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The Cell as the Basic Unit of Life

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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 Rudolf Virchow conceived the law of *omnis cellula e cellula* (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 (Figure 1.1). We see an astonishing constancy in fundamental structures and mechanisms. Owing to this, it is possible to limit the discussion of the general characteristics of a cell to a few basic types (Figure 1.2):

- Bacterial cells
- Plant cells
- Animal cells

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).

A highly resolved tree of life is based on completely sequenced genomes (Ciccarelli 2006). The image was generated using Interactive Tree Of Life (iTOL) (Letunic 2007), an online phylogenetic tree viewer and Tree of Life resource. Eukaryotes are colored red, archaea green, and bacteria blue.

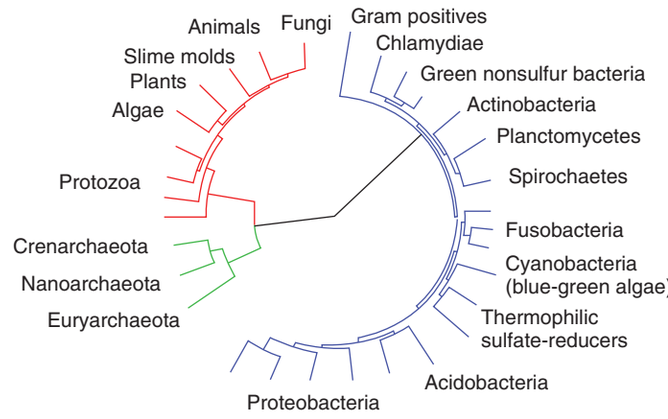

Figure 1.1 Tree of life – phylogeny of life domains.

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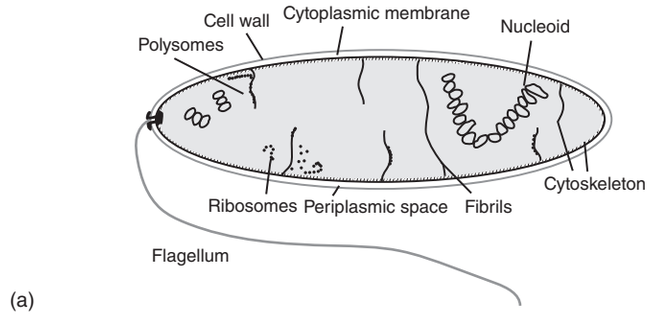
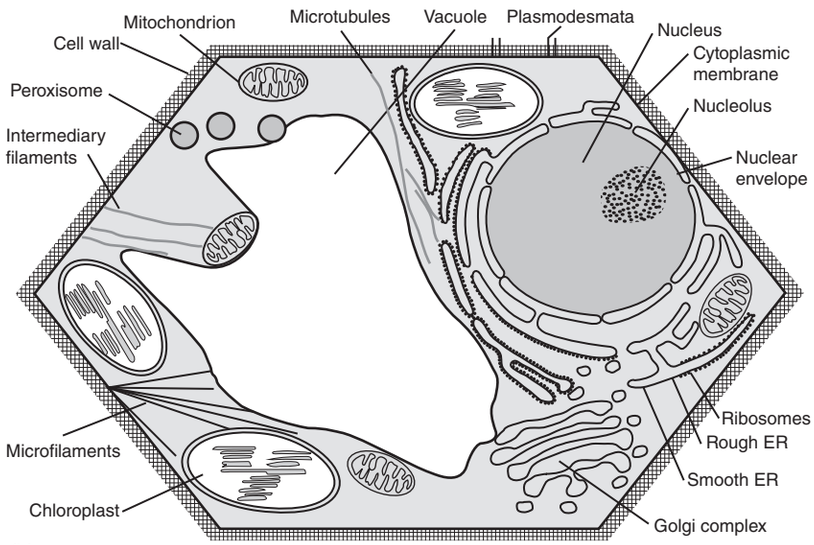
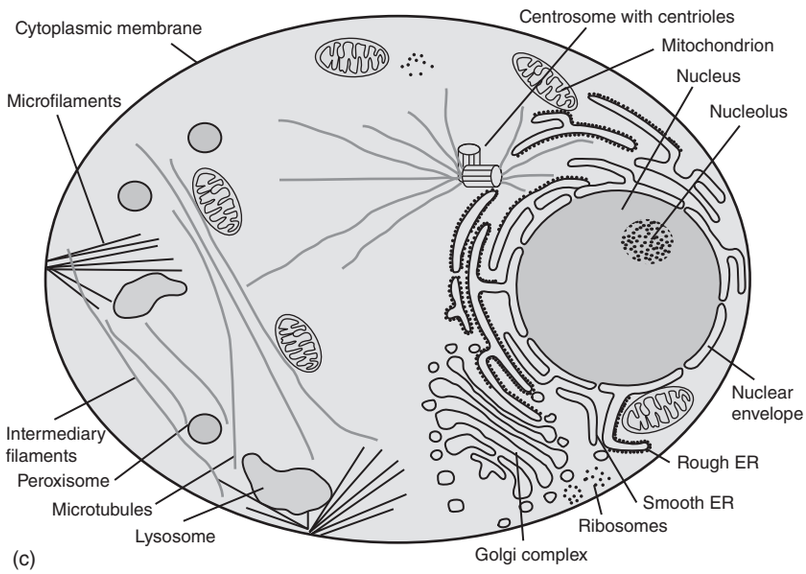


(a)



(b)

Figure 1.2 Schematic structure of prokaryotic and eukaryotic cells. (a) Bacterial cell, (b) plant mesophyll cell, and (c) animal cell.



