RAMSADAY COLLEGE

Semester-2
Core Course

CC-2/GE2: BACTERIOLOGY AND VIROLOGY (THEORY)

MCB-G-CC-2-2-TH

Unit 1 Cell organization

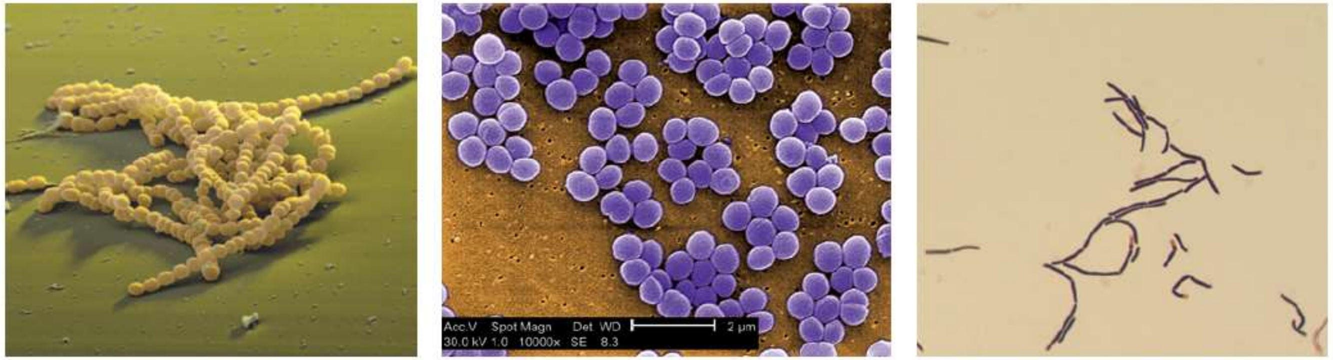
Bacteria and archaea have long been lumped together and referred to as prokaryotes. **Prokaryotes lack a membrane-bound nucleus, a cytoskeleton, membrane-bound organelles, and internal membranous structures such as the endoplasmic reticulum and Golgi apparatus.**

Bacteria Are Diverse but Share Some Common Features:

Shape, Arrangement, and Size

It might be expected that bacterial cells, being small and relatively simple, would be uniform in shape and size. The two most common shapes are cocci and rods (**figure 3.1**).

Cocci (s., **coccus**) **are roughly spherical cells**. They can **exist singly or can be associated in characteristic arrangements** that can be useful in their identification. **Diplococci** (s., **diplococcus**) arise when **cocci divide and remain together to form pairs**. **Long chains of cocci** result when **cells adhere after repeated divisions in one plane**; this pattern is seen in the genera ***Streptococcus, Enterococcus,* and *Lactococcus*** (figure 3.1*a*). Members of the **genus *Staphylococcus* divide in random planes to generate irregular, grapelike clusters** (figure 3.1*b*). **Divisions in two or three planes can produce symmetrical groupings of cocci**. Bacteria in the **genus *Micrococcus* often divide in two planes to form square groups of four cells called tetrads**. In the genus ***Sarcina*, cocci divide in three planes, producing cubical packets of eight cells.**



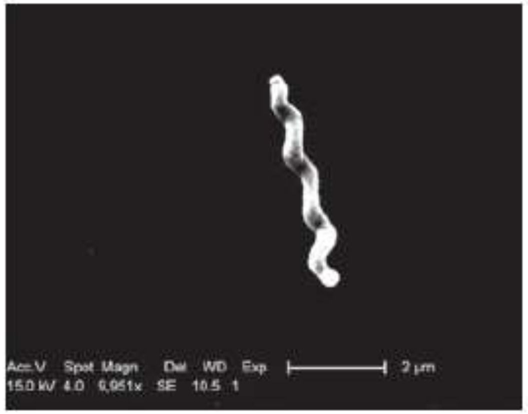
(a) *S. agalactiae*—cocci in chains (b) *S. aureus*—cocci in clusters (c) *B. megaterium*—rods in chains

Figure 3.1 Cocci and Rods Are the Most Common Bacterial Shapes. (a) *Streptococcus agalactiae*, the cause of Group B streptococcal infections; color-enhanced scanning electron micrograph (×4,800). (b) *Staphylococcus aureus*; color-enhanced scanning electron micrograph. (c) *Bacillus megaterium*, Gram stain (×1,000).

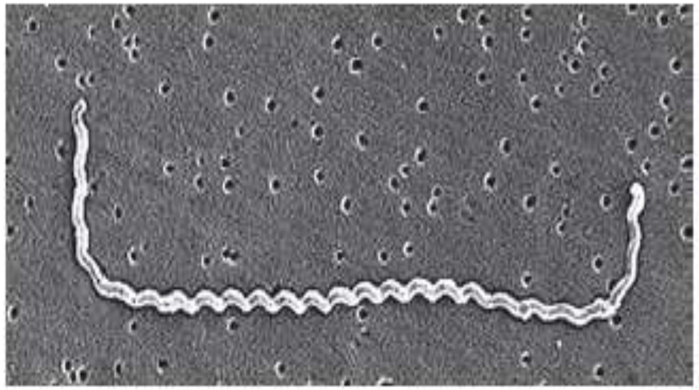
***Bacillus megaterium* is an example of a bacterium with a rod shape** (figure 3.1*c*). Rods, sometimes called **bacilli** (s., **bacillus**), differ considerably in their **length-to-width ratio**. The shape of the **rod's end often varies** between species and **may be flat, rounded, cigar-shaped, or bifurcated**. Although many **rods occur singly, some remain together after division to form pairs or chains (e.g., *Bacillus megaterium* is found in long chains).**

