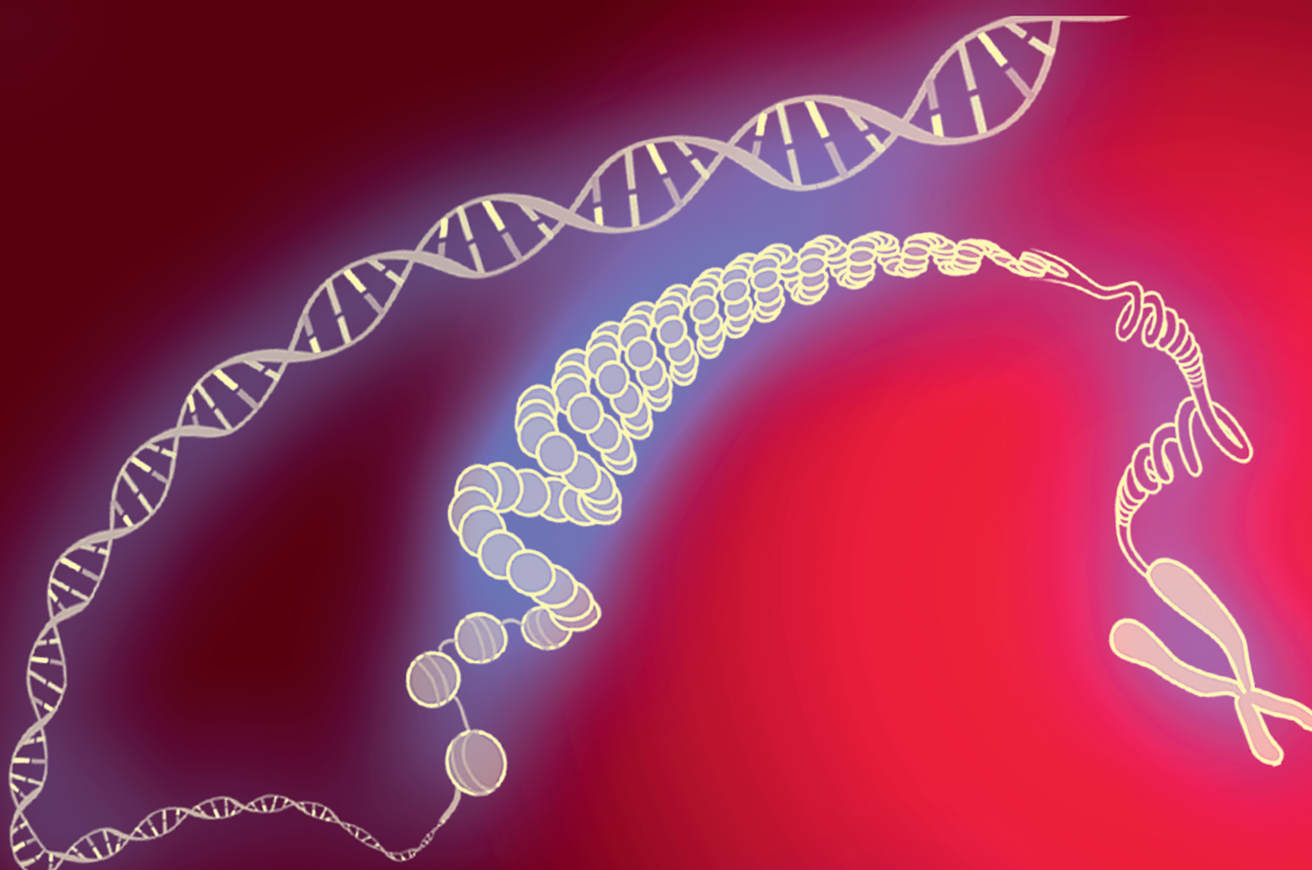
Part I
Fundamentals of Cellular and Molecular Biology



1
The Cell as the Basic Unit of Life

Learning Objectives
This chapter offers a short introduction into the structure of prokaryotic and eukaryotic cells, as well as that of viruses.

The base unit of life is the **cell**. Cells constitute the base element of all **prokaryotic cells** (cells without a cell nucleus, e.g., **Bacteria** and **Archaea**) and **eukaryotic cells** (or **Eukarya**) (cells possessing a nucleus, e.g., protozoa, fungi, plants, and animals). Cells are small, membrane-bound units with a diameter of 1–20 μm and are filled with concentrated aqueous solutions. Cells are not created *de novo*, but possess the ability to copy themselves, meaning that they emerge from the division of a previous cell. This means that all cells, since the beginning of life (around 4 billion years ago), are connected with each other in a continuous lineage. In 1885, the famous cell biologist Virchow conceived the law of *omnis cellula e cellulae* (all cells arise from cells), which is still valid today.

