Eukaryotic Ribosome - 80S (60S+40S)
28S rRNA 18S rRNA
5S rRNA
5.8S rRNA

Prokaryotic Ribosome - 70S
(50S (23S+5S rRNA) + 30S (16S rRNA))

Table 1.1. **A comparison of prokaryotic organisms (bacteria and cyanobacteria) and eukaryotic organisms (protists, fungi, plants and animals)**

Feature	Prokaryotes	Eukaryotes
1. Cell size and cell organization	1–10 μm; unicellular	5–100 μm; multicellular (many cell types)
2. Organelles	Few or none	Nucleus, mitochondria, chloroplasts, endoplasmic reticulum, golgi apparatus, etc.
3. DNA	Circular (or linear) DNA organized in a nucleoid	Linear DNA molecules organized in chromosomes bounded in a nucleus
4. Synthesis of RNA and proteins	RNA and proteins synthesized in same compartment	RNA synthesized and processed in the nucleus; proteins synthesized in the cytoplasm
5. Cytoskeleton	Absent	Present
6. Spindle apparatus in cell division	Absent; replicated DNA pulled by attachment to plasma membrane	Present ; chromosomes pulled by spindle apparatus
7. Metabolism	Anaerobic/aerobic	Aerobic

Table 1.2. **In archaea, the distribution of eukaryotic, prokaryotic and novel unique genes.**

Eukaryotic genes	Prokaryotic genes	Novel unique genes
1. DNA replication 2. Transcription 3. Translation 4. Histone genes	1. Transport of inorganic ions (e.g. Na^+, K^+) across the cell 2. Cell surface structure	1. Only one DNA polymerase 2. Several tRNA aminoacyl synthetase enzymes missing 3. Numerous inteins (18 in all) are known that are inserted into proteins and then removed

for inteins consult chapter 40.

I. ARCHAEA AND BACTERIA : DIFFERENTIATING FEATURES

The second edition of Bergey's Manual of Systematic Bacteriology (2001) recognizes two **Domains**—Archaea and bacteria—in which all prokaryotic organisms are included. The major differentiating features of the two domains are presented in Table 4.1.

Table 4.1 : Major differences between Archaea and Bacteria

Character	Archaea	Bacteria
Cell wall contains muramic acid	–	+
Cross-links in cell wall contains	L-amino acids	D-amino acids
Membrane lipids	Long chain alcohols bound to glycerol by ether linkage	Long chain fatty acids bound to glycerol by ester linkage
First amino acid to initiate protein synthesis	Methionine*	Formylmethionine
Protein synthesis inhibited by chloramphenicol and kanamycin	–*	+
Protein synthesis inhibited by anisomycin	+*	–
Polypeptide chain elongation factor EF-2 inhibited by diphtheria toxin	+*	–
DNA-dependent RNA polymerase inhibited by rifampicin and streptolydigin	–*	+
RNA polymerases consist of	8-12 subunits**	4 subunits
Ribothymin present in one arm (TψC) of t-RNA	+	–
Photosynthetic ability	–	+
Ability to grow at 100°C or above	+	–
Extreme halophilism (1.5 M NaCl or more)	+	–

* Similarity with eukaryotes

** Eukaryotic RNA polymerases contain 12-14 subunits.

From Table IV-1 it is evident that in several features the archaebacteria resemble eukaryotes r than bacteria, particularly in characters relating to the information processing system, like transcri and translation. The presence of these differentiating features strongly indicates that archaebacteri other prokaryotes evolved as separate lines from a very remote past. Similarities between archaeba and eukaryotes also suggest that the eukaryotes evolved from the archaebacterial line afte archaebacteria branched of from the rest off the prokaryotes (Fig. 4.1) :

