

PHYS 101 Supplement #1 - Cell sizes and structures

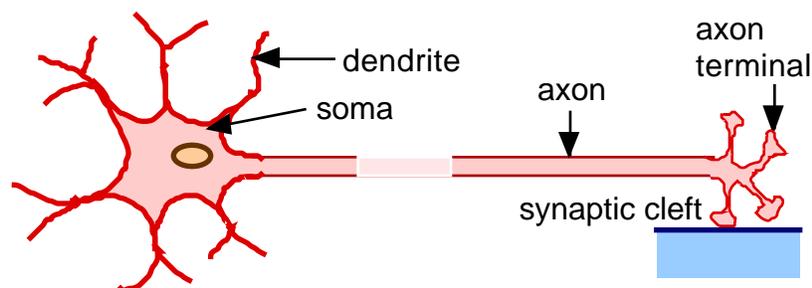
In the PHYS 101 lectures on viscous drag, we chose several examples from the world of cells. Here, we provide a very brief overview of cell structure - enough to introduce a physics students to the lexicon, and certainly more than what is needed to understand the examples in class.

The operative length scale for cells is the micron or 10^{-6} meter. The smallest cells are a third of a micron in diameter, while the largest ones may be more than a hundred microns across. Nerve cells have particularly long sections called axons which may be up to a meter in length, yet just a micron in diameter. Structural elements of a cell, such as its filaments and sheets, generally have a transverse dimension within a factor of two of 10 nm; for example, the membranes that bound the cell are 4-5 nm thick, and the filaments that permeate structurally advanced cells cover the range from 5 to 25 nm in diameter.

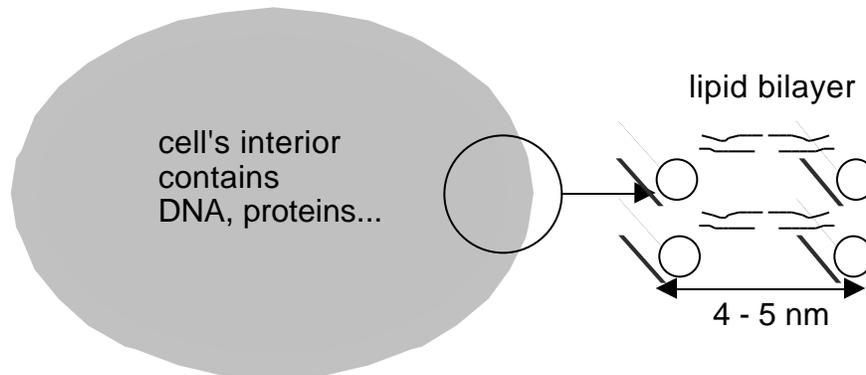
Let's now examine a few representative cells to see how membranes, networks and filaments appear in their construction. The two principal categories of cells are procaryotes (without a nucleus) such as mycoplasmas and bacteria, and eucaryotes (with a nucleus) such as plant and animal cells. Having few internal mechanical elements, some of today's procaryotic cells are structural cousins of the earliest cells, which emerged more than 3.5 billion years ago.

Mycoplasmas and bacteria

Mycoplasmas are among the smallest known cells and have diameters as low as a third of a micron. As displayed in the cartoon below, the cell is bounded by a plasma membrane, which is a two-dimensional fluid sheet composed primarily of lipid molecules and embedded proteins. In an aqueous environment, some types of lipids can self-assemble into a fluid sheet consisting of two layers, referred to as a lipid bilayer, with a combined thickness of 4 - 5 nm. The interior of a mycoplasma contains, among other things, the cell's genetic blueprint, DNA, as well as large numbers of proteins.



Schematic representation of a nerve cell, with its extended axon.

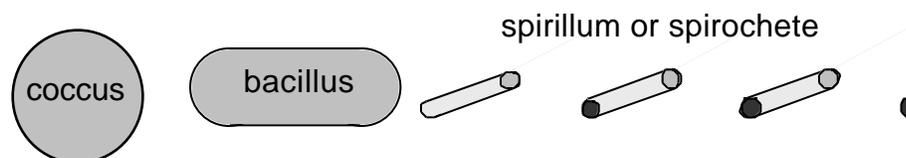


Schematic representation of a mycoplasma, whose boundary is a lipid bilayer with embedded proteins and other molecules.

