Cellular Structure of Bacteria and Archaea

Cellular structure of bacteria and archaea

In this section, we will discuss the basic structural features of both bacteria and archaea. There are many structural, morphological, and physiological similarities between bacteria and archaea. As discussed in the previous section, these microbes inhabit many ecological niches and carry out a great diversity of biochemical and metabolic processes. Both bacteria and archaea lack a membrane-bound nucleus and membrane-bound organelles, which are hallmarks of eukaryotes.

While bacteria and archaea are separate domains, morphologically they share a number of structural features. As a result, they face similar problems, such as the transport of nutrients into the cell, the removal of waste material from the cell, and the need to respond to rapid local environmental changes. In this section, we will focus on how their common cell structure allows them to thrive in various environments and simultaneously puts constraints on them. One of the biggest constraints is related to cell size.

Although bacteria and archaea come in a variety of shapes, the most common three shapes are as follows: cocci (spherical), bacilli (rod-shaped), and spirilli (spiral-shaped) (figure below). Both bacteria and archaea are generally small compared to typical eukaryotes. For example, most bacteria tend to be on the order of 0.2 to 1.0 µm (micrometers) in diameter and 1-10 µm in length. However, there are exceptions. *Epulopiscium fishelisoni* is a bacillus-shaped bacterium that is typically 80 µm in diameter and 200-600 µm long. *Thiomarganta namibiensis* is a spherical bacterium between 100 and 750 µm in diameter and is visible to the naked eye. For comparison, a typical human neutrophil is approximately 50 µm in diameter.
Figure 1. This figure shows the three most common shapes of bacteria and archaea: (a) cocci (spherical), (b) bacilli (rod-shaped), and (c) spirilli (spiral-shaped).

Possible NB Discussion

Point: Why are bacteria and archaea so tiny anyway?

Why are bacteria and archaea typically so small? What are the constraints that are keeping them microscopic in size (i.e., what is preventing from getting bigger?)? How then exactly does the relatively giant *Thiomargarita namibiensis* (which has a cell volume that is three million times the volume of an average bacteria and is visible to the naked eye) and other larger bacteria overcome these constraints? Think of possible explanations or hypotheses that might answer these questions. We'll explore and develop an understanding of these questions in more detail below and in class.

The bacterial and archaeal cell: common structures

Introduction to the basic cell structure

Bacteria and archaea are unicellular organisms, which lack internal membrane-bound structures that are disconnected from the plasma membrane, a phospholipid membrane that defines the boundary between the inside and outside of the cell. In bacteria and archaea, the cytoplasmic membrane also contains all membrane-bound reactions, including those related to the electron transport chain, ATP synthase, and photosynthesis. By definition, these cells lack a nucleus. Instead, their genetic material is located in a self-defined area of the cell called the nucleoid. The bacterial and archaeal chromosome is often a single covalently closed circular double-stranded DNA molecule. However, some bacteria have linear chromosomes, and some bacteria and archaea have more than one chromosome or small non-essential circular replicating elements of DNA called plasmids. Besides the nucleoid, the next common feature is the cytoplasm (or cytosol), the "aqueous," jelly-like region encompassing the internal portion of the cell. The cytoplasm is where the soluble (non-membrane-associated) reactions occur and contains the ribosomes, the protein-RNA complex where proteins are synthesized. Finally, many bacteria and archaea also have cell walls, the rigid structural feature surrounding the plasma membrane that helps provide protection and constrain the cell shape. You should learn to create a simple sketch of a general bacterial or archaeal cell from memory.
Constraints on the bacterial and archaeal cell

One common, almost universal, feature of bacteria and archaea is that they are small, microscopic to be exact. Even the two examples given as exceptions, *Epulopiscium fishelsoni* and *Thiomargarita namibiensis*, still face the basic constraints all bacteria and archaea face; they simply found unique strategies around the problem. So what is the largest constraint when it comes to dealing with the size of bacteria and archaea? Think about what the cell must do to survive.

Some basic requirements

So what do cells have to do to survive? They need to transform energy into a usable form. This involves making ATP, maintaining an energized membrane, and maintaining productive NAD$^+/\text{NADH}_2$ ratios. Cells also need to be able to synthesize the appropriate macromolecules (proteins, lipids, polysaccharides, etc.) and other cellular structural components. To do this, they need to be able to either make the core, key precursors for more complex molecules or get them from the environment.

Diffusion and its importance to bacteria and archaea

Movement by diffusion is passive and proceeds down the concentration gradient. For compounds to move from the outside to the inside of the cell, the compound must be able to cross the phospholipid bilayer. If the concentration of a substance is lower inside the cell than outside and it has chemical properties that allow it to move across the cell membrane, that compound will energetically tend to move into the cell. While the "real" story is a bit more complex and will be discussed in more detail later, diffusion is one of the mechanisms bacteria and archaea use to aid in the transport of metabolites.

Diffusion can also be used to get rid of some waste materials. As waste products accumulate inside the cell, their concentration rises compared to that of the outside environment, and the waste product can leave the cell. Movement within the cell works the same way: compounds will move down their concentration gradient, away from where they are synthesized to places where their concentration is low and therefore may be needed. Diffusion is a random process—the ability of two different compounds or reactants for chemical reactions to interact becomes a meeting of chance. Therefore, in small, confined spaces, random interactions or collisions can occur more frequently than they can in large spaces.

Figure 2. The features of a typical prokaryotic cell are shown.
The ability of a compound to diffuse depends on the viscosity of the solvent. For example, it is a lot easier for you to move around in air than in water (think about moving around underwater in a pool). Likewise, it is easier for you to swim in a pool of water than in a pool filled with peanut butter. If you put a drop of food coloring into a glass of water, it quickly diffuses until the entire glass has changed color. Now what do you think would happen if you put that same drop of food coloring into a glass of corn syrup (very viscous and sticky)? It will take a lot longer for the glass of corn syrup to change color.

The relevance of these examples is to note that the cytoplasm tends to be very viscous. It contains many proteins, metabolites, small molecules, etc. and has a viscosity more like corn syrup than water. So, diffusion in cells is slower and more limited than you might have originally expected. Therefore, if cells rely solely on diffusion to move compounds around, what do you think happens to the efficiency of these processes as cells increase in size and their internal volumes get bigger? Is there a potential problem to getting big that is related to the process of diffusion?

So how do cells get bigger?

As you've likely concluded from the discussion above, with cells that rely on diffusion to move things around the cell—like bacteria and archaea—size does matter. So how do you suppose *Epulopiscium fishelsoni* and *Thiomargarita namibiensis* got so big? Take a look at these links, and see what these bacteria look like morphologically and structurally: [Epulopiscium fishelsoni](https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_-_Molecules_to_Cell/MA...) and [Thiomargarita namibiensis](https://bio.libretexts.org/Courses/University_of_California_Davis/BIS_2A%3A_Introductory_Biology_-_Molecules_to_Cell/MA...).

Based on what we have just discussed, in order for cells to get bigger, that is, for their volume to increase, intracellular transport must somehow become independent of diffusion. One of the great evolutionary leaps was the ability of cells (eukaryotic cells) to transport compounds and materials intracellularly, independent of diffusion. Compartmentalization also provided a way to localize processes to smaller organelles, which overcame another problem caused by the large size. Compartmentalization and the complex intracellular transport systems have allowed eukaryotic cells to become very large in comparison to the diffusion-limited bacterial and archaeal cells. We'll discuss specific solutions to these challenges in the following sections.