There are several less common cell shapes and arrangements:
Vibrios are **comma-shaped** (**figure 3.2*a***).
Spirilla are **rigid, spiral-shaped cells** (figure 3.2*b*). Many have tufts of flagella at one or both ends. **Spirochetes are flexible, spiral-shaped bacteria** that have a unique, internal flagellar arrangement (figure 3.2*c*). These bacteria are distinctive in other ways, and all belong to a single phylum, *Spirochaetes*.
Some **bacteria form stalks** (e.g., *Caulobacter crescentus*) (figure 3.2*d*).
Other bacteria are **pleomorphic, being variable in shape and lacking a single, characteristic form.**

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



(b) *C. jejuni*—Spiral shaped



(c) *Leptospira interrogans*—a spirochete

(d) *C. Crescentus*—a stalked bacterium

Some bacteria can be thought of as multicellular. **Many actinobacteria form long filaments called hyphae**. **The hyphae form a network called a mycelium** (figure 3.2*e*).

Many cyanobacteria, a group of photosynthetic bacteria, are also filamentous. Some filamentous cyanobacteria form **heterocysts** within the filament; these are specialized cells **that carry out nitrogen fixation.**

Myxobacteria have an unique structure. These bacteria sometimes aggregate to form complex structures called fruiting bodies (figure 3.2*f*).

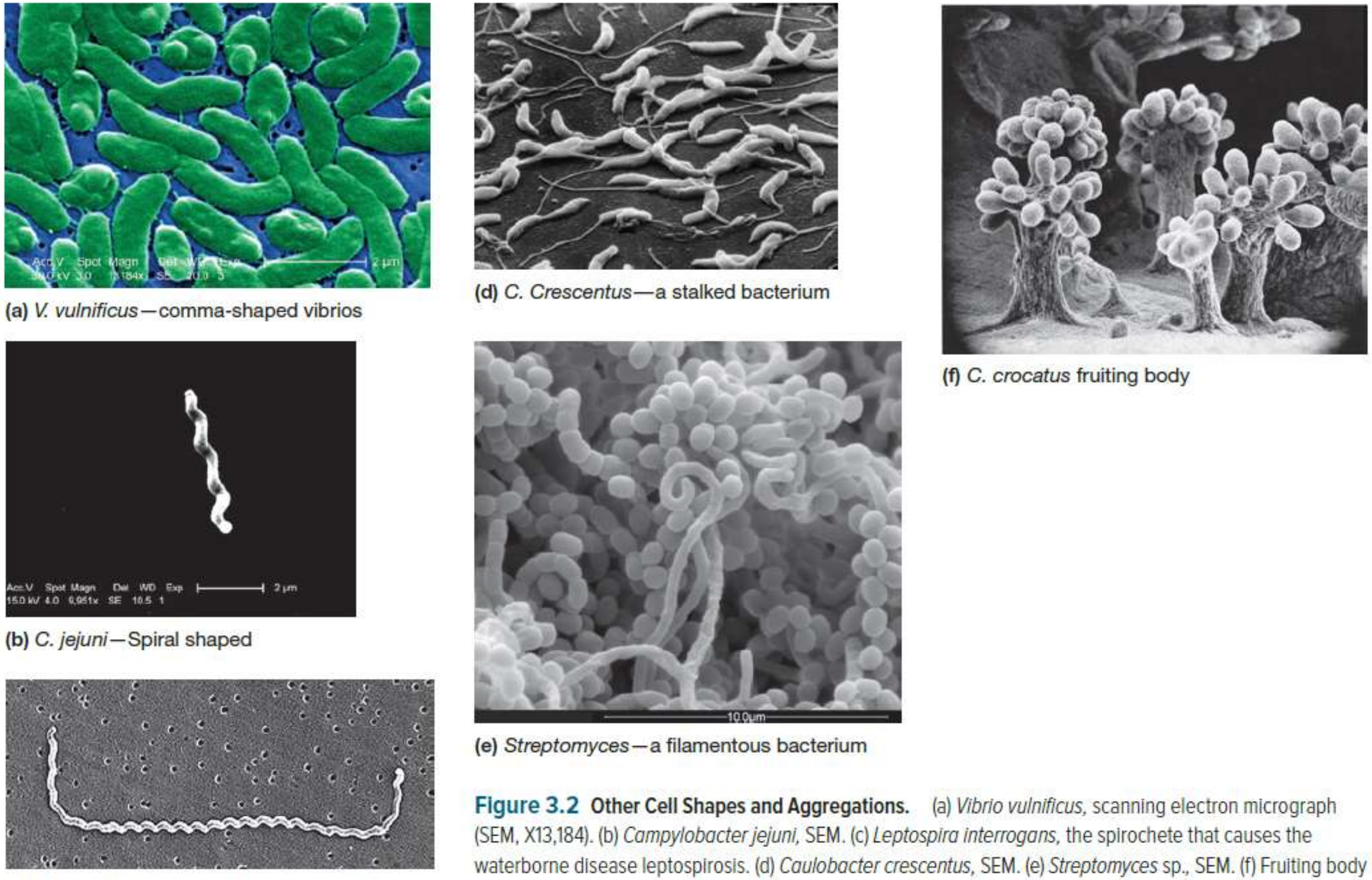

(a) *V. vulnificus*—comma-shaped vibrios
(b) *C. jejuni*—Spiral shaped
(c) *Leptospira interrogans*—a spirochete
(d) *C. Crescentus*—a stalked bacterium
(e) *Streptomyces*—a filamentous bacterium
(f) *C. crocatus* fruiting body