The structure and composition of all cells are very similar due to their shared evolution and phylogeny (Fig. 1.1). Owing to this, it is possible to limit the discussion of the general characteristics of a cell to a few basic types (Fig. 1.2):
- Bacterial cells.
- Plant cells.
- Animal cells.

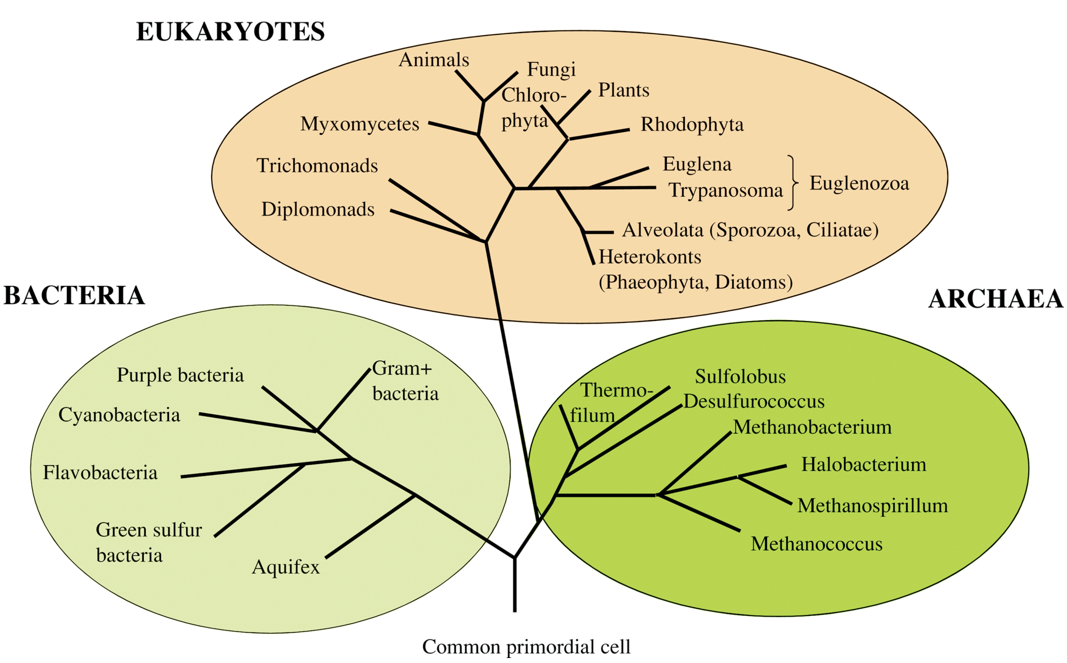


Fig. 1.1 Tree of life – phylogeny of life domains. Nucleotide sequences from 16S rRNA, amino acid sequences of cytoskeleton proteins, and characteristics of the cell structure were used to reconstruct this phylogenetic tree. Prokaryotes are divided into **Bacteria** and **Archaea**. Archaea form a sister group with eukaryotes; they share important characteristics (Tables 1.1 and 1.2). Many monophyletic groups can be recognized within the eukaryotes (diplomonads/trichomonads, Euglenozoa, Alveolata, Stramenopilata (heterokonts), red algae and green algae/plants, fungi and animals; see Tables 6.3–6.5 for details).