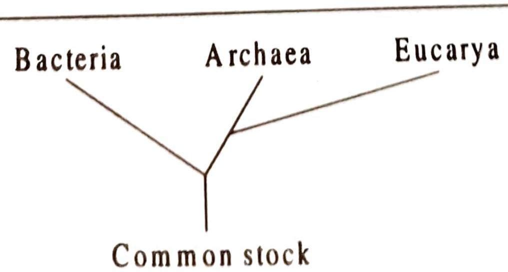


Fig. 4.1 : Probable lines of evolution of Bacteria, Archaea and Eucarya

ine the main components of eukaryotic cells—the internal organelles and fibers—and techniques for their isolation and purification. The extracellular substances that surround cells and give them shape and strength are also investigated. Finally, we discuss the most crucial aspect of cell division, the duplication of the cell in such a way that every daughter cell receives an identical copy of its genetic material. We touch on the marked difference between the way that prokaryotic and eukaryotic cells coordinate DNA synthesis and the subsequent equal partitioning of DNA during cell division. The following chapter will detail the ways in which different types of cells are cultured in the laboratory. The concepts and experimental techniques introduced in these two chapters form the basis of modern molecular cell biology.

➤ *Prokaryotic and Eukaryotic Cells*

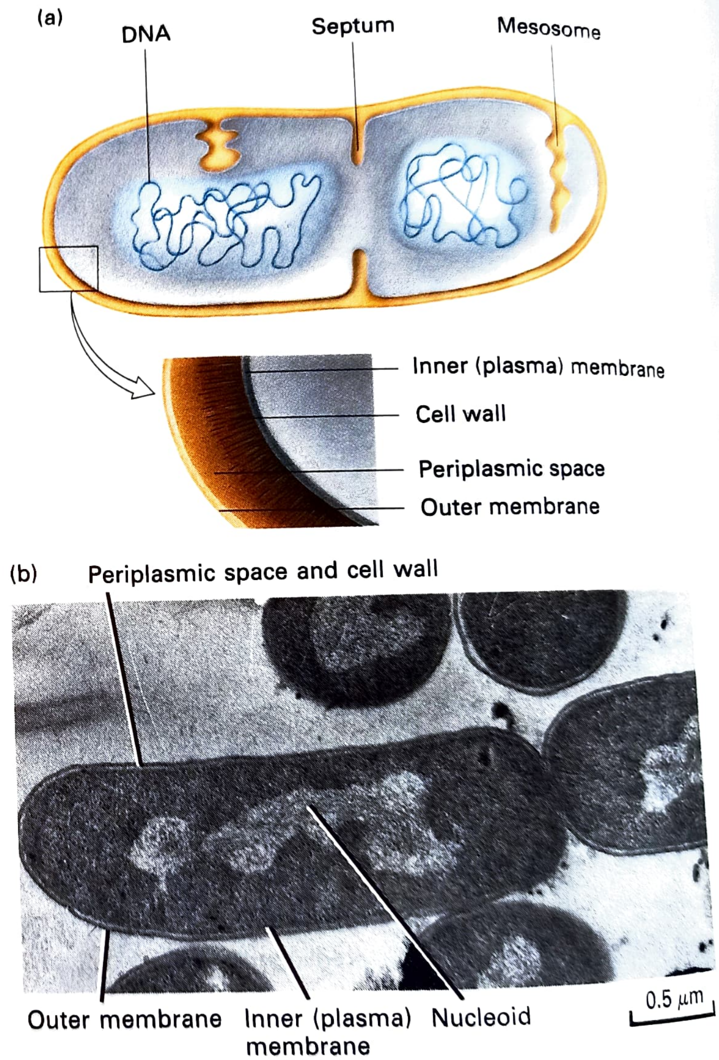
Eukaryotes include all members of the protist, fungus, animal, and plant kingdoms—from the most primitive ferns to the most complex flowering plants, and from amebas and simple sponges to insects and mammals. Although the variety of organisms classified as eukaryotes is large, they all share certain structural features.