Figure 3.2 Other Cell Shapes and Aggregations. (a) *Vibrio vulnificus*, scanning electron micrograph (SEM, X13,184). (b) *Campylobacter jejuni*, SEM. (c) *Leptospira interrogans*, the spirochete that causes the waterborne disease leptospirosis. (d) *Caulobacter crescentus*, SEM. (e) *Streptomyces* sp., SEM. (f) Fruiting body of the myxobacterium *Chondromyces crocatus*. The fruiting body is composed of thousands of cells.

***Escherichia coli* is an excellent representative of the average size of bacteria. This rod-shaped bacterium is 1.1 to 1.5 µm wide by 2.0 to 6.0 µm long.**

However, the size range of bacterial cells extends far beyond this average (**figure 3.3**). Near the **small end of the size** continuum are members of the genus ***Mycoplasma* (0.3 µm in diameter).**

At the other end of the continuum are bacteria such as some **spirochetes, which can reach 500 µm in length**, and the **cyanobacterium *Oscillatoria*, which is about 7 µm in diameter (the same diameter as a red blood cell).**

An **even larger bacterium, *Thiomargarita namibiensis***, has been **discovered in ocean sediment.** Thus a few bacteria are much larger than the **average eukaryotic cell (typical plant and animal cells are around 10 to 50 µm in diameter).**

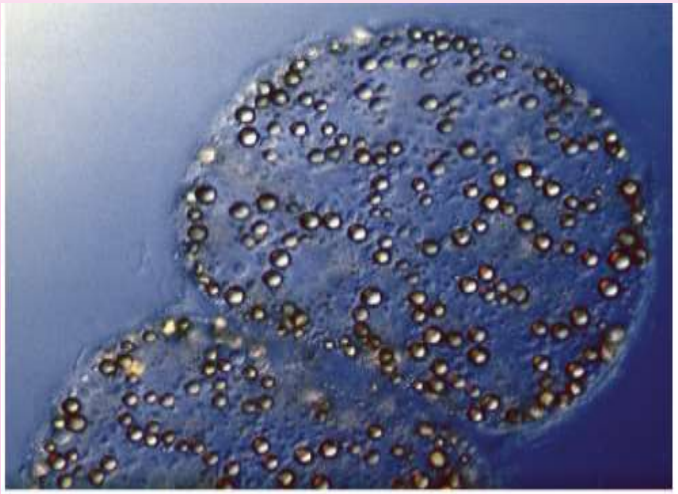


Figure 22.24 ***Thiomargarita namibiensis*, the World's Largest Known Bacterium.** This bacterium, usually 100–300 µm in diameter, occasionally reaches a size of 750 µm (larger than a period on this page), 100 times the size of a common bacterium. *T. namibiensis* uses sulfide from bottom sediments as an energy source and nitrate, which is found in the overlying waters, as an electron acceptor. Vacuoles that store high concentrations of nitrate appear beadlike in this image.