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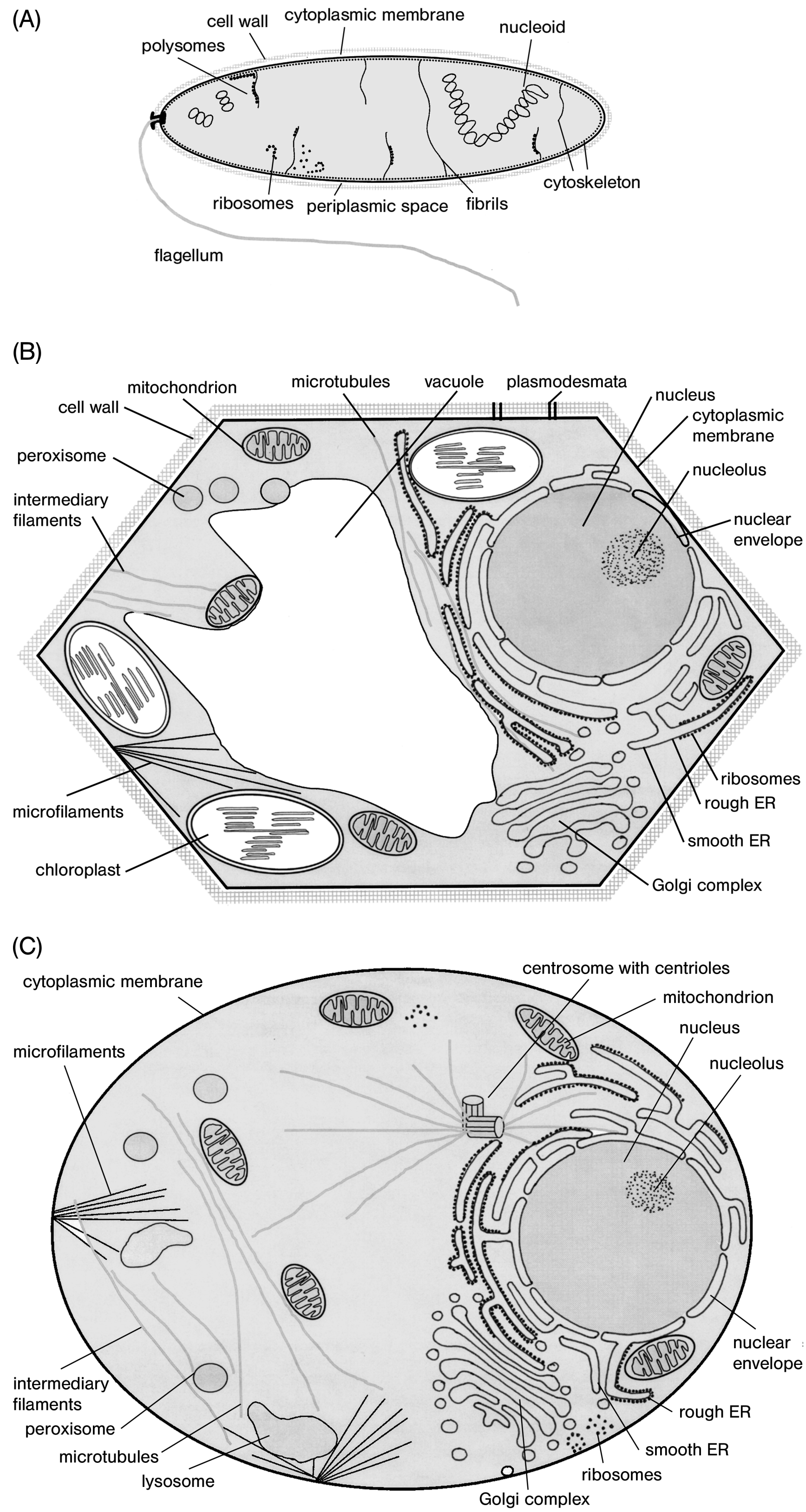

Fig. 1.2 Schematic structure of prokaryotic and eukaryotic cells. (A) Bacterial cell. (B) Plant mesophyll cell. (C) Animal cell.

Table 1.1 Comparison of important biochemical and molecular characteristics of the three domains of life.

Character	Prokaryotes		Eukaryotes
	Archaea	Bacteria	
Organization	Unicellular	Unicellular	Unicellular or multicellular
Cytology			
Internal membranes	Rare	Rare	Always (Table 1.2)
Compartments	Only cytoplasm	Only cytoplasm	Several (Table 1.2)
Organelles	No	No	mitochondria; plastids
Ribosomes	70S	70S	80S (mt, cp: 70S)
Membrane lipids	Ether lipids	Ester lipids, hopanoids	Ester lipids, sterols
Cell wall	Pseudopeptidoglycan, polysaccharides, glycoproteins	Murein (peptidoglycan), polysaccharides, proteins	PL: polysaccharides, cellulose F: chitin A: no
Cytoskeleton	FtsZ and MreB protein	FtsZ and MreB protein	Tubulin, actin, intermediary filaments
Cell division	Binary fission	Binary fission	Mitosis
Genetics			
Nuclear structure	Nucleoid	Nucleoid	Membrane-enclosed nucleus
Recombination	Similar to conjugation	Conjugation	Meiosis, syngamy
Chromosome	Circular, single	Circular, single	Linear, several
Introns	Rare	Rare	Frequent
Noncoding DNA	Rare	Rare	Frequent
Operon	Yes	Yes	No
Extrachromosomal	DNA plasmids (linear)	Plasmids (circular)	mtDNA, cpDNA, plasmids in fungi
Transcription/ translation	Concomitantly	Concomitantly	Transcription in nucleus; translation in cytoplasm
Promotor structure	TATA box	–35 and –10 sequences	TATA box
RNA polymerases	Several (8–12 subunits)	1 (4 subunits)	3 (with 12–14 subunits)
Transcription factors	Yes	No (sigma factor)	Yes
Initiator tRNA	Methionyl-tRNA	*N*-formylmethionyl-tRNA	Methionyl-tRNA
Cap structure of mRNA polyadenylation	No	No	Yes