Prokaryotes include all bacteria, divided into two separate lineages: *eubacteria* and *archaebacteria*. Most bacteria studied in laboratories are eubacteria (Figure 5-1); in general, when bacterial structure or metabolism is discussed in this book, eubacteria are the subject. The eubacteria include the *photosynthetic organisms* formerly known as *blue-green algae* but better known today as *cyanobacteria*. Less is known about the archaebacteria, which grow in unusual environments. The *methanogens* live only in oxygen-free milieus such as swamps. These bacteria generate methane (CH_4), also known as "swamp gas," by the reduction of carbon dioxide. Other archaebacteria include the *halophiles,* which require high concentrations of salt to survive, and the *thermoacidophiles,* which grow in hot (80°C) sulfur springs, where a pH of less than 2 is common.

Interestingly, the archaebacteria are believed by many to represent a third cell lineage. Although they are prokaryotes, they have numerous eukaryotic features. Like eubacteria, archaebacteria have a circular genomic DNA, yet, like eukaryotes, they have introns in their tRNA genes. Their ribosomal subunits form functional ribosomes with eukaryotic ribosomal subunits and not with those from eubacteria. And, in contrast to eubacteria, they lack a peptidoglycan layer in their cell wall. (These prokaryotic and eukaryotic characteristics will be discussed below; here, it is sufficient to note the differences between the archaebacteria and eubacteria.)

Prokaryotes Have a Relatively Simple Structure

The Plasma Membrane In general, only one type of membrane, the ***plasma membrane,*** forms the boundary of the cell proper in prokaryotes. Like all biological membranes, the structure of the plasma membrane is based on a



▲ FIGURE 5-1 (a) Structure of a gram-negative eubacterial cell; note the periplasmic space between the inner and outer membranes. (b) Electron micrograph of a thin section of *E. coli*, a gram-negative bacterium. The micrograph shows the inner (plasma) membrane, the outer surface membrane that is part of the cell wall, and the nucleoid, the DNA-containing fibrous central region of the cell. [Part (b) courtesy of I. D. J. Burdett and R. G. E. Murray.]

phospholipid bilayer (see Figure 2-17), which is permeable to certain gases, such as oxygen and carbon dioxide, and to water—these substances can diffuse across it. However, it is virtually impermeable to most molecules that the cell must obtain from its environment, such as sugars, amino acids, and inorganic ions (for example, K^+ or Cl^-). The plasma membrane utilizes many membrane proteins called *channels*, or *transporters*, which allow these and other molecules to enter or leave the cell.

The Outer Membrane and Cell Wall Eubacterial species can be divided into two classes. *Gram-negative bacteria* (those not stained by the Gram technique), such as the common intestinal bacterium *Escherichia coli* (*E. coli*), are surrounded by two surface membranes (Figure 5-1b). The inner membrane is the actual plasma membrane—the major permeability barrier of the cell. The outer membrane is unusual in that it is permeable to many chemicals having a molecular weight of 1000 or more; it contains proteins called *porins*, which line channels large enough to accommodate such molecules. Between the two membranes lie the *cell wall*, containing *peptidoglycan* (a complex of proteins and oligosaccharides that gives rigidity to the cell), and the *periplasm* (a space generally occupied by proteins secreted by the cell). *Gram-positive bacteria,* such as *Bacillus polymyxa,* have only a plasma membrane and a cell wall.

Eukaryotic Cells Have Complex Systems of Internal Membranes and Fibers

Both prokaryotic and eukaryotic cells are surrounded by a plasma membrane. However, unlike most prokaryotic cells, eukaryotic cells also contain extensive internal membranes that enclose specific regions, separating them from the rest of the *cytoplasm,* the region of the cell lying outside of the nucleus. These membranes define a collection of subcellular structures called *organelles.*

