

Principles of Organization

The unity and diversity of organisms become apparent even at the cellular level. The smallest organisms consist of single cells and are microscopic. Larger, multicellular organisms contain many different types of cells, which vary in size, shape, and specialized function. Despite these obvious differences, all cells of the simplest and most complex organisms share certain fundamental properties, which can be seen at the biochemical level.

Structural and Functional Units of All Living Organisms

Cells of all kinds share certain structural features (Fig. 1). The plasma membrane defines the periphery of the cell, separating its contents from the surroundings. It is composed of lipid and protein molecules that form a thin, tough, pliable, hydrophobic barrier around the cell. The membrane is a barrier to the free passage of inorganic ions and most other charged or polar compounds. Transport proteins in the plasma membrane allow the passage of certain ions and molecules; receptor proteins transmit signals into the cell; and membrane enzymes participate in some reaction pathways. Because the individual lipids and proteins of the plasma membrane are not covalently linked, the entire structure is remarkably flexible, allowing changes in the shape and size of the cell. As a cell grows, newly made lipid and protein molecules are inserted into its plasma membrane; cell division produces two cells, each with its own membrane. This growth and cell division (fission) occurs without loss of membrane integrity.

The internal volume enclosed by the plasma membrane, the cytoplasm (Fig. 1), is composed of an aqueous solution, the cytosol, and a variety of suspended particles with specific functions. These particulate components (membranous organelles such as mitochondria and chloroplasts; supramolecular structures such as ribosomes and proteasomes, the sites of protein synthesis and degradation) sediment

when cytoplasm is centrifuged at 150,000g (g is the gravitational force of Earth). What remains as the supernatant fluid is the cytosol, a highly concentrated solution containing enzymes and the RNA molecules that encode them; the components (amino acids and nucleotides) from which these macromolecules are assembled; hundreds of small organic molecules called metabolites, intermediates in biosynthetic and degradative pathways; coenzymes, compounds essential to many enzyme-catalyzed reactions; and inorganic ions.

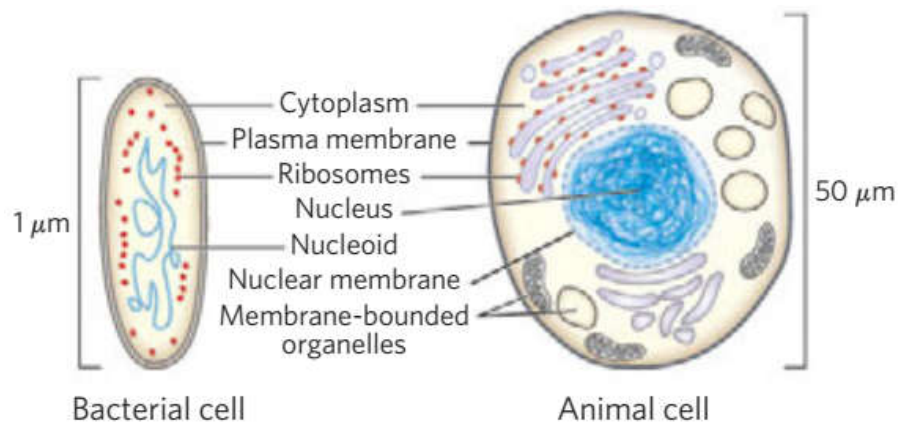


Fig 1. The universal features of living cells.

All cells have, for at least some part of their life, either a nucleoid or a nucleus, in which the genome—the complete set of genes, composed of DNA—is replicated and stored, with its associated proteins. The nucleoid, in bacteria and archaea, is not separated from the cytoplasm by a membrane; the nucleus, in eukaryotes, is enclosed within a double membrane, the nuclear envelope. Cells with nuclear envelopes make up the large domain Eukarya (Greek *eu*, “*true*” and *karyon*, “*nucleus*”). Microorganisms without nuclear membranes, formerly grouped together as prokaryotes (Greek *pro*, “*before*”), are now recognized as comprising two very distinct groups: the domains Bacteria and Archaea.