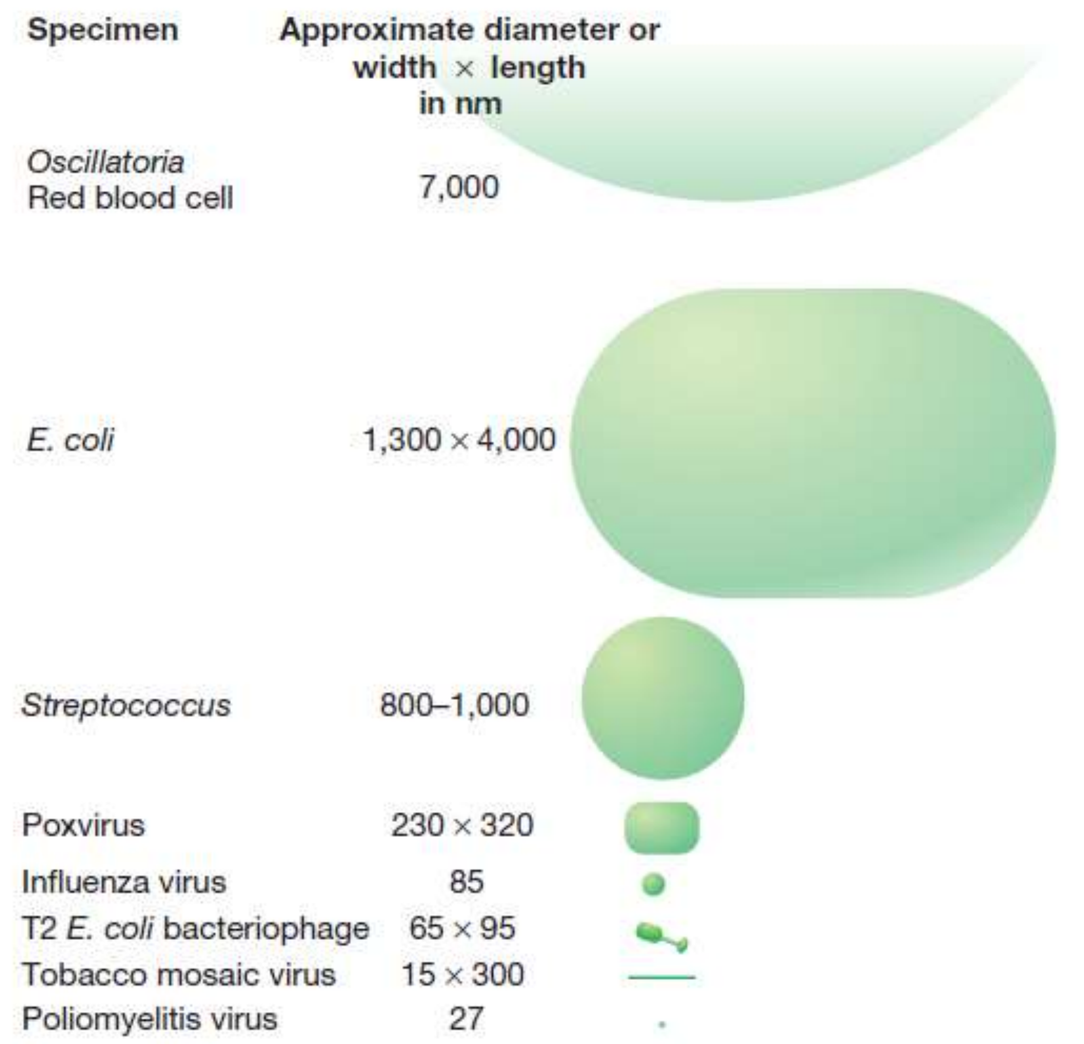


Figure 3.3 **Sizes of Bacteria Relative to a Red Blood Cell and Viruses.** Recall that 1,000 nm = 1 µm. Thus *E. coli* is 1.3 × 4 µm.

S/V Ratio Is An Important Determinant of Cell Size:

If surface area-to-volume ratio (S/V ratio; figure 3.5) increases, the uptake of nutrients and the diffusion of these and other molecules within the cell become more efficient, which in turn facilitates a rapid growth rate.

Shape affects the S/V ratio. **A rod with the same volume as a coccus has a higher S/V ratio than does the coccus**.

This means that a rod can have greater nutrient flux across its plasma membrane.

In addition, **large cells are less likely to be eaten by predatory protists. Cells that are filamentous, have stalks, or are oddly shaped are also less susceptible to predation**.

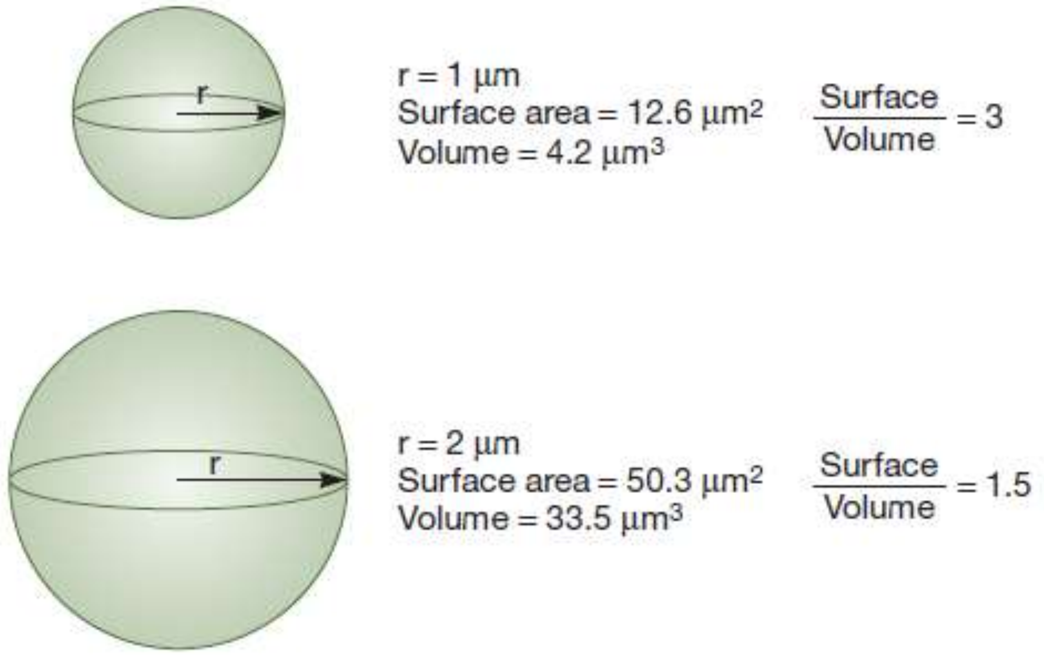


Figure 3.5 The Surface-to-Volume Ratio Is an Important Determinant of Cell Size. Surface area is calculated by the formula $4\pi r^2$. Volume is calculated by the formula $4/3\pi r^3$. Shape also affects the S/V ratio; rods with the same diameter as a coccus have a greater S/V ratio.

