All organisms from the simplest to the most complex plant or animal are composed of cells. Some organisms, like a bacterium or an amoeba, consist of a single cell. A complex organism like an adult human is made up of more than one hundred trillion (10^{14}) cells. The appearance, behavior, activities, and functions of all organisms represent the sum total of the properties of the cell or cells of which they are made. Therefore, the study of the cell is overwhelmingly important for understanding life in all its forms.

The contemporary study of the cell is an enormous enterprise that combines many scientific disciplines and methods, including microscopy, genetics, biochemistry, biophysics, and physiology. New information has accumulated rapidly, particularly in the last 30 years, and a great deal about cells is now understood—how they function, how they are constructed, and how they work together within a multicellular organism. However, much remains to be learned.

The beginnings of cell biology go back more than three centuries to discoveries by the first pioneering microscopists. In 1665 the Englishman Robert Hook observed the cell walls of cork with a primitive microscope and also discovered the cellular nature of a living plant leaf. A leaf was easily studied with Hooke's microscope because a leaf is thin enough for light to pass through, allowing its large cells to be seen (Figure 1-1). Hooke applied the term *cell* to describe the microscopic units he discovered. A contemporary of Hooke, Antonie van Leeuwenhoek, discovered sperm cells, red blood cells, and many kinds of microorganisms using a microscope consisting of a single lens. These early observations set the stage for almost two centuries of microscopic studies. As microscopes gradually improved, the cell nucleus was discovered, and the cellular nature of all plants and animals came to be recognized. By the 1830s enough observations had been accumulated to allow Schleiden, a botanist, and Schwann, a zoologist, to propose that *all organisms are constructed of cells,* a statement now known as the **cell doctrine.** This pronouncement constitutes the first major tenet upon which the contemporary science of cell biology is