Cellular Dimensions

Most cells are microscopic, invisible to the unaided eye. Animal and plant cells are typically 5 to 100 μm in diameter, and many unicellular microorganisms are only 1 to 2 μm long (see the inside back cover for information on units and their abbreviations). What limits the dimensions of a cell? The lower limit is probably set by the minimum number of each type of biomolecule required by the cell. The smallest cells, certain bacteria known as mycoplasmas, are 300 nm in diameter and have a volume of about 10^{-14} mL. A single bacterial ribosome is about 20 nm in its longest dimension, so a few ribosomes take up a substantial fraction of the volume in a mycoplasmal cell. The upper limit of cell size is probably set by the rate of diffusion of solute molecules in aqueous systems.

For example, a bacterial cell that depends on oxygen consuming reactions for energy extraction must obtain molecular oxygen by diffusion from the surrounding medium through its plasma membrane. The cell is so small, and the ratio of its surface area to its volume is so large, that every part of its cytoplasm is easily reached by O_2 diffusing into the cell. With increasing cell size, however, surface-to-volume ratio decreases, until metabolism consumes O_2 faster than diffusion can supply it. Metabolism that requires O_2 thus becomes impossible as cell size increases beyond a certain point, placing a theoretical upper limit on the size of cells. Oxygen is only one of many low molecular weight species that must diffuse from outside the cell to various regions of its interior, and the same surface-to-volume argument applies to each of them as well.

Domains of Life

All living organisms fall into one of three large groups (domains) that define three branches of the evolutionary tree of life originating from a common progenitor (Fig. 2). Two large groups of single-celled microorganisms can be distinguished on genetic and biochemical grounds: Bacteria and Archaea. Bacteria inhabit soils, surface waters, and the tissues of other living or decaying organisms. Many of the

Archaea, recognized as a distinct domain by **Carl Woese** in the 1980s, inhabit extreme environments—salt lakes, hot springs, highly acidic bogs, and the ocean depths. The available evidence suggests that the Archaea and Bacteria diverged early in evolution. All eukaryotic organisms, which make up the third domain, Eukarya, evolved from the same branch that gave rise to the Archaea; eukaryotes are therefore more closely related to archaea than to bacteria.

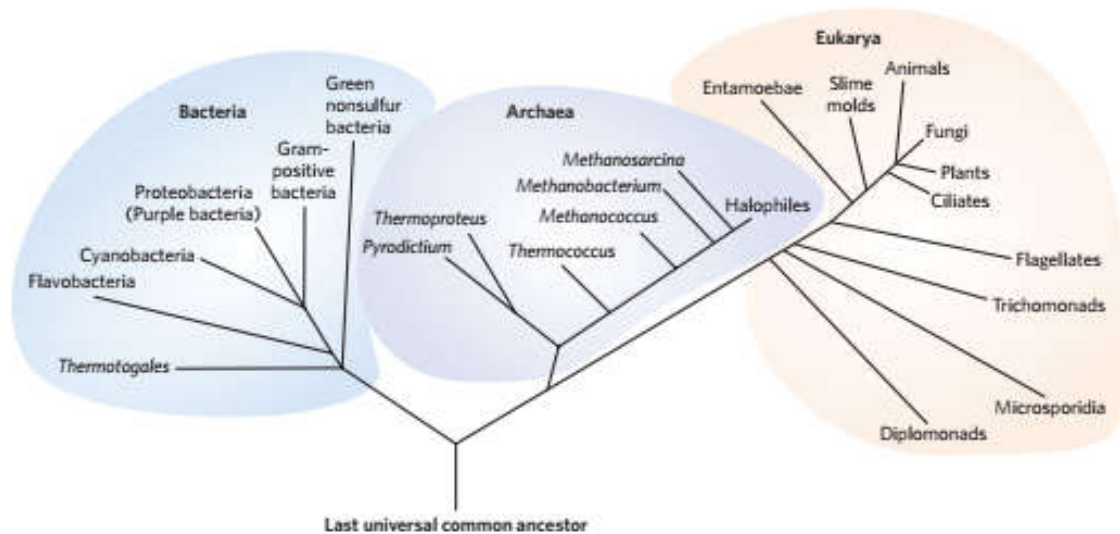


Fig 2. Phylogeny of the three domains of life.