- Bacterial cells are often surrounded by several layers, which are collectively called the cell envelope.
- The most common cell envelope layers are the plasma membrane, cell wall, and capsule or slime layer.
- The innermost layer of the cell envelope is the plasma membrane, which surrounds the cytoplasm. Most bacteria have a chemically complex cell wall, which covers the plasma membrane.
- Many bacteria are surrounded by a capsule or slime layer external to the cell wall.
- Because most bacteria do not contain internal, membrane-bound organelles, their interior appears morphologically simple.
- The genetic material is localized in a discrete region called the nucleoid and usually is not separated from the surrounding cytoplasm by membranes. Ribosomes and larger masses called inclusions are scattered about the cytoplasm.
- Finally, many bacteria use flagella for locomotion.

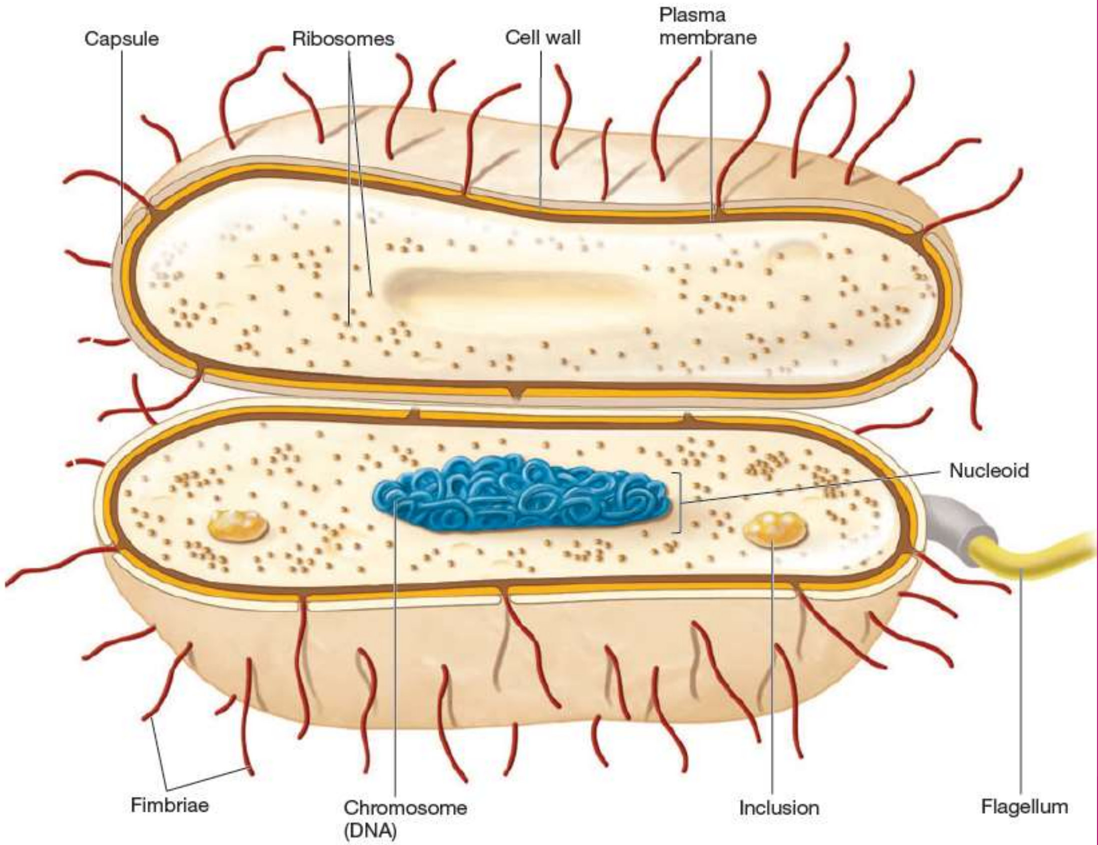


Figure 3.6 Structure of a Bacterial Cell.

Structures often observed in bacterial cells are summarized and illustrated in **table 3.1** and **figure 3.6**.

Note that no single bacterium possesses all of these structures at all times. Some are found only in certain cells in certain conditions or in certain phases of the life cycle. However, there are several common features of bacterial cell structure.

Table 3.1	Common Bacterial Structures and Their Functions
Plasma membrane	Selectively permeable barrier, mechanical boundary of cell, nutrient and waste transport, location of many metabolic processes (respiration, photosynthesis), detection of environmental cues for chemotaxis
Gas vacuole	An inclusion that provides buoyancy for floating in aquatic environments
Ribosomes	Protein synthesis
Inclusions	Storage of carbon, phosphate, and other substances; site of chemical reactions (microcompartments); movement
Nucleoid	Localization of genetic material (DNA)
Periplasmic space	In typical Gram-negative bacteria, contains hydrolytic enzymes and binding proteins for nutrient processing and uptake; in typical Gram-positive bacteria, may be smaller or absent
Cell wall	Protection from osmotic stress, helps maintain cell shape
Capsules and slime layers	Resistance to phagocytosis, adherence to surfaces
Fimbriae and pili	Attachment to surfaces, bacterial conjugation and transformation, twitching
Flagella	Swimming and swarming motility
Endospore	Survival under harsh environmental conditions

Bacterial Plasma Membranes Control What Enters and Leaves the Cell

❖The **cell envelope is defined as the plasma membrane and all the surrounding layers external to it**. The cell **envelopes of many bacteria consist of the plasma membrane, cell wall, and at least one additional layer (e.g., capsule or slime layer**).