The Many Organelles of a Eukaryotic Cell As noted in Chapter 1, the largest organelle in a cell is generally the *nucleus,* which contains most of the cellular DNA and is the site of synthesis of cellular RNAs. Most eukaryotic cells contain many other organelles (Figures 5-2 and 5-3): the *mitochondria,* in which the oxidation of small molecules generates most cellular ATP; the *rough* and *smooth endoplasmic reticula* (ERs), a network of membranes in which glycoproteins and lipids are synthesized; *Golgi vesicles,* which direct membrane constituents to appropriate places in the cell; *peroxisomes* in all eukaryotes and *glyoxisomes* in plant seeds, which metabolize hydrogen peroxide; and assorted smaller vesicles. Animal cells contain *lysosomes,* which degrade many proteins, nucleic acids, and lipids. Plant cells contain *chloroplasts,* the site of photosynthesis. Both plant cells and certain eukaryotic microorganisms contain one or more *vacuoles* (see Figure 5-3a on page 146), large fluid-filled organelles that store many nutrient and waste molecules and also participate in the degradation of cellular proteins and other macromolecules. Each type of organelle plays a unique role in the growth and metabolism of the cell, and each contains a collection of specific enzymes that catalyze requisite chemical reactions. Some of this specificity resides in the organelle membranes, to which a number of the enzymes and other proteins are bound.

The Cytoskeleton The *cytosol* is the part of the cytoplasm that is not contained in membrane-limited organelles. The cytosol of eukaryotic cells contains an array of fibrous proteins collectively called the *cytoskeleton.* Among these fibers are the *microfilaments,* built of the protein actin; the somewhat wider *microtubules,* built of tubulin; and the *intermediate filaments,* built of one or more rod-shaped protein subunits. Cytoskeletal fibers give the cell strength and rigidity. They also control movement within the cell; microtubules, for instance, are critical to chromosomal movement during cell division. Some cytoskeletal fibers may connect to organelles or provide tracks along which organelles move.

Eukaryotic Cell Walls Plant cells are surrounded by a rigid cell wall containing cellulose and other polymers, which also contributes to the strength and rigidity of the cell. Fungi are also surrounded by a cell wall, but of different composition from the walls of bacterial or plant cells. During cell growth, a cell wall must expand; during cell division, a new wall must be laid down between the two daughter cells. Animal cells generally are not surrounded by walls.

Prokaryotes and Eukaryotes Contain Similar Macromolecules

The volume of a typical animal or plant cell is several hundred times that of a typical bacterial cell, yet the chemical composition of prokaryotic and eukaryotic cells is strikingly similar. By weight, about 70 percent of a typical cell is water. Other small molecules, including salts, lipids, amino acids, and nucleotides, account for another 7 percent. About 20 percent is protein, 2 percent is RNA, and less than 1 percent is DNA, the genetic material. These proportions are actually useful to know, as seen by the following examples.

Calculating the Abundance of Important Proteins Consider a hepatocyte, the major cell type in the liver. It is roughly a cube 15 μm on a side, with a volume of $(0.0015\ \text{cm})^3$, or 3.4×10^{-9} ml. Assuming a cell density of $\approx$1.03 g/ml, the cell would weigh 3.5×10^{-9} g, 20 percent of which, or 6.9×10^{-10} g, would be protein. Since the

Since each … size an average protein of ≈400 amino acids, in 24 hours the 4 million ribosomes in a HeLa cell would synthesize about 1.1×10^{10} protein molecules. This is almost exactly what is required to allow the cell to divide every 24 hours, given that some proteins have very short lifetimes and need to be synthesized repeatedly during cell growth. This calculation indicates that the number of ribosomes within a cell is regulated so as to meet precisely the needs of a cell for new protein. The levels of all macromolecules within a cell are precisely controlled, as later chapters will emphasize repeatedly.

