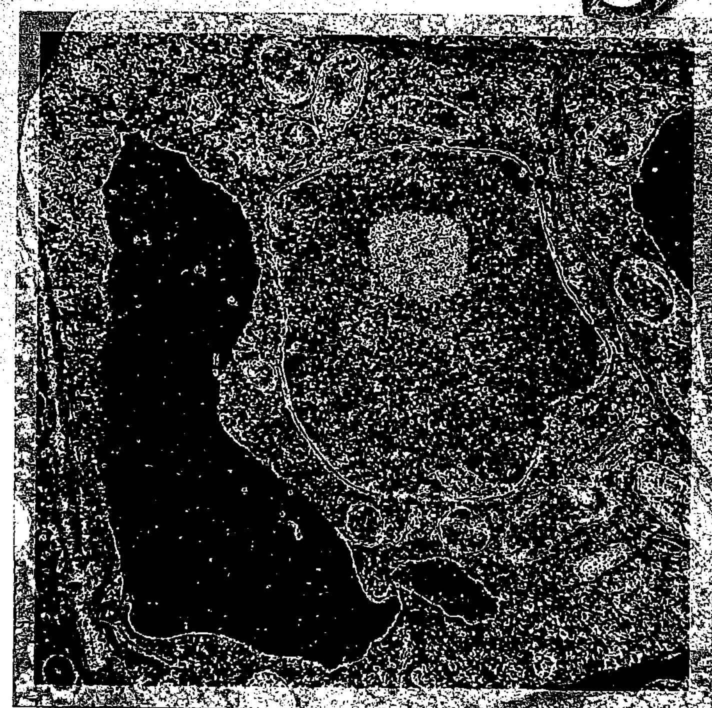
C H A P T E R 3

Cell Structure and Function

Chapter Concepts



The colored micrograph of a plant cell shows you how many structures are packed inside its boundaries.

If you've ever tried to stuff a week's worth of clothing, toiletries, and other necessities into a piece of carry-on luggage, you would be amazed at what cells can pack into a space smaller than the period at the end of this sentence. Like the human body, which is composed of many trillions of cells working in harmony, cells have an internal skeleton that gives them shape and controls their movement. They harbor microscopic assembly lines that manufacture a wide array of proteins. Every cell even has its own power stations that produce energy. And nestled among such structures, often in a specialized area walled off from the rest of the cell, are the all-important chromosomes, which store the instruction manual for life.

The likeness of organisms is revealed at the cellular level. Every cell, whether a plant or human cell, must carry out essentially the same processes—take in and break down nutrients, get rid of wastes, build new parts, and even divide. We will be able to study only one structure or process at a time, but it's important to remember all the activities of a cell go on at the same time. Let's begin our journey to see what cells are made of and what they do during their daily lives.

3.1 The Cellular Level of Organization

The cell marks the boundary between the nonliving and the living. The molecules that serve as food for a cell and the macromolecules that make up a cell are not alive, and yet the cell is alive. Thus, the answer to what life is must lie within the cell, because the smallest living organisms are unicellular, while larger organisms are multicellular—that is, composed of many cells. The diversity of cells is exemplified by the many types in the human body, such as muscle cells and nerve cells. But despite variety of form and function, cells contain the same components. The basic components that are common to all cells regardless of their specializations are the subject of this chapter. The Science Focus on these two pages introduces you to the microscopes most used today to study cells. Electron microscopy and biochemical analysis have revealed that the cell actually contains **organelles,** tiny specialized structures performing specific cellular functions.

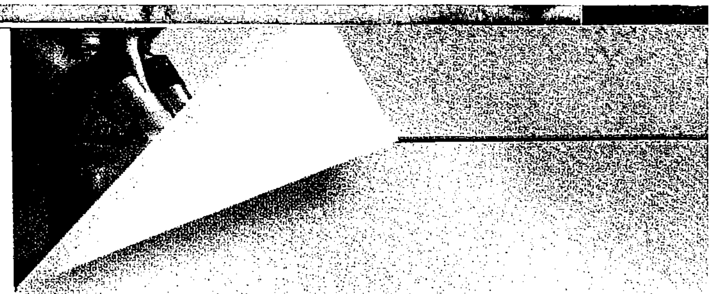
Today we are accustomed to thinking of living things as being constructed of cells. But the word cell didn't enter biology until the seventeenth century. Antonie van Leeuwenhoek of Holland is now famous for making his own microscopes and observing all sorts of tiny things that no one had seen before. Robert Hooke, an Englishman, confirmed Leeuwenhoek's observations and was the first to use the term **cell.** The tiny chambers he observed in the honeycomb structure of cork reminded him of the rooms, or cells, in a monastery.