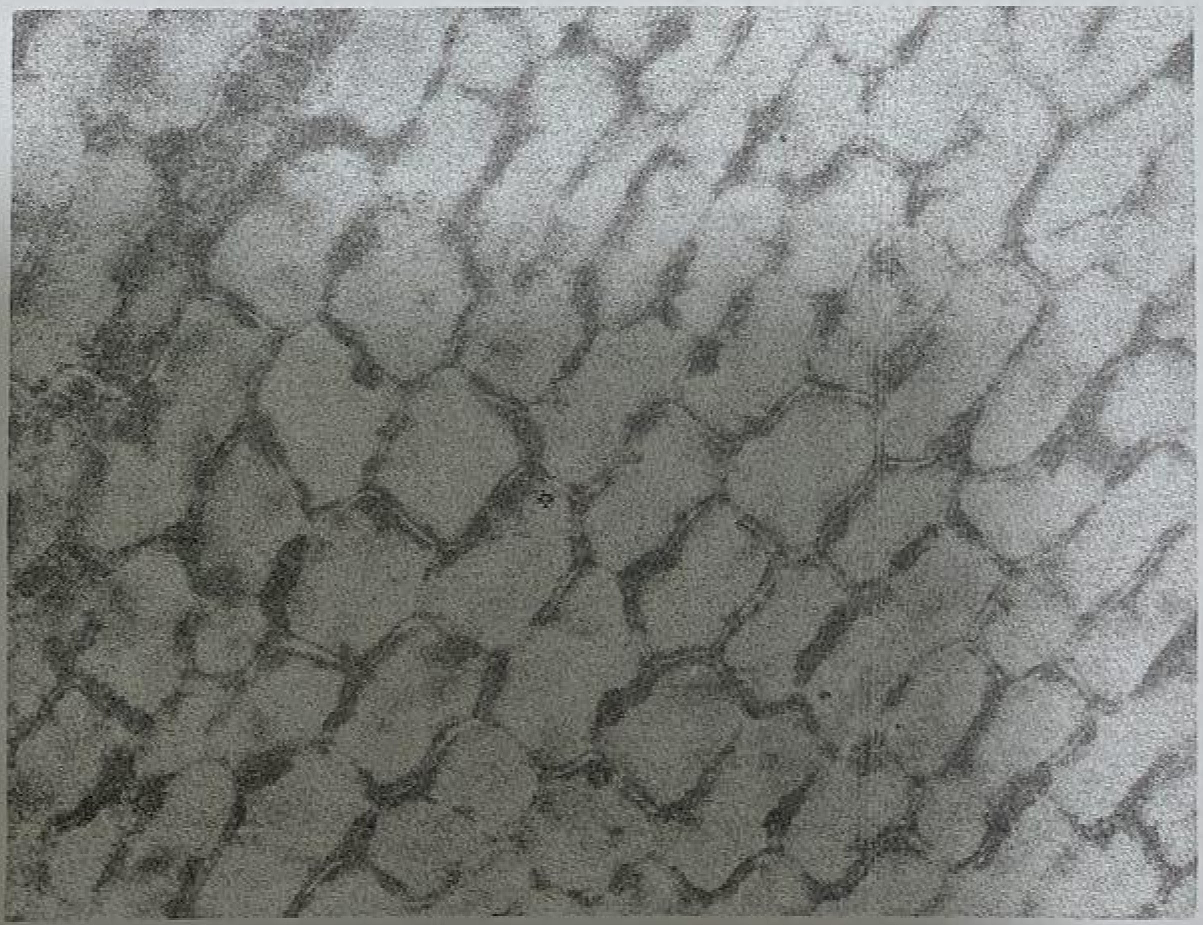

FIGURE 1-1

Light micrograph of living cells in a water fern. The walls of plant cells are prominent and were readily seen by microscopists using a single-lens microscope. In this micrograph most of the cell volume is occupied by the large central vacuole, obscuring visibility of all internal structur except a few chloroplasts (small spheres founded. Following the formulation of the cell doctrine, biologists established that new cells do not arise *de novo* but come only by **cell division,** that is, division of a preexisting cell into two daughter cells. By the end of the nineteenth century, cell biologists had discovered chromosomes and described **mitosis**—the distribution at cell division of chromosomes to daughter cells. Studies that followed soon led cell biologists to conclude that chromosomes are the hereditary material, and that during cell division, the process of mitosis distributes this material equally to the two daughter cells.

Although microscopic studies from 1665 to 1900 convinced cell biologists that the cell is the building block of all multicellular organisms, a major question remained: Were microorganisms such as bacteria and protozoa single-celled organisms or were they instead noncellular or acellular? As biologists came to understand the genetic, physiological, and biochemical properties of cells, it became clear that microorganisms are single, free-living cells. All modern research recognizes that in both unicellular and multicellular organisms *the cell is the fundamental structural unit,* housing the genetic material and the biochemical organization that account for the existence of life.

This book describes the main elements of what has been learned so far about cells: how they are constructed and how they carry out such activities as self-maintenance, growth, cell division, differentiation, movement, sensory perception, and cell–cell communication. The discussions of cell activities and structures are based on integration of various kinds of information derived both from the more traditional tools (microscopy, physiology, and conventional genetics) and from the more recent approaches of biochemistry, macromolecular chemistry, and molecular genetics. Integration information derived from these diverse disciplines should eventually provide a complete understanding of all the functional and structural properties of cells.

ALL CELLS POSSESS THE SAME BASIC PROPERTIES

We speak of *the* cell, yet one must be aware of the tence of millions of different species of cells that show tremendous diversity in structure and metabolic capabilities. A bacterium, a yeast, an amoeba, a plant cell, and a liver cell would appear to be so different in structure and life-style that they might seem to have little in common, yet the similarities among these diverse cell types are more profound than the differences. The main properties in common are the following:

1. All cells store information in genes made of DNA.
2. The genetic code used in the genes of all cells is, with minor exceptions, the same.
3. All cell types decode the genes in their DNA by an RNA system that translates genetic information into proteins.
4. All cells synthesize proteins using a structure called the ribosome.
5. Proteins govern function and structure in all cells.
6. All cells need energy to maintain their internal environment and to drive the synthesis of their complex constituents. All cells use the molecule ATP as the currency for transfer of energy from energy sources to energy needs.
7. All cells are enclosed by a plasma membrane composed of proteins and a double layer of lipid molecules.

Because of these similarities, it is possible to generalize about the structures and functions of cells. One can begin constructing a set of principles of function and structure that has been present throughout the evolution of the great diversity of cell types that now exists.

CLASSIFICATION OF CELLS—PROKARYOTES AND EUKARYOTES

On the basis of certain major properties, all cell types currently found on this planet fall into two major groups: the **prokaryotes** and the **eukaryotes.** *Karyote* is a word root meaning nucleus. The word *prokaryote* (before a nucleus) therefore designates cells that do not have a structurally delineated unit containing the ge-