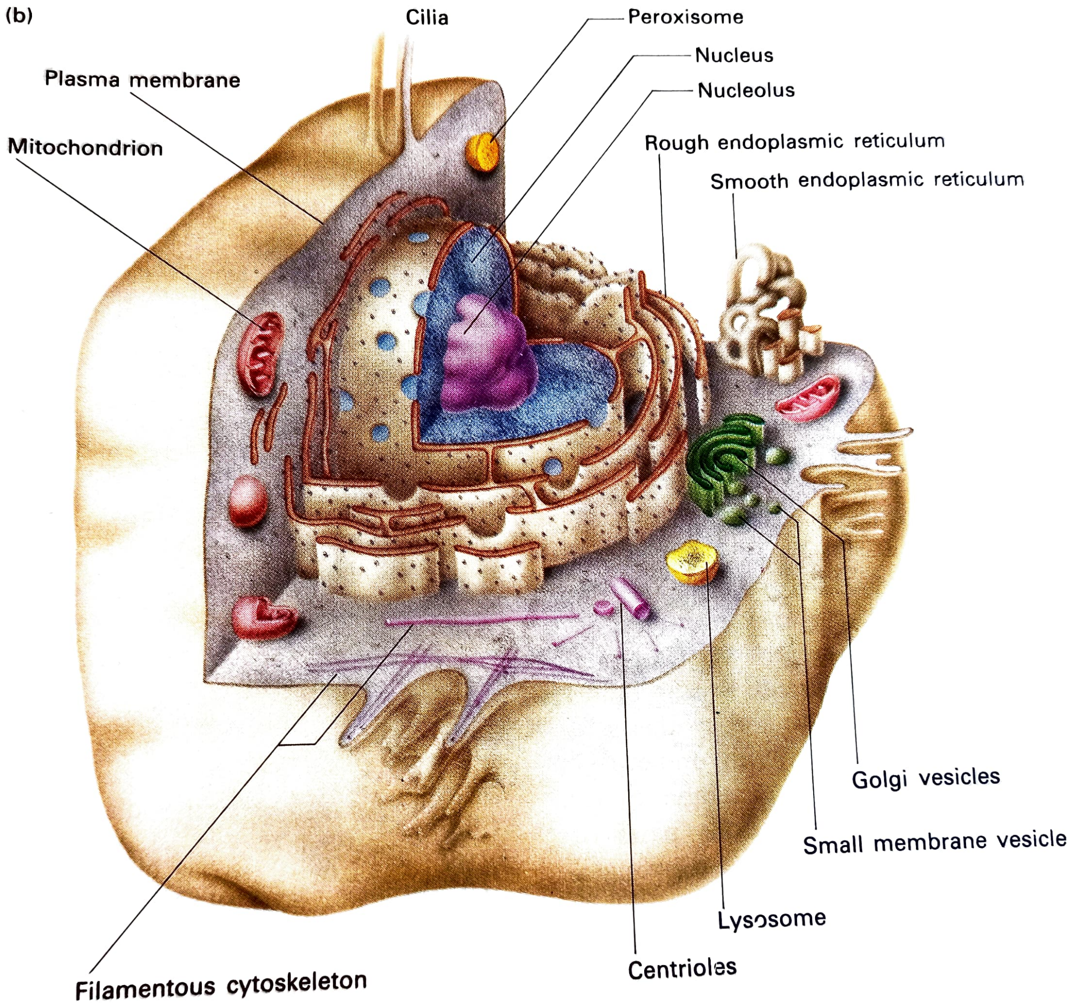
every animal cell contains all of the organelles, granules, and fibrous structures shown here, and other substructures can be present in some cells. Animal cells also differ considerably in shape and in the prominence of various organelles and substructures. [Part (a) courtesy of Biophoto Associates.]

Prokaryotes and Eukaryotes Differ in the Amount of DNA per Cell

The differences in genetic organization between typical prokaryotic and eukaryotic cells become obvious when we consider the amount of DNA per cell (Table 5-2). The genome of *E. coli* contains 4.4×10^{-15} g, or 0.0044 picograms (pg), of DNA, an amount equal to 4×10^6 base pairs. Because three DNA bases encode each amino acid in a protein and an average protein contains about 400 amino acids, approximately 1200 DNA base pairs are used to encode each protein species. Thus *E. coli* DNA has a maximum coding capacity of about 3300 different proteins. Not all of the bacterial DNA encodes proteins, however, although a large part of it does. An *E. coli* cell may actually contain as many as 2000 different species of mRNAs and thus of proteins.

