shaped
  - secreted proteins thought to move through a translocation channel

Components External to Cell Wall

Figure 3.27c
Capsules, Slime Layers, and S-Layers

- layers of material lying outside the cell wall
  - capsules
    - usually composed of polysaccharides
    - well organized and not easily removed from cell
  - slime layers
    - similar to capsules except diffuse, unorganized and easily removed

Capsules, Slime Layers, and S-Layers

- glycocalyx
  - network of polysaccharides extending from the surface of the cell
  - a capsule or slime layer composed of polysaccharides can also be referred to as a glycocalyx

Capsules, Slime Layers, and S-Layers

- S-layers
  - regularly structured layers of protein or glycoprotein
  - common among Archaea, where they may be the only structure outside the plasma membrane
Functions of capsules, slime layers, and S-layers

• protection from host defenses (e.g., phagocytosis)
• protection from harsh environmental conditions (e.g., desiccation)
• attachment to surfaces

More functions...

• protection from viral infection or predation by bacteria
• protection from chemicals in environment (e.g., detergents)
• motility of gliding bacteria
• protection against osmotic stress
Pili and Fimbriae
- fimbriae (s., fimbr) - short, thin, hairlike, proteinaceous appendages
  - up to 1,000/cell
  - mediate attachment to surfaces
  - some (type IV fimbriae) required for twitching motility or gliding motility that occurs in some bacteria
- sex pili (s., pilus)
  - similar to fimbriae except longer, thicker, and less numerous (1-10/cell)
  - required for mating

Flagella and Motility

Patterns of arrangement
- 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
Flagellar Ultrastructure

- 3 parts
  - filament
  - basal body
  - hook

The filament
- hollow, rigid cylinder
- composed of the protein flagellin
- some procaryotes have a sheath around filament
The hook and basal body

- **hook**
  - links filament to basal body
- **basal body**
  - series of rings that drive flagellar motor

Flagellar Synthesis

- an example of self-assembly
- complex process involving many genes and gene products
- new molecules of flagellin are transported through the hollow filament
- growth is from tip, not base
The Mechanism of Flagellar Movement

- flagellum rotates like a propeller
  - in general, counterclockwise rotation causes forward motion (run)
  - in general, clockwise rotation disrupts run causing a tumble (twiddle)

Figure 3.36

Figure 3.37
Other types of motility

- spirochetes
  - axial filaments cause flexing and spinning movement
- gliding motility
  - cells coast along solid surfaces
  - no visible motility structure has been identified

Chemotaxis

- movement towards a chemical attractant or away from a chemical repellant
- concentrations of chemoattractants and chemorepellants detected by chemoreceptors on surfaces of cells

Figure 3.38
Figure 3.39
Travel towards attractant

- caused by lowering the frequency of tumbles
- biased random walk

Travel away from repellant

- involves similar but opposite responses

Mechanism of chemotaxis

- complex but rapid
  - responses occur in less than 20 milliseconds
- involves conformational changes in proteins
- also involves methylation or phosphorylation of proteins
The Bacterial Endospore

- formed by some bacteria
- dormant
- resistant to numerous environmental conditions
  - heat
  - radiation
  - chemicals
  - desiccation

Figure 3.40

Figure 3.42
What makes an endospore so resistant?

- calcium (complexed with dipicolinic acid)
- acid-soluble, DNA-binding proteins
- dehydrated core
- spore coat
- DNA repair enzymes

Sporogenesis

- normally commences when growth ceases because of lack of nutrients
- complex multistage process
Transformation of endospore into vegetative cell

- complex, multistage process

Figure 3.45

Stages in transformation

- activation
  - prepares spores for germination
  - often results from treatments like heating
- germination
  - spore swelling
  - rupture of absorption of spore coat
  - loss of resistance
  - increased metabolic activity
- outgrowth
  - emergence of vegetative cell