❖Of all these layers, the **plasma membrane is the most important because it encompasses the cytoplasm and defines the cell. If it is removed, the cell's contents spill into the environment and the cell no longer exists.**

❖The plasma membrane is responsible for much of the cell's relationship with the outside world. **Cells must interact in a selective fashion with their environment, acquire nutrients, and eliminate waste.**

❖A primary role of all **plasma membranes is that they are selectively permeable barriers: they allow particular ions and molecules to pass either into or out of the cell, while preventing the movement of others. Thus the plasma membrane prevents the loss of essential components through leakage while allowing the movement of other molecules**.

❖Bacterial plasma membranes play additional critical roles. **They are the location of several crucial metabolic processes: respiration, photosynthesis, and the synthesis of lipids and cell wall constituents**.

<u>Fluid Mosaic Model of Membrane Structure</u>

The most widely accepted model for membrane structure is the **<u>fluid mosaic model of Singer and Nicholson, which proposes that membranes are lipid bilayers within which proteins float</u> (figure 3.7).**

<u>The model is based on studies of eukaryotic and bacterial membranes</u>, and was established using a variety of experimental approaches, **<u>including transmission electron microscopy (TEM) and atomic force microscopy.</u>**

<u>Cell membranes are very thin structures, about 5 to 10 nm thick</u>, that look like two dark lines on either side of a light interior when imaged by TEM.

This characteristic appearance is evidence that the **<u>membrane is composed of two sheets of molecules arranged end-to-end</u>** (figure 3.7).

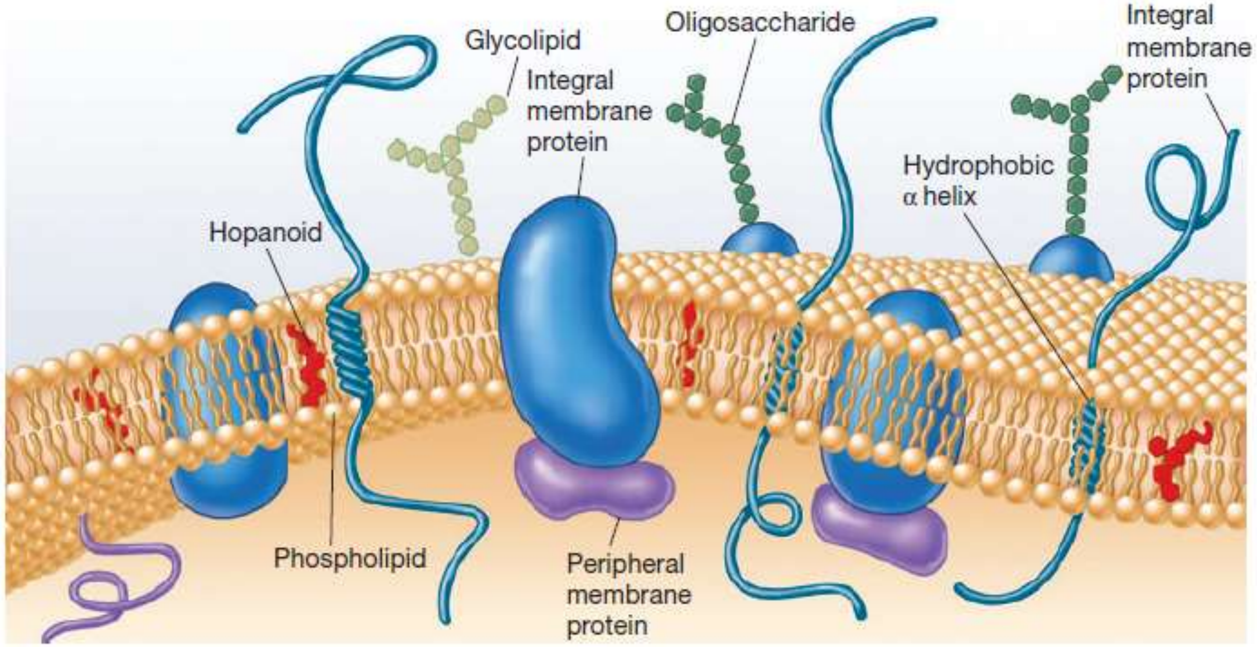


Figure 3.7 The Fluid Mosaic Model of Bacterial Membrane Structure. This diagram shows the integral membrane proteins (blue) floating in a lipid bilayer. Peripheral membrane proteins (purple) are associated loosely with the inner membrane surface. Small spheres represent the hydrophilic ends of membrane phospholipids, and wiggly tails are the hydrophobic fatty acid chains. Other membrane lipids such as hopanoids (red) may be present. Phospholipids are drawn much larger than their actual size.

❖The chemical nature of **membrane lipids is critical to their ability to form bilayers.**

❖Most membrane-associated lipids (e.g., the phospholipids (shown in figure 3.7) are **amphipathic: they are structurally asymmetric, with polar and nonpolar ends (figure 3.8).**

❖**The polar ends interact with water and are hydrophilic; the nonpolar hydrophobic ends are insoluble in water and tend to associate with one another**.