All eukaryotic cells contain more DNA than prokaryotic cells do. Yeast cells, which have some of the smallest genomes among eukaryotes, contain about three times as much DNA as *E. coli* does. The cells of higher plants and animals typically have 40–1000 times as much DNA as

(b)


Cilia
Peroxisome
Nucleus
Nucleolus
Plasma membrane
Mitochondrion
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Golgi vesicles
Small membrane vesicle
Lysosome
Centrioles
Filamentous cytoskeleton

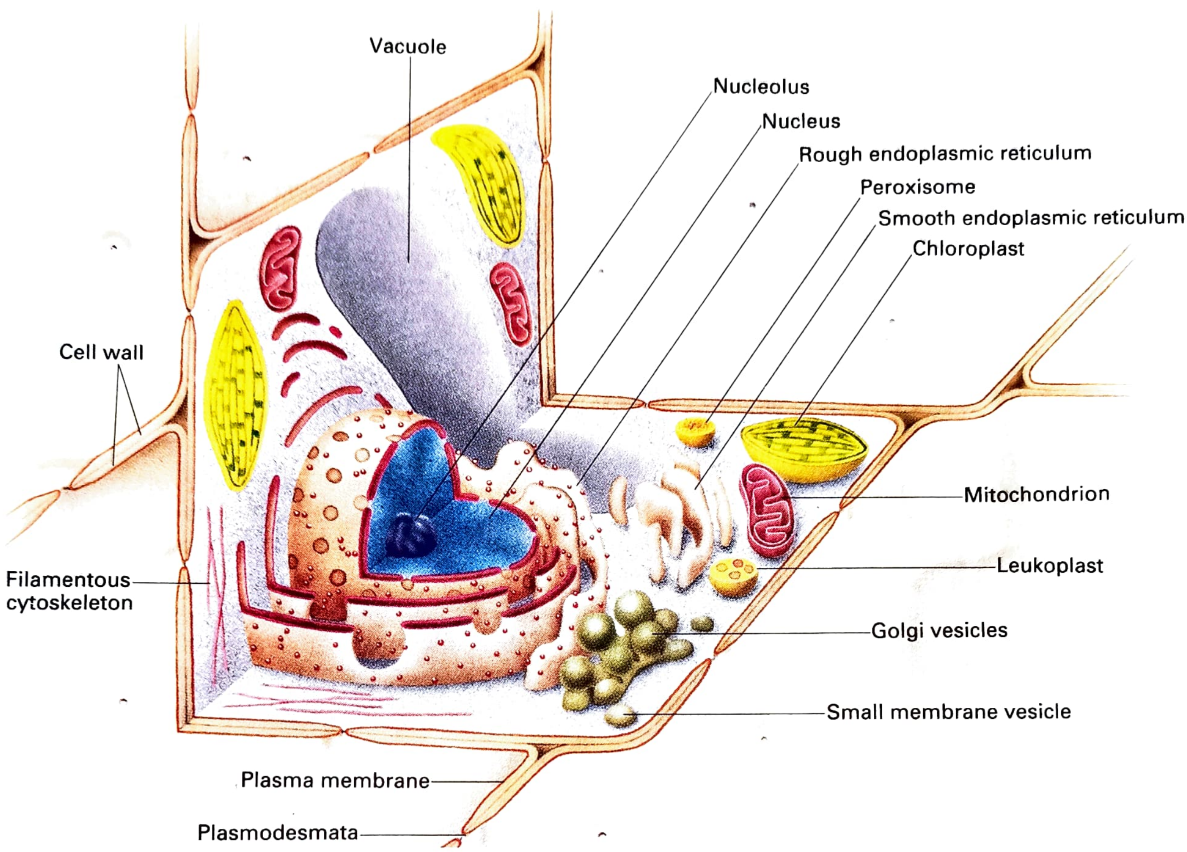
several million different
As detailed in Chapter 27, this variety is generated by rearrangements of DNA segments that encode parts of immunoglobulins and by mutations in these rearranged genes.