PL, plants; F, fungi; A, animals; mt, mitochondria; cp, plastid.

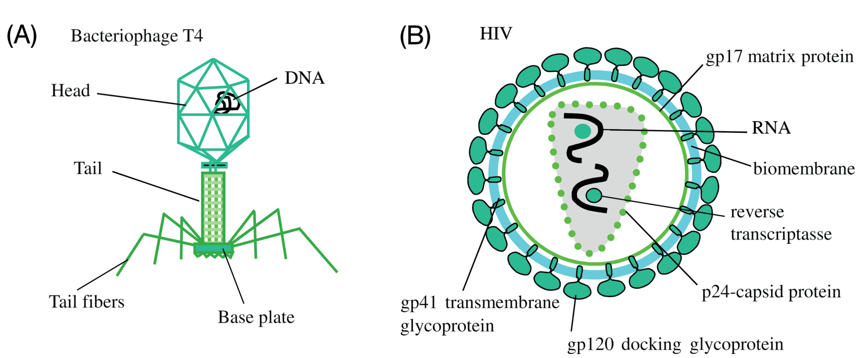

Fig. 1.3 Schematic structure of bacteriophages and viruses. (A) Bacteriophage T4. (B) Structure of a retrovirus (human immunodeficiency virus causing AIDS).

Table 1.2 Compartments of animal and plant cells and their main functions.

Compartment	Occurrence		Functions
	Animal	Plant	
Nucleus	A	P	Harbors chromosomes; site of replication, transcription, and assembly of ribosomal subunits
Endoplasmic reticulum			
rough ER	A	P	Posttranslational modification of proteins
smooth ER	A	P	Synthesis of lipids and lipophilic substances
Golgi apparatus	A	P	Posttranslational modification of proteins; modification of sugar chains
Lysosome	A		Harbors hydrolytic enzymes; degrades organelles and macromolecules, macrophages eat invading microbes
Vacuole		P	Sequestration of storage proteins, defense and signal molecules, contains hydrolytic enzymes, degrades organelles and macromolecules
Mitochondrium	A	P	Organelle derived from endosymbiotic bacteria; contains circular DNA, own ribosomes; enzymes of citric acid cycle, β-oxidation, and respiratory chain (ATP generation)
Chloroplast		P	Organelle derived from endosymbiotic bacteria; contains circular DNA, own ribosomes; chlorophyll and proteins of photosynthesis, enzymes of CO_2 fixation and glucose formation (Calvin cycle)
Peroxisome	A	P	Contains enzymes that generate and degrade H_2O_2
Cytoplasm	A	P	Harbors all compartments, organelles, and the cytoskeleton of a cell; many enzymatic pathways (e.g., glycolysis) occur in the cytoplasm

A, animal; P, plant.

The most important **biochemical and cell biological characters** of Archaea, Bacteria, and Eukarya are summarized in Table 1.1.

As **viruses** and **bacteriophages** (Fig. 1.3) do not have their own metabolism they therefore do not count as organisms in the true sense of the word. They share several macromolecules and structures with cells. Viruses and bacteriophages are dependent on the host cells for reproduction, and therefore their physiology and structure are closely linked to that of the host cell.

Eukaryotic cells are characterized by **compartments** that are enclosed by biomembranes (Table 1.2). As a result of these compartments, the multitude of metabolic reactions can run in a cell at the same time.

In the following discussion on the shared characteristics of all cells, the diverse differences that appear in **multicellular organisms** should not be forgotten. The human body has more than 200 different cell types, which show diverse structures and compositions. These differences must be understood in detail if cell-specific disorders, such as cancer, are to be understood and consequently treated.

Before a detailed discussion of cellular structures and their functions (see Chapters 3–5), a short summary of the biochemical basics of cellular and molecular biology is given in Chapter 2.