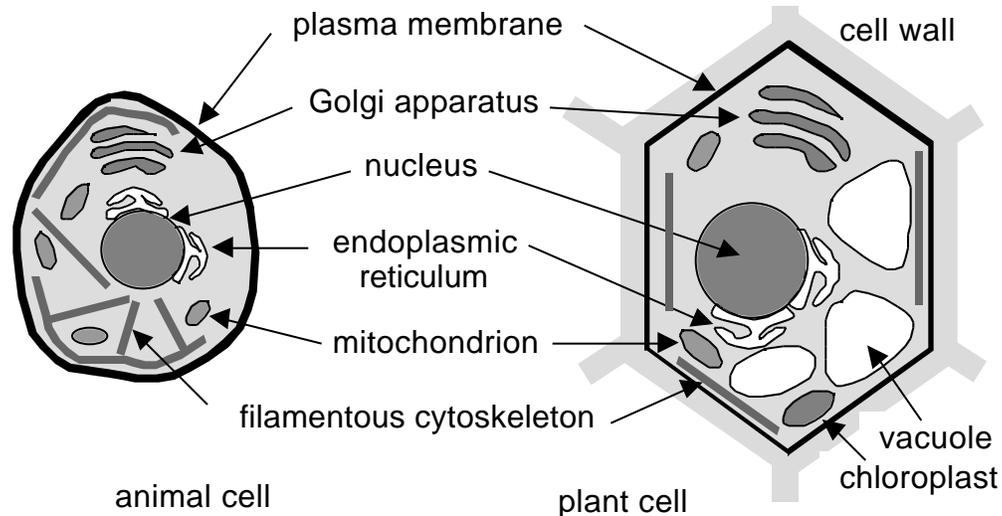
Most bacteria both are larger and have a more complex boundary than the simple plasma membrane of the mycoplasma. Further, the interior of a bacterium may be under considerable pressure - up to 25 atmospheres - but the presence of a strong cell wall outside the plasma membrane prevents mechanical failure of the cell. Some common bacterial shapes are displayed below, although these are not the full catalogue. Cells in one category of shapes are approximately spherical; referred to as *cocci* (plural of coccus) they typically have diameters of a few microns. Rods or *bacilli* (plural of bacillus) make up a second category; these are often 0.5 - 1 μm in diameter and several times that in length, although they may range up to 500 μm long for the cigar-shaped *Epulopiscium fishelsoni*. A third category includes corkscrew-shaped bacteria such as rigid *spirilla* and flexible *spirochetes*, whose tubular cross section may have a diameter of just 0.1 μm and an overall length of a few microns (although, again, some may approach hundreds of microns). Typically, the density of a bacterium is similar to that of water ($1.0 \times 10^3 \text{ kg/m}^3$), implying that the mass of a spherical coccus of radius 1 μm would be $(4/3) \cdot (10^{-6})^3 \cdot 10^3 \sim 4 \times 10^{-15} \text{ kg}$.

Plant and animal cells

The general layout of a plant cell is displayed below. Exterior to their plasma membrane, plant cells are bounded by a cell wall, permitting them to withstand higher internal pressures than a wall-less animal cell can support. However, both the thickness and the chemical composition of the wall of a plant cell are different from those of a bacterium. The thickness of the plant cell wall is in the range of 0.1 to 10 μm , which may be larger than the total length of some bacteria, and the plant cell wall



Common bacterial shapes (configurations are not drawn to the same scale).



is composed of cellulose, rather than the protein/sugar composite of bacteria. Also in contrast to bacteria, both plant and animal cells contain many internal membrane-bounded compartments called organelles.

As illustrated above, animal cells share a number of common features with plant cells, but their lack of space-filling vacuoles means that animal cells tend to be smaller in linear dimension. Neither do they have a cell wall, relying instead upon a filamentous cytoskeleton for much of their mechanical rigidity. As an internal network of thin filaments, the cytoskeleton does not have the strength of an external cell wall that would permit an animal cell to support a significant internal pressure. The most important organelles of plant and animal cells include:

- The nucleus, with a diameter in the range 3 to 10 μm , contains almost all of the cell's DNA.
- The endoplasmic reticulum surrounds the nucleus and is continuous with its outer membrane; it is the site of proteins synthesis.
- The membrane-bounded Golgi apparatus is the location of protein sorting, and appears like layers of flattened disks with diameters of a few microns. Small vesicles, with diameters in the range of 0.2 to 0.5 μm , pinch off from the Golgi and transport proteins and other material to various regions of the cell.
- Mitochondria and chloroplasts, the latter present only in plant cells, produce the cell's energy currency, ATP (adenosine triphosphate).

All of the material within the cell, with the exclusion of its nucleus, is defined as the cytoplasm, which contains organelles as well as the largely-aqueous cytosol. Although filled with proteins and other molecules, the density of the cytosol is not that different from water. In contrast, the viscosity of the cytosol may be an order of magnitude larger than water. The various filament types of the cytoskeleton may be organized into distinct networks; for example, stiff microtubules radiate from near the cell's nucleus. In addition to providing the cell with mechanical strength, elements of the cytoskeleton may be used as pathways for the transportation of material, much like the roads of a city.