TABLE 5-2 The DNA Content of Various Cells

Organism	Size of DNA Genome: Number of Base Pairs	Size of DNA Genome: Total Length (mm)	Maximum Number of Proteins Encoded*	Number of Chromosomes (haploid)†
PROKARYOTIC				
Escherichia coli (bacterium)	4×10^6	1.36	3.3×10^3	1
EUKARYOTIC				
Saccharomyces cerevisiae (yeast)	1.35×10^7	4.60	1.125×10^4	17
Drosophila melanogaster (insect)	1.65×10^8	56	1.375×10^5	4
Homo sapiens (human)	2.9×10^9	990	2.42×10^6	23
Zea mays (corn)	5.0×10^9	1710	4.0×10^6	10

*Assuming 1200 base pairs per protein.
†Most insect and human cells are diploid, so they have twice the number of chromosomes shown.

(b)



The Organization of DNA Differs in Prokaryotic and Eukaryotic Cells

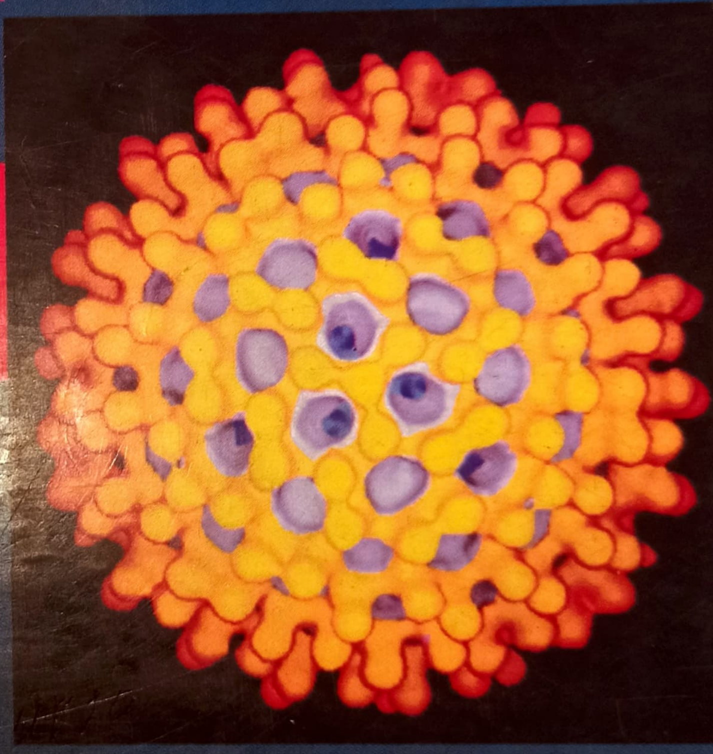
In all prokaryotes studied to date, most or all cellular DNA is in the form of a single circular molecule. The cell is said to have a single *chromosome,* although the arrangement of DNA within this chromosome differs greatly from that within the chromosomes of eukaryotic cells. Rapidly growing cells may have up to four copies of this chromosome.

Prokaryotic cells lack, as we have said, a membrane-bound nucleus; most of the genomic DNA lies in the central region of the cell (see Figure 5-1). The DNA must be folded back on itself many times: one *E. coli* chromosomal DNA molecule stretched out to its full length would be over 1 millimeter (mm) long, or 1000 times as long as the cell itself.

The nuclear DNA of all eukaryotic cells, in contrast, is divided between two or more chromosomes which, except during cell division, are contained in a membrane-bound nucleus. The number and size of individual chromosomes vary widely among different eukaryotes (see Chapter 9). Yeasts, for example, have 12–18 chromosomes, each of which contains, on average, only 20 percent of the DNA in an *E. coli* chromosome. Human cells, at the other extreme, contain two sets of 23 chromosomes, each of which has about 30 times the amount of DNA present in an *E. coli* chromosome. Each eukaryotic chromosome is believed to contain a single, linear, double-stranded DNA molecule.

Despite their many differences, prokaryotic and eukaryotic cells have many biochemical pathways in common, and in most aspects the translation of mRNA into proteins is similar in all cells. Hence prokaryotes and eukaryotes are believed to be descended from the same primitive cell. Their divergence must have occurred before the separation of plant and animal cells. All extant prokaryotic and eukaryotic cells and organisms are the result of over one billion years of biological evolution. It is not surprising, then, that cells are so well adapted to their own environmental niches.