❖In aqueous environments, **amphipathic lipids can interact to form a bilayer.**

❖**The outer surfaces of the bilayer are hydrophilic, whereas hydrophobic ends are buried in the interior away from the surrounding water**.

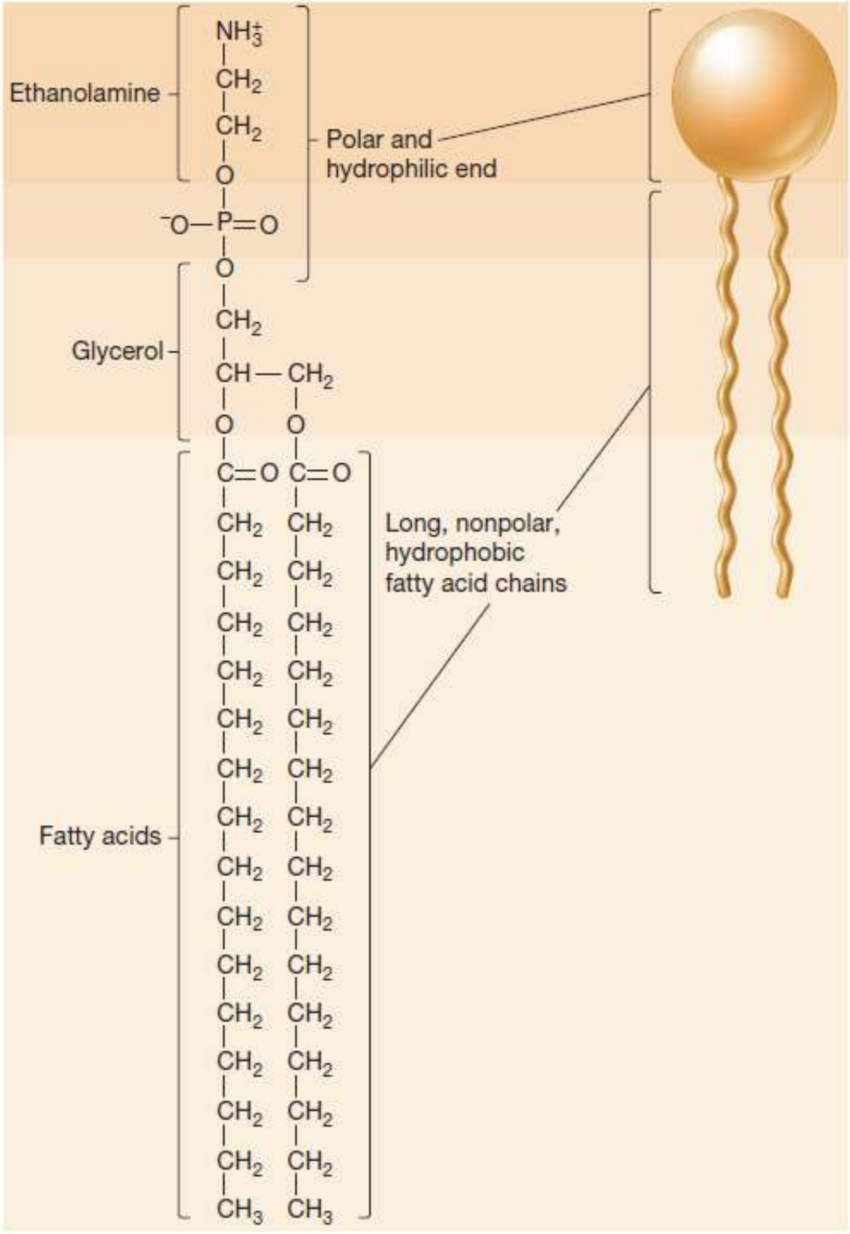


Figure 3.8 The Structure of a Phospholipid. Phosphatidylethanolamine, a phospholipid often found in bacterial membranes.

Two types of membrane proteins have been identified based on their ability to be separated from the membrane.

1) **<u>Peripheral membrane proteins are loosely connected to the membrane and can be easily removed</u>** (figure 3.7). **<u>They are soluble in aqueous solutions and make up about 20 to 30% of total membrane protein.</u>**
2) **<u>Integral membrane proteins are not easily extracted from membranes and are insoluble in aqueous solutions when freed of lipids. Integral membrane proteins, like membrane lipids, are amphipathic; their hydrophobic regions are buried in the lipid while the hydrophilic portions project from the membrane surface.</u>**

Integral membrane proteins carry out some of the most important functions of the membrane. Many are <u>transport proteins used to move materials either into or out of the cell.</u> Others <u>are involved in energy-conserving processes, such as the proteins found in electron transport chains.</u> Those <u>integral membrane proteins with regions exposed to the outside of the cell enable the cell to interact with its environment</u>.