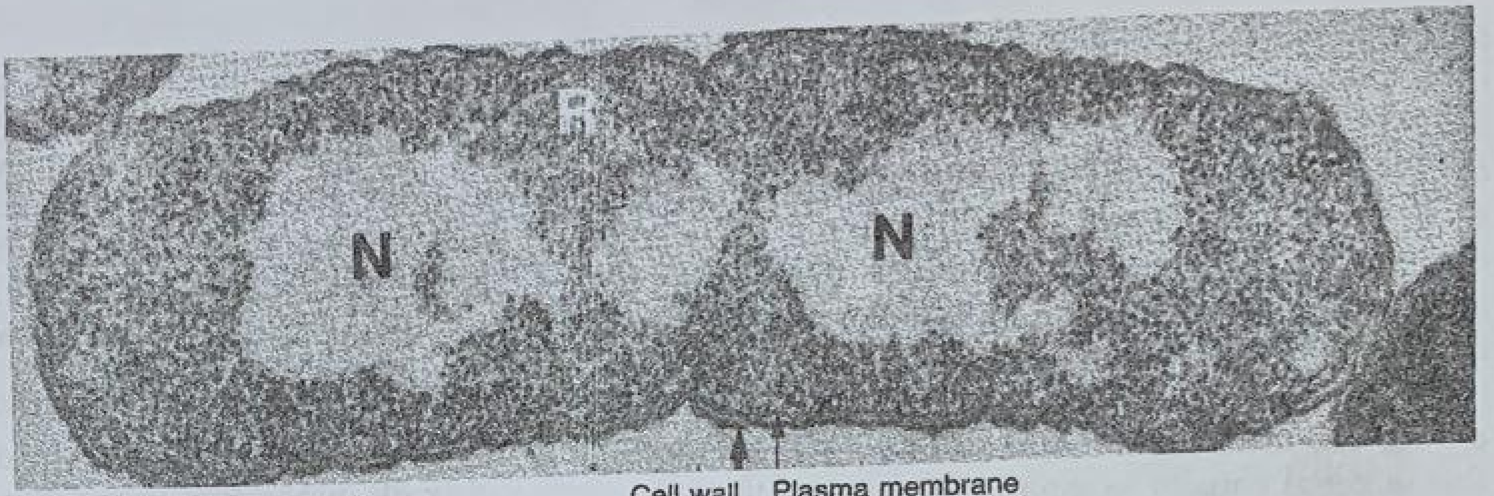

FIGURE 1-2

A section through a bacterial cell (*E. coli*) observed with an electron microscope. The cell is enclosed by a wall (thick arrow). The plasma membrane (thin arrow) is just inside the cell wall. The granular appearance is due to ribosomes (R). The lighter regions are portions of the nucleoid (N), which is separating into two parts. The cell is about to divide, as indicated by the slight indentation of the cell wall in the middle of the cell. [Courtesy of Nanne Nanninga. From *Molecular Cytology of Escherichia coli* (1985) N. Nanninga, ed. Academic Press, London.]

netic material (a nucleus). *Eu* means true; hence, the word *eukaryote* (true nucleus) designates cells that have a well defined nucleus whose chromosomal material is separated from the remainder of the cell contents (the cytoplasm) by a nuclear envelope. Prokaryotes do not have a nuclear envelope. The nucleus of a prokaryote is less well delineated and is usually called a **nucleoid** (see Figure 1-2). The prokaryotic cells are the bacteria, and all are unicellular. These include the blue-green bacteria, or *cyanobacteria,* which were until recently called blue-green algae. All other cell types are eukaryotes. These include many unicellular organisms, for example, protozoa, fungi, and some algae, as well as all multicellular plants and animals.

Originally, prokaryotes were distinguished from eukaryotes on the basis of a single characteristic, the absence of a nuclear envelope. Subsequently, other equally distinct differences have been discovered. The main differences are listed in Table 1-1. Some of the characteristics listed in Table 1-1 need explanations, for example introns in genes; the explanations are given in later chapters. Prokaryotic cells are both smaller and structurally less complex than eukaryotic cells. In addition, eukaryotes contain far more DNA than prokaryotes. Among the hundreds of eukaryotes examined, those with the least amount of DNA (yeast cells) still have several times more than the prokaryote thought to possess the most DNA (the bacterium *Serratia marcescens*). This difference in DNA content reflects the fact that eukaryotes are genetically more complex than prokaryotes.

It is thought that prokaryote-like cells preceded eukaryotic cells in evolution and that the first eukaryote evolved from some type of prokaryote, probably a billion or more years ago. We have no clear idea which difference between prokaryotes and eukaryotes was the first to arise; hence, we do not know which of the differences was fundamental in the origination of eukaryotes. Presumably, a prokaryotic cell acquired one or another of the key characteristics for eukaryotes listed in Table 1-1, and this created the potential for subsequent evolution of the other distinguishing characteristics of eukaryotes. For instance, the acquisition through evolution of an unusually large amount of DNA could have been the innovative step that first separated an emerging eukaryote from prokaryotes. What could have brought about an increase in DNA content, however, is not known. Whatever the first step in the origination of eukaryotic cells, that step must have created the potential for great evolutionary diversification. The range in function and structure among contemporary cells is many times greater among eukaryotes than it is among prokaryotes.

Throughout this book comparisons between prokaryotes and eukaryotes enter into discussions of cell