Fundamentals of MICROBIOLOGY AND IMMUNOLOGY



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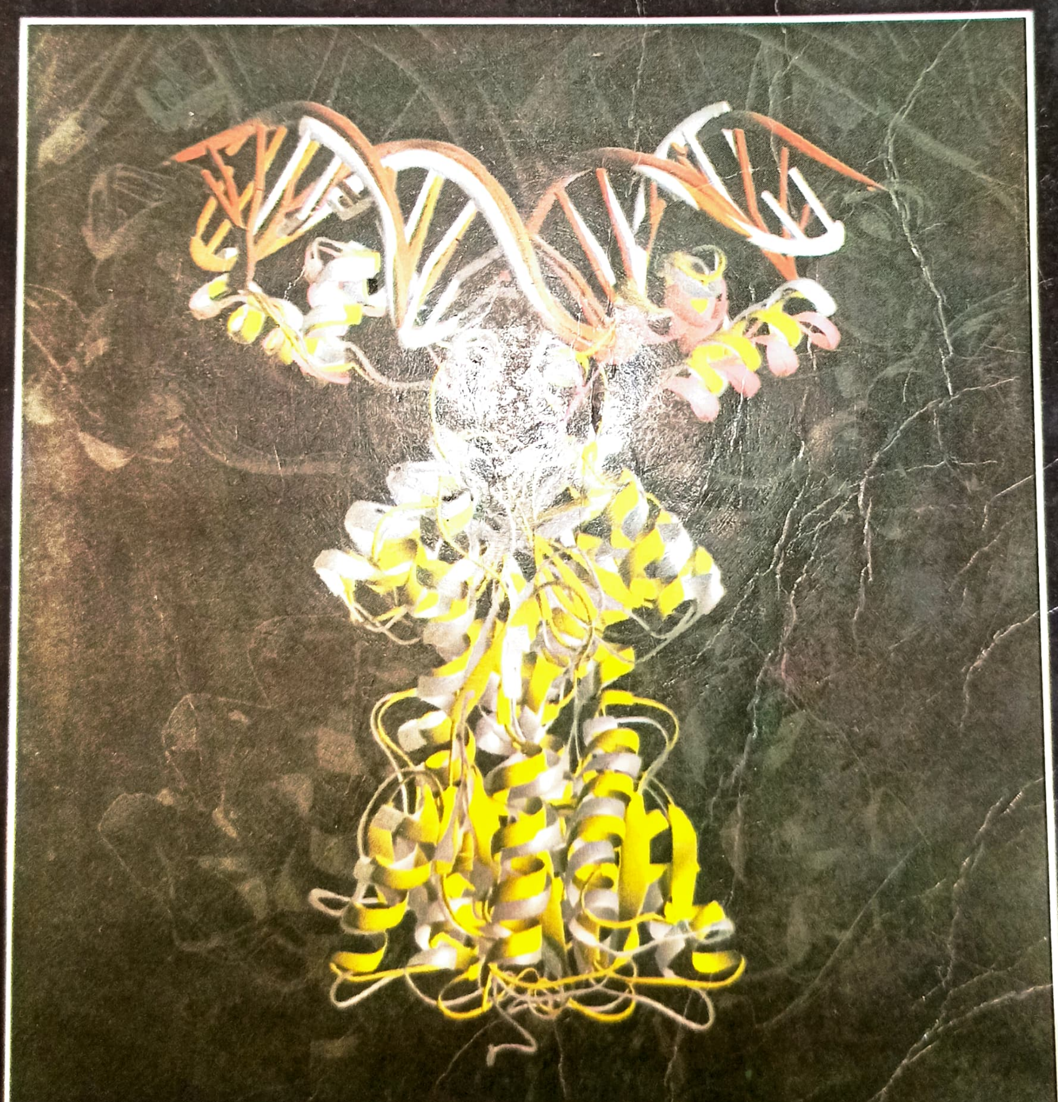
CELL AND MOLECULAR BIOLOGY



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