Within the domains of Archaea and Bacteria are subgroups distinguished by their habitats. In aerobic habitats with a plentiful supply of oxygen, some resident organisms derive energy from the transfer of electrons from fuel molecules to oxygen within the cell. Other environments are anaerobic, virtually devoid of oxygen, and microorganisms adapted to these environments obtain energy by transferring electrons to nitrate (forming N_2), sulfate (forming H_2S), or CO_2 (forming CH_4). Many organisms that have evolved in anaerobic environments are obligate anaerobes: they die when exposed to oxygen. Others are facultative anaerobes, able to live with or without oxygen.

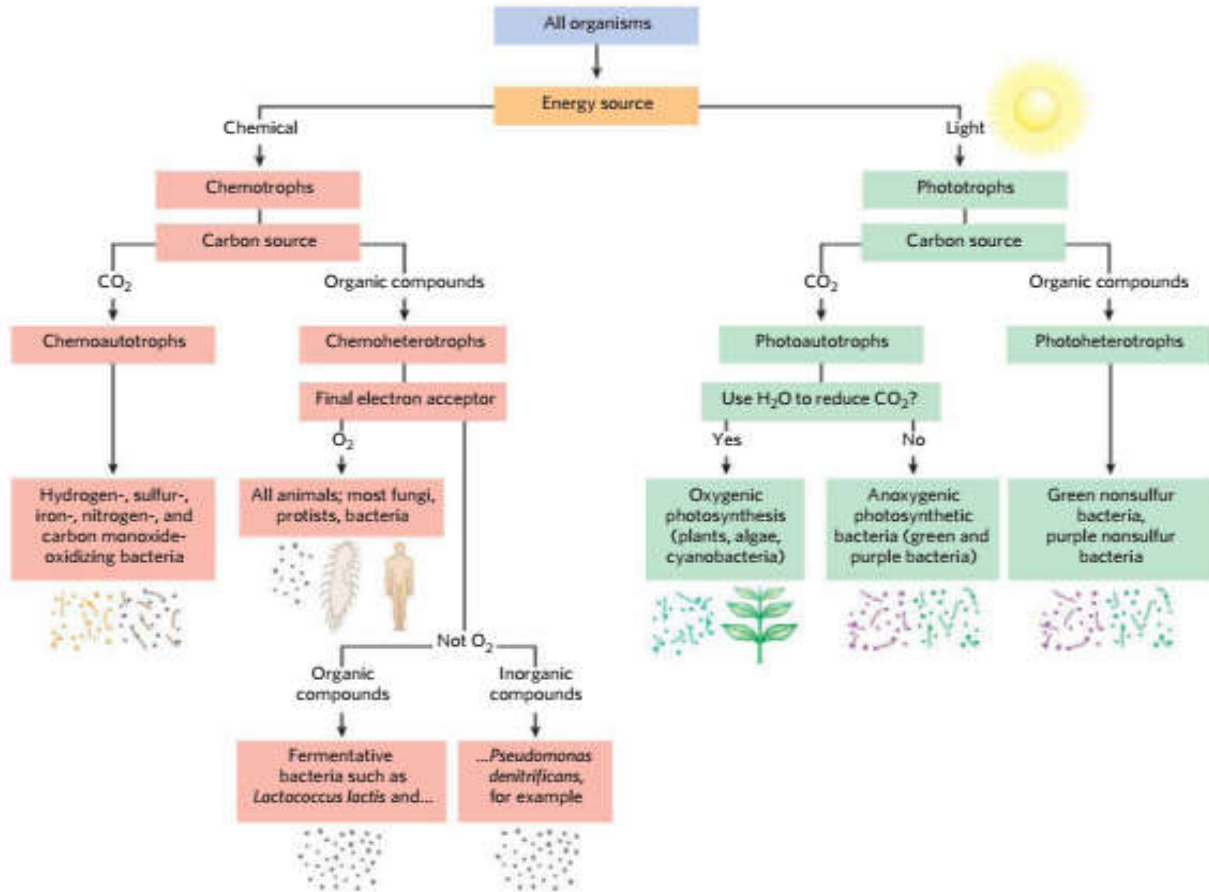


Fig 3. All organisms can be classified according to their source of energy (sunlight or oxidizable chemical compounds) and their source of carbon for the synthesis of cellular material.