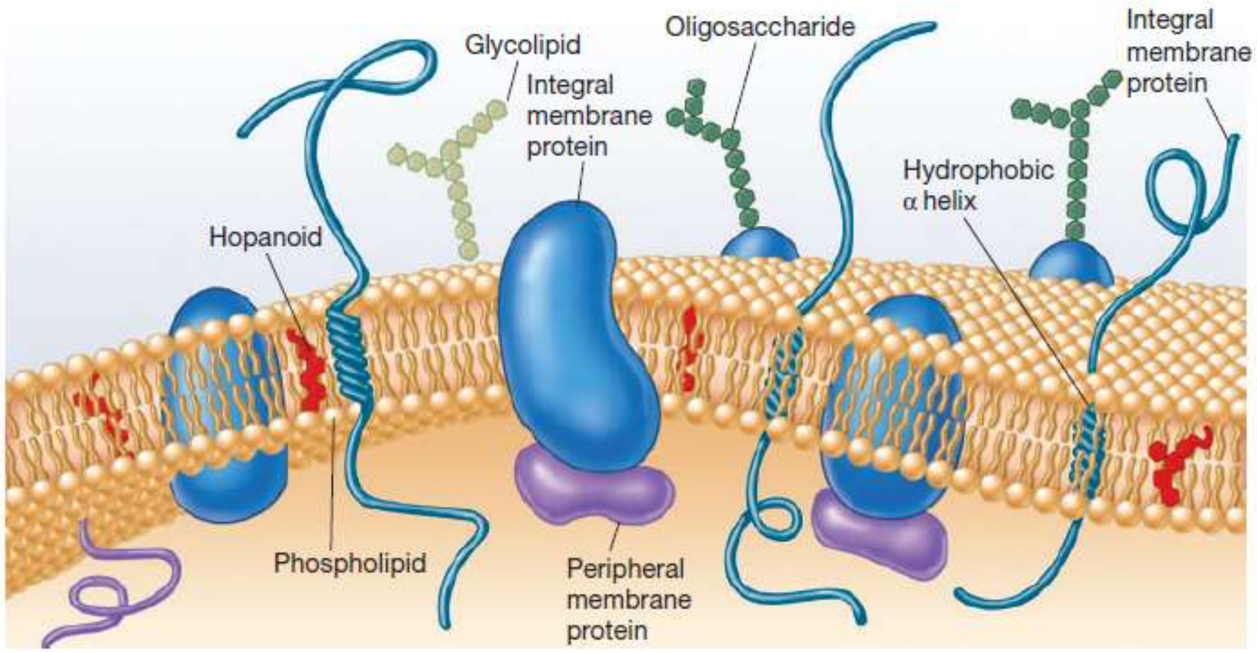


Figure 3.7 The Fluid Mosaic Model of Bacterial Membrane Structure. This diagram shows the integral membrane proteins (blue) floating in a lipid bilayer. Peripheral membrane proteins (purple) are associated loosely with the inner membrane surface. Small spheres represent the hydrophilic ends of membrane phospholipids, and wiggly tails are the hydrophobic fatty acid chains. Other membrane lipids such as hopanoids (red) may be present. Phospholipids are drawn much larger than their actual size.

Bacterial Plasma Membranes Contain Lipids Not Found in Eukaryotic Membranes

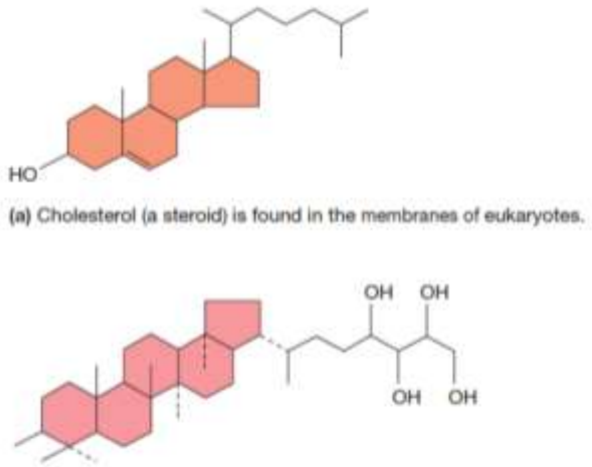
The plasma membrane is very dynamic: the lipid composition varies with environmental temperature in such a way that the membrane remains fluid during growth. For example,

1) **bacteria growing at lower temperatures** have **more unsaturated fatty acids** in their membrane phospholipids; that is, there are **one or more double covalent bonds in the long hydrocarbon chain.**
2) **At higher temperatures, their phospholipids have more saturated fatty acids—those** in which the **carbon atoms are connected only with single covalent bonds**.

Other factors also affect the lipid composition of membranes. For instance, some pathogens change the lipids in their plasma membranes to protect themselves from antimicrobial peptides produced by the immune system.

Bacterial membranes usually differ from eukaryotic membranes in lacking sterols (steroid-containing lipids) such as cholesterol (figure 3.9a). However, many bacterial membranes contain hopanoids, which are similar to, but distinct from, steroids (figure 3.9*b*).

Hopanoids **are synthesized from the same precursors as steroids**, and like the sterols in eukaryotic membranes, they probably **stabilize the membrane**. Hopanoids are also of interest to ecologists and geologists: the total mass of hopanoids stored in sediments is estimated to be around 10^{11}-10^{12} tons—about as much as the **total mass of organic carbon in all living organisms (10^{12}tons)—and evidence exists that hopanoids have contributed significantly to the formation of petroleum.**



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

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

Figure 3.9 Membrane Steroids and Hopanoids.

THANK YOU