(c)

Figure 1.2 (*Continued*)

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 with chromosomes
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.

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

As **viruses** and **bacteriophages** (Figure 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 structures 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

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

Compartment	Occurrence		Functions
Nucleus	A	P	Harbors chromosomes, site of replication, transcription, and assembly of ribosomal subunits
Endoplasmic reticulum (ER)			
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.

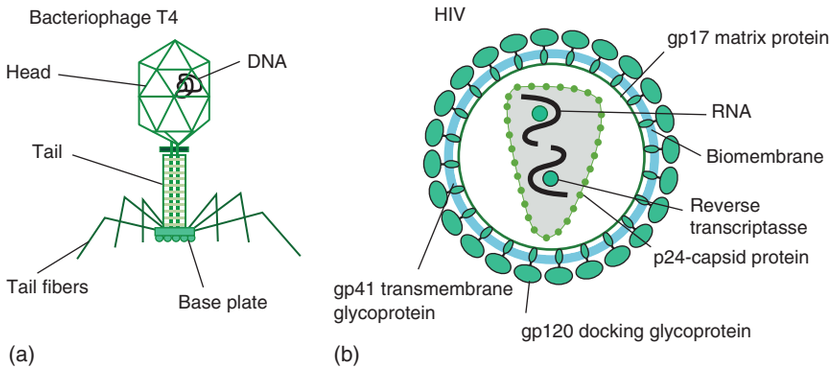


Figure 1.3 Schematic structure of bacteriophages and viruses. (a) Bacteriophage T4 and (b) structure of a retrovirus (human immunodeficiency virus causing AIDS).

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. Modern technology with Next-Generation Sequencing (NGS) allows a study of single cells at a genomic and transcriptomic level.

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.

Progress in cell biology and biotechnology largely depends on innovative methods, as new methods often open windows to look deeper into biology and to solve old questions. Table 1.3 summarizes some of the important tools, which are important for cell and molecular biology today.

Table 1.3 Important methodological tools of modern biology.

Problem	Technique/instrument	Remarks
Structure elucidation of proteins	Protein isolation, column chromatography (gel filtration, ion exchange, affinity)	Chapter 7
	Gel electrophoresis	Chapter 7
	Protein–protein interactions (FRET, two hybrid systems, FRAP)	Chapters 19 and 23
	Crystallization	
	X-ray diffraction	
	NMR	
	Cryoelectron microscopy	
	Mass spectrometry	Chapter 8
	Protein sequencing	
DNA	PCR and quantitative PCR (qPCR)	Chapter 13
	DNA/RNA isolation	Chapter 9
	DNA hybridization	Chapter 11
	Sanger sequencing	Chapter 14
	Restriction enzymes	Chapter 12
	Gel and capillary electrophoresis	Chapter 10
	Next generation sequencing	Chapter 14
	Microsatellite analysis	Chapter 11
	SNP analysis	Chapters 14 and 21
	FISH	Chapter 11
	In situ hybridization	Chapter 11
RNA (transcriptomics)	RNA-seq (NGS)	Chapters 14 and 21
	DNA microarrays	Chapter 11
	In situ hybridization	Chapter 11
Cell and tissue culture	Cells with reporter genes	
	Cell sorting	
	Organoid cultures	
	Stem cells	
	Cancer cells	
	Hybridoma cells for production of monoclonal antibodies	
	Cell cycle analysis	Chapter 18
	Patch clamp recording	Chapter 17
Microscopy	Light microscope (bright field, dark field, phase contrast, differential interference contrast)	Chapter 19
	Fluorescence microscope (confocal)	Chapters 19 and 20
	Immunofluorescence and GFP fusion proteins	Chapter 19
	Super-resolution microscopy (STED, SIM, PALM, STORM)	Chapter 19
	Atomic force microscopy	Chapter 19
	Electron microscope	Chapter 19
	Scanning electron microscope (SEM)	
	Cryoelectron microscopy	Chapter 19
	Image processing	
Cloning and expression	Plasmid and viral vectors	Chapter 15
	Expression vectors	Chapters 15 and 16
	Fermenters	
	Genomic and cDNA libraries	Chapter 21
	Reverse genetics	

Table 1.3 (Continued)

Problem	Technique/instrument	Remarks
Genetic engineering	Transformation	Chapter 15
	Transfection	Chapter 15
	RNAi	
	CRISPR–Cas gene editing	
	Transgenic organism	
New active agents	Recombinant antibodies	Chapter 16
	Recombinant vaccines	Chapter 16
	Recombinant enzymes	Chapter 16
Information	DNA sequences	Chapter 24
	Genomes	Chapter 24
	Proteins	Chapter 23
	System biology	Chapter 23

Abbreviations: SNP, single nucleotide polymorphism; GFP, green fluoresecnt protein; NGS, next generation sequencing.

References

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Further Reading

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