A hundred years later—in the 1830s—the German microscopist Matthias Schleiden said that plants are composed of cells; his counterpart, Theodor Schwann, said that animals are also made up of living units called cells. This was quite a feat, because aside from their own exhausting work, both had to take into consideration the studies of many other microscopists. Rudolf Virchow, another German microscopist, later came to the conclusion that cells don't suddenly appear; rather, they come from preexisting cells.

Today, the **cell theory,** which states that all organisms are made up of basic living units called cells and that cells come only from preexisting cells, is a basic theory of biology.

The cell theory states the following:

- All organisms are composed of one or more cells.
- Cells are the basic living unit of structure and function in organisms.
- All cells come only from other cells.



Three types of microscopes are most commonly used today: the compound light microscope, transmission electron microscope, and scanning electron microscope. Figure 3A depicts these microscopes, along with a micrograph of red blood cells viewed with each one.

In a compound light microscope, light rays passing through a specimen are brought to a focus by a set of glass lenses, and the resulting image is then viewed by the human eye. In the transmission electron microscope, electrons passing through a specimen are brought to a focus by a set of magnetic lenses, and the resulting image is projected onto a fluorescent screen or photographic film.

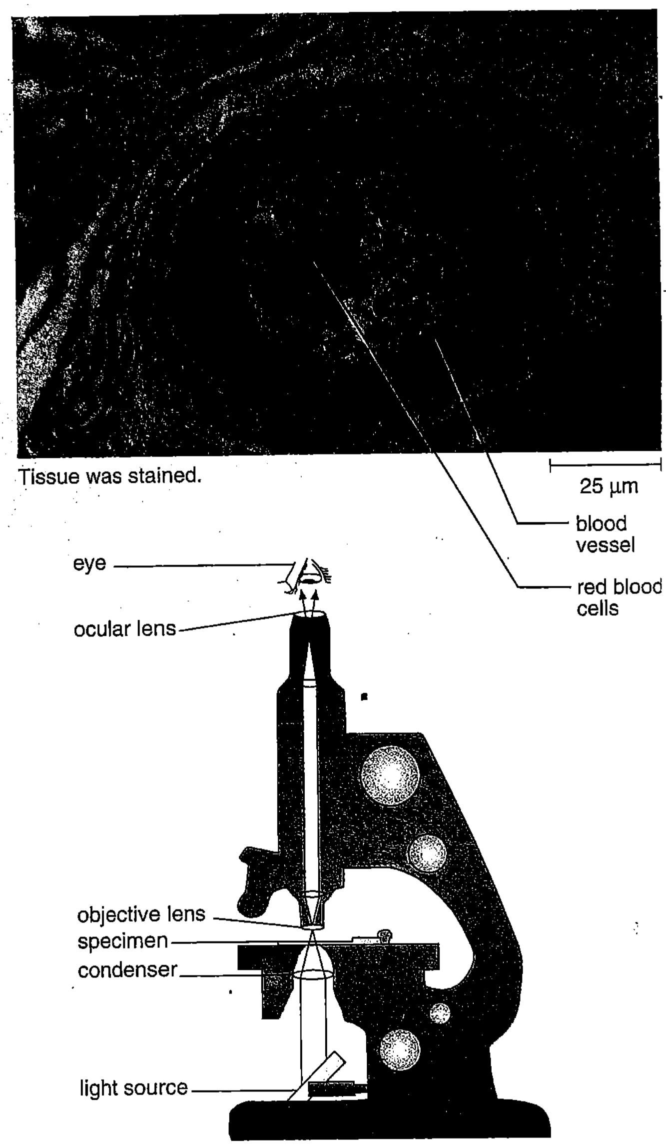


Figure 3A **Blood vessels and red blood cells viewed with three different types of microscopes.**

Science Focus

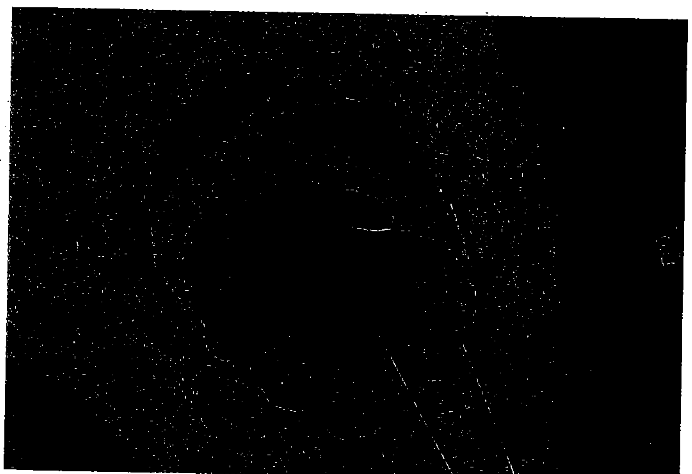
Microscopy Today

The magnification produced by an electron microscope is much higher than that of a light microscope (50,0003 compared to 1,0003). Also, the ability of the electron microscope to make out detail is much greater. The distance needed to distinguish two points as separate is much less for an electron microscope than for a light microscope (10 nm compared to 200 nm[1]). The greater resolving power of the electron microscope is due to the fact that electrons travel at a much shorter wavelength than do light rays. However, because electrons only travel in a vacuum, the object is always dried out before viewing, whereas even living objects can be observed with a light microscope.

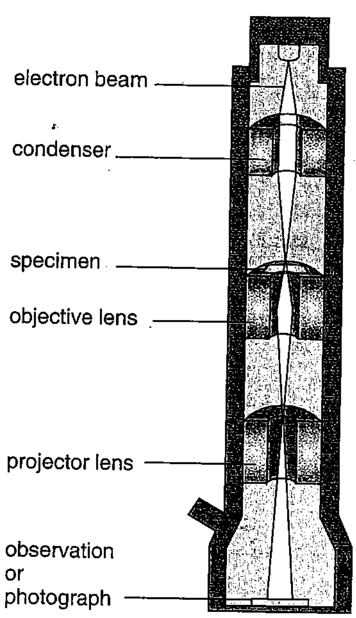
A scanning electron microscope provides a three-dimensional view of the surface of an object. A narrow beam of electrons is scanned over the surface of the specimen, which has been coated with a thin layer of metal. The metal gives off secondary electrons, which are collected to produce a television-type picture of the specimen's surface on a screen.

A picture obtained using a light microscope is sometimes called a photomicrograph, and a picture resulting from the use of an electron microscope is called a transmission electron micrograph (TEM) or a scanning electron micrograph (SEM), depending on the type of microscope used.

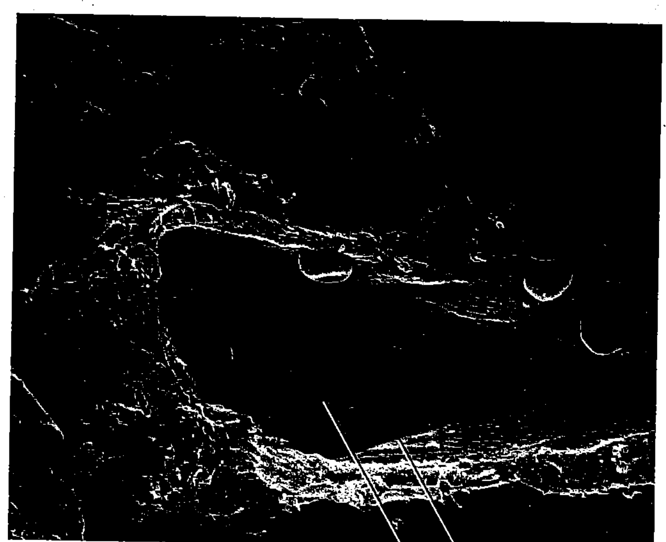
[1]nm = nanometer. See Appendix C, Metric System.



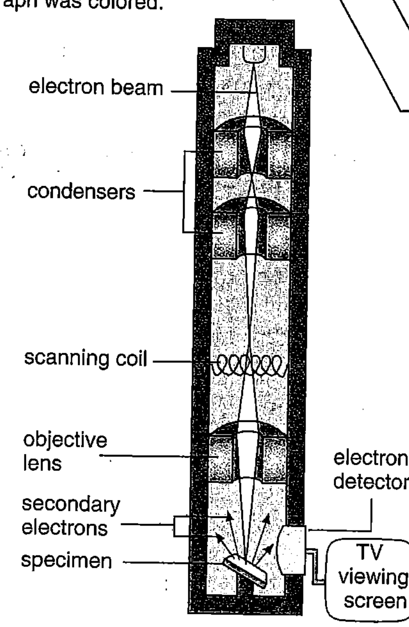
Tissue was stained.



Transmission electron microscope



Micrograph was colored.



Scanning electron microscope

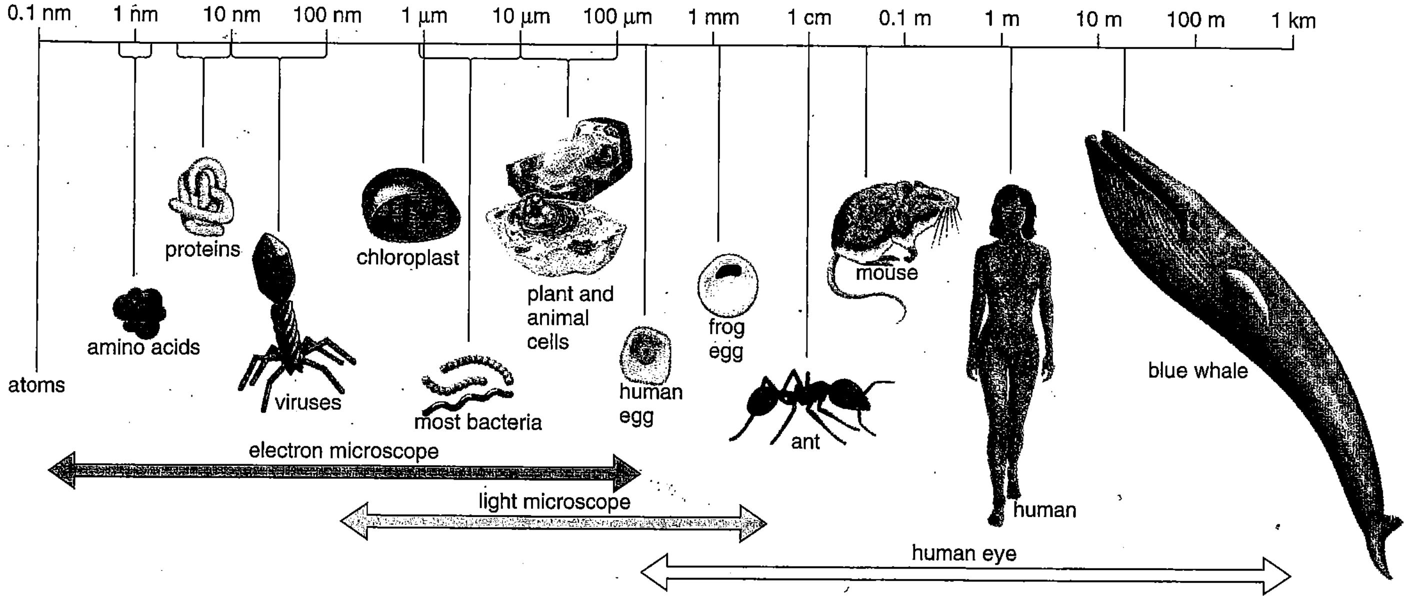
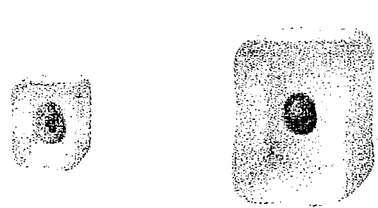


Figure 3.1 The sizes of living things and their components.
It takes a microscope to see most cells and lower levels of biological organization. Cells are visible with the light microscope, but not in much detail. An electron microscope is needed to see organelles in detail and to make out viruses and molecules. Notice that in this illustration each higher unit is 10 times greater than the lower unit. (In the metric system, 1 meter = 10^2 cm = 10^3 mm = 10^6 µm = 10^9 nm—see Appendix C.)

Cell Size

Figure 3.1 outlines the visual ranges of the eye, light microscope, and electron microscope. Cells are quite small. A frog's egg, at about one millimeter (mm) in diameter, is large enough to be seen by the human eye. But most cells are far smaller than one millimeter; some are even as small as one micrometer (µm)—one-thousandth of a millimeter. Cell inclusions and macromolecules are even smaller than a micrometer and are measured in terms of nanometers (nm).

To understand why cells are so small and why we are multicellular, consider the surface/volume ratio of cells. Nutrients enter a cell and wastes exit a cell at its surface; therefore, the amount of surface represents the ability to get material in and out of the cell. A large cell requires more nutrients and produces more wastes than a small cell. In other words, the volume represents the needs of the cell. Yet, as cells get larger in volume, the proportionate amount of surface area actually decreases, as you can see by comparing these two cells:



small cell—
more surface area
per volume

large cell—
less surface area
per volume

A small cube that is 1 mm tall has a surface area of 6 mm^2 because each side has a surface area of 1 mm^2, and 6 × 1 mm^2 is 6 mm^2. Notice that the ratio of surface area to volume is 6:1 because the surface area is 6 mm^2 and the volume is 1 mm^3. Contrast this with a larger cube that is 2 mm tall. The surface area increases to 24 mm^2 because the surface area of each side is 4 mm^2, and 6 × 4 is 24 mm^2. The volume of this larger cube is 8 mm^3 because height × width × depth is 8 mm^3. The ratio of surface area to volume of the larger cube is 3:1 because the surface area is 24 mm^2 and the volume is 8 mm^3. We can conclude then that a small cell has a greater surface area to volume ratio than does a larger cell.

Therefore, small cells, not large cells, are likely to have an adequate surface area for exchanging wastes for nutrients. We would expect, then, a size limitation for an actively metabolizing cell. A chicken's egg is several centimeters in diameter, but the egg is not actively metabolizing. Once the egg is incubated and metabolic activity begins, the egg divides repeatedly without growth. Cell division restores the amount of surface area needed for adequate exchange of materials. Further, cells that specialize in absorption have modifications that greatly increase the surface area per volume of the cell. For example, the columnar cells along the surface of the intestinal wall have surface foldings called microvilli (sing., microvillus), which increase their surface area.

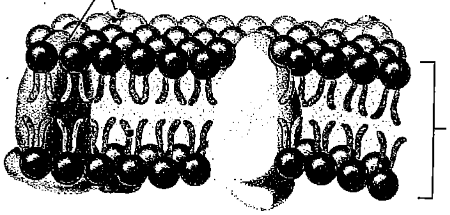
A cell needs a surface area that can adequately exchange materials with the environment. Surface-area-to-volume considerations require that cells stay small.

3.2 Eukaryotic Cells

Eukaryotic cells have a nucleus, a large structure that controls the workings of the cell because it contains the genes.

Outer Boundaries of Animal and Plant Cells

All cells, including plant and animal cells, are surrounded by a **plasma membrane,** a phospholipid bilayer in which protein molecules are embedded.



The plasma membrane is a living boundary that separates the living contents of the cell from the nonliving surrounding environment. Inside the cell, the nucleus is surrounded by the **cytoplasm,** a semifluid medium that contains organelles. The plasma membrane regulates the entrance and exit of molecules into and out of the cytoplasm.

Plant cells (but not animal cells) have a permeable but protective **cell wall** in addition to a plasma membrane. Many plant cells have both a primary and secondary cell wall. A main constituent of a primary cell wall is cellulose molecules. Cellulose molecules form fibrils that lie at right angles to one another for added strength. A cell wall sometimes forms inside the primary cell wall. Such secondary cell walls contain lignin, a substance that makes them even stronger than primary cell walls.

Organelles of Animal and Plant Cells

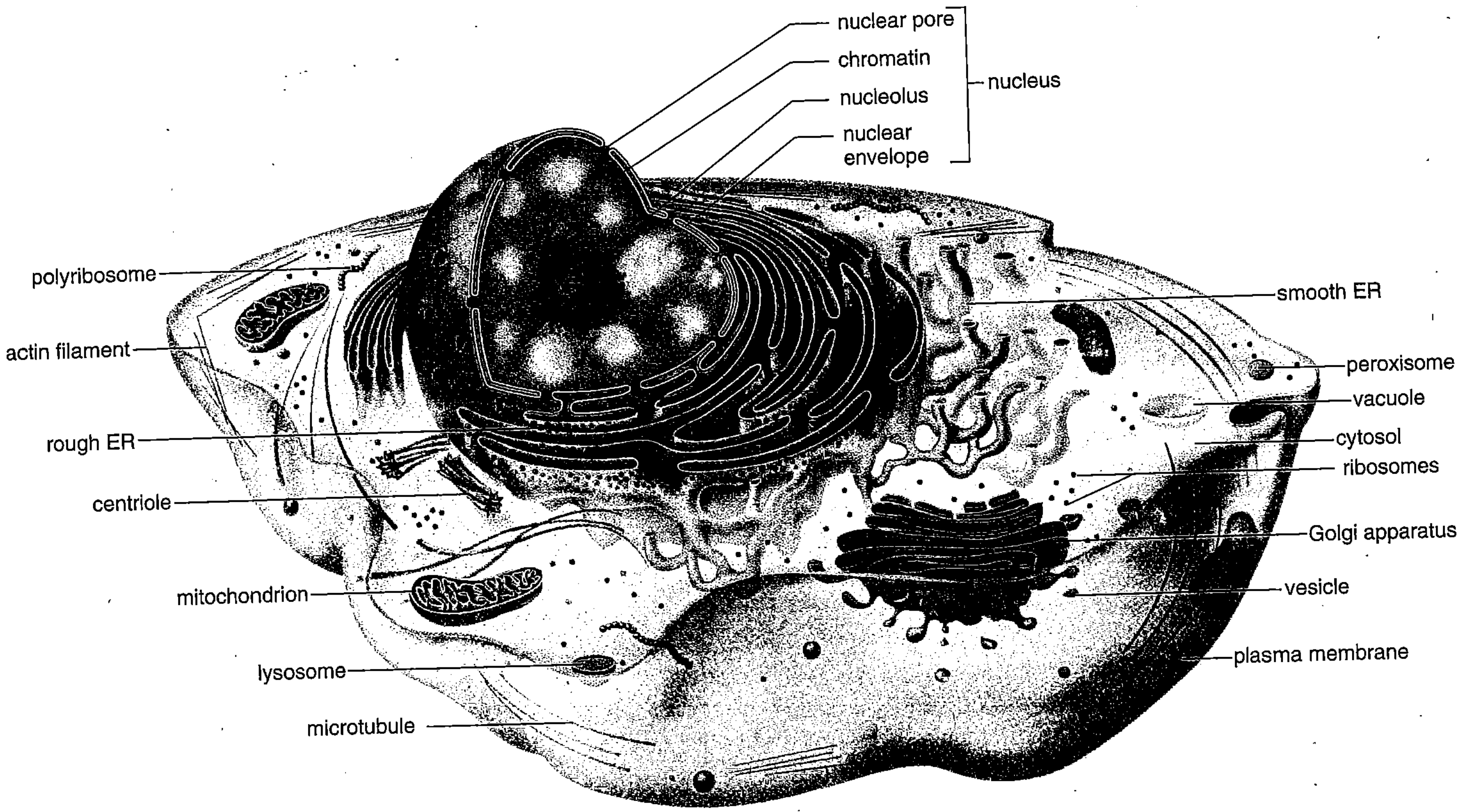
Animal and plant cells contain **organelles,** small bodies that have a specific structure and function. Originally the term organelle referred to only membranous structures, but we will use it to include any well-defined internal subcellular structure (Table 3.1). Still, membranes compartmentalize the cell so that its various functions are kept separate from one another. Just as all the assembly lines of a factory are in operation at the same time, so all the organelles of a cell function simultaneously. Raw materials enter a factory and then are turned into various products by different departments. In the same way, chemicals are taken up by the cell and then processed by the organelles. The cell is a beehive of activity the entire twenty-four hours of every day.

Both animal cells (Fig. 3.2) and plant cells (Fig. 3.3) contain mitochondria, while only plant cells have chloroplasts. Only animal cells have centrioles. Note that the color chosen to represent each structure in the plant and animal cell is used for that structure throughout the chapters of this part.

Table 3.1 Eukaryotic Structures in Animal Cells and Plant Cells

Name	Composition	Function
Cell wall*	Contains cellulose fibrils	Support and protection
Plasma membrane	Phospholipid bilayer with embedded proteins	Defines cell boundary; regulation of molecule passage into and out of cells
Nucleus	Nuclear envelope nucleoplasm, chromatin, and nucleoli	Storage of genetic information; synthesis of DNA and RNA
Nucleolus	Concentrated area of chromatin, RNA, and proteins	Ribosomal subunit formation
Ribosome	Protein and RNA in two subunits	Protein synthesis
Endoplasmic reticulum (ER)	Membranous flattened channels and tubular canals	Synthesis and/or modification of proteins and other substances, and transport by vesicle formation
Rough ER	Studded with ribosomes	Protein synthesis
Smooth ER	Having no ribosomes	Various; lipid synthesis in some cells
Golgi apparatus	Stack of membranous saccules	Processing, packaging, and distribution of proteins and lipids
Vacuole and vesicle	Membranous sacs	Storage of substances
Lysosome	Membranous vesicle containing digestive enzymes	Intracellular digestion
Peroxisome	Membranous vesicle containing specific enzymes	Various metabolic tasks
Mitochondrion	Inner membrane (cristae) bounded by an outer membrane	Cellular respiration
Chloroplast*	Membranous grana bounded by two membranes	Photosynthesis
Cytoskeleton	Microtubules, intermediate filaments, actin filaments	Shape of cell and movement of its parts
Cilia and flagella	9 + 2 pattern of microtubules	Movement of cell
Centriole**	9 + 0 pattern of microtubules	Formation of basal bodies

*Plant cells only
**Animal cells only



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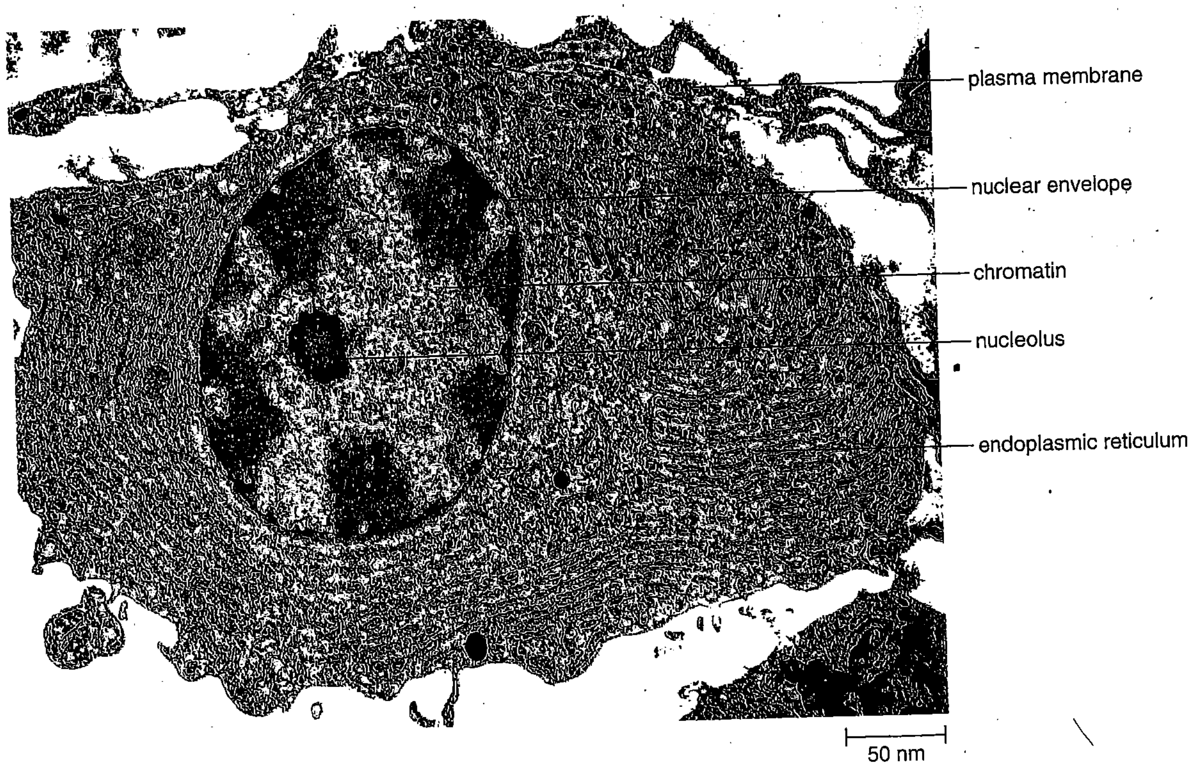
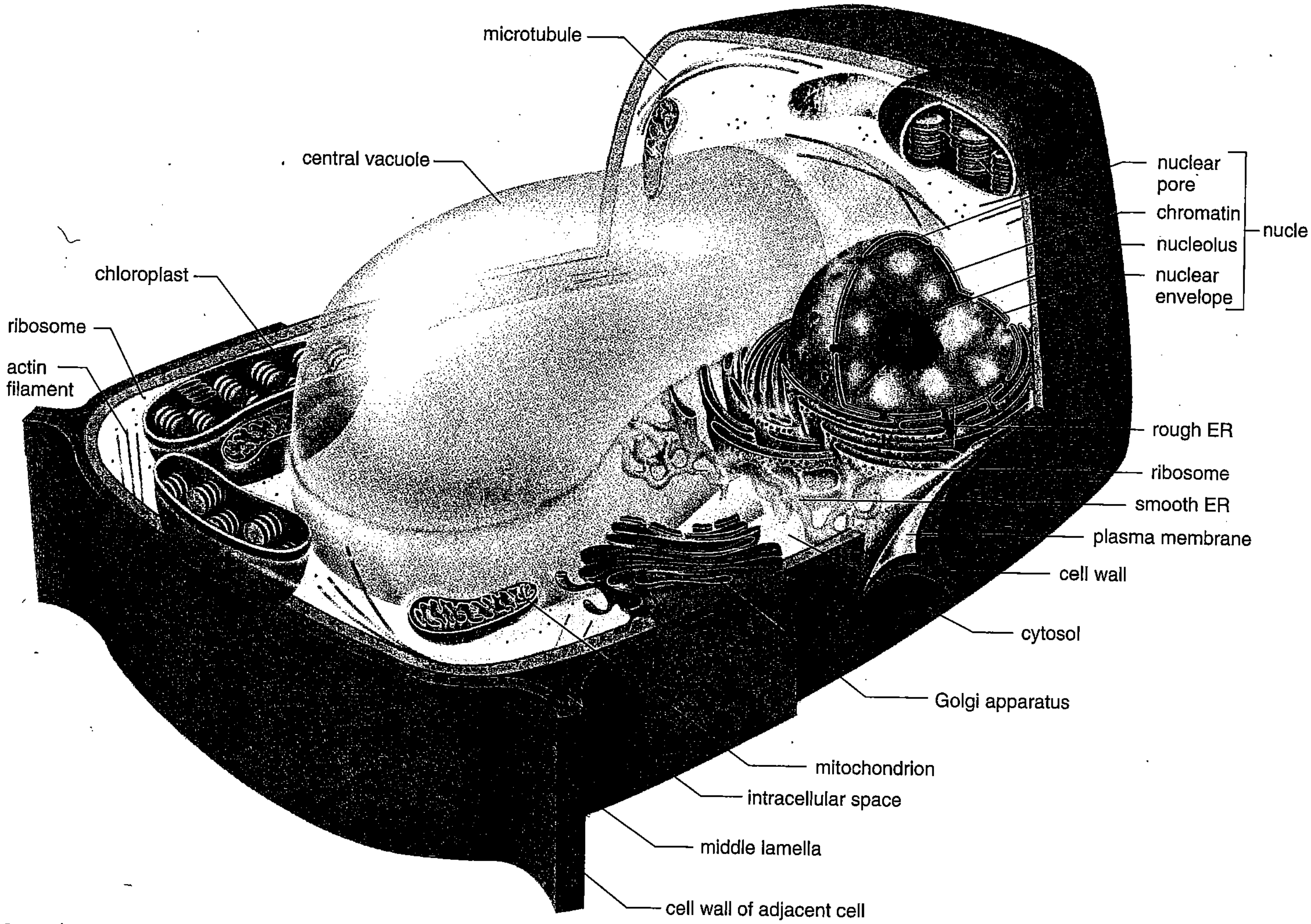
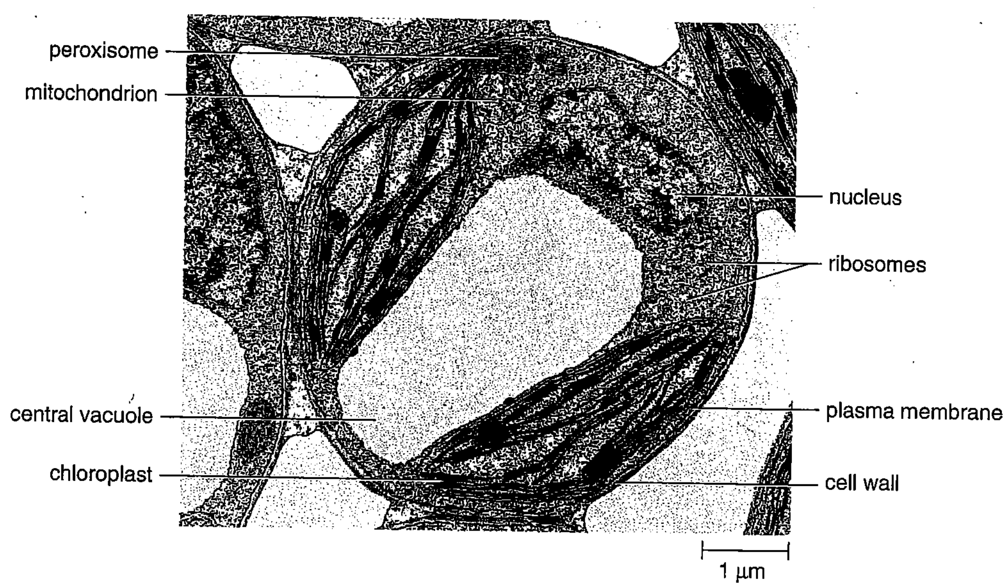


b.

Figure 3.2 Animal cell anatomy.
a. Generalized drawing. **b.** Transmission electron micrograph. See Table 3.1 for a description of these structures, along with a listing of their functions.



a.



b.

Figure 3.3 Plant cell anatomy.
a. Generalized drawing. **b.** Transmission electron micrograph of a young leaf cell. See Table 3.1 for a description of these structures, along with a listing of their functions.

The Nucleus

The **nucleus,** which has a diameter of about 5 μm, is a prominent structure in the eukaryotic cell. The nucleus is of primary importance because it stores genetic information that determines the characteristics of the body's cells and their metabolic functioning. Every cell in the same individual contains the identical genetic information, but each cell type has certain genes, or segments of DNA, turned on, and others turned off. Activated DNA, with RNA acting as an intermediary, specifies the sequence of amino acids when a protein is synthesized. The proteins of a cell determine its structure and the functions it can perform.

When you look at the nucleus, even in an electron micrograph, you cannot see DNA molecules. You can see chromatin, which consists of DNA and associated proteins (Fig. 3.4). **Chromatin** looks grainy, but actually it is a threadlike material that undergoes coiling to form rodlike structures, called **chromosomes,** just before the cell divides. Chromatin is immersed in a semifluid medium called the **nucleoplasm.** A difference in pH between the nucleoplasm and the cytoplasm suggests that the nucleoplasm has a different composition.

Most likely, too, when you look at an electron micrograph of a nucleus, you will see one or more regions that look darker than the rest of the chromatin. These are nucleoli (sing., **nucleolus**) where another type of RNA, called ribosomal RNA (rRNA), is produced and where rRNA joins with proteins to form the subunits of ribosomes. (Ribosomes are small bodies in the cytoplasm that contain rRNA and proteins.)

The nucleus is separated from the cytoplasm by a double membrane known as the **nuclear envelope,** which is continuous with the endoplasmic reticulum discussed on the next page. The nuclear envelope has **nuclear pores** of sufficient size (100 nm) to permit the passage of proteins into the nucleus and ribosomal subunits out of the nucleus.

The structural features of the nucleus include the following.

Chromatin:	DNA and proteins
Nucleolus:	Chromatin and ribosomal subunits
Nuclear envelope:	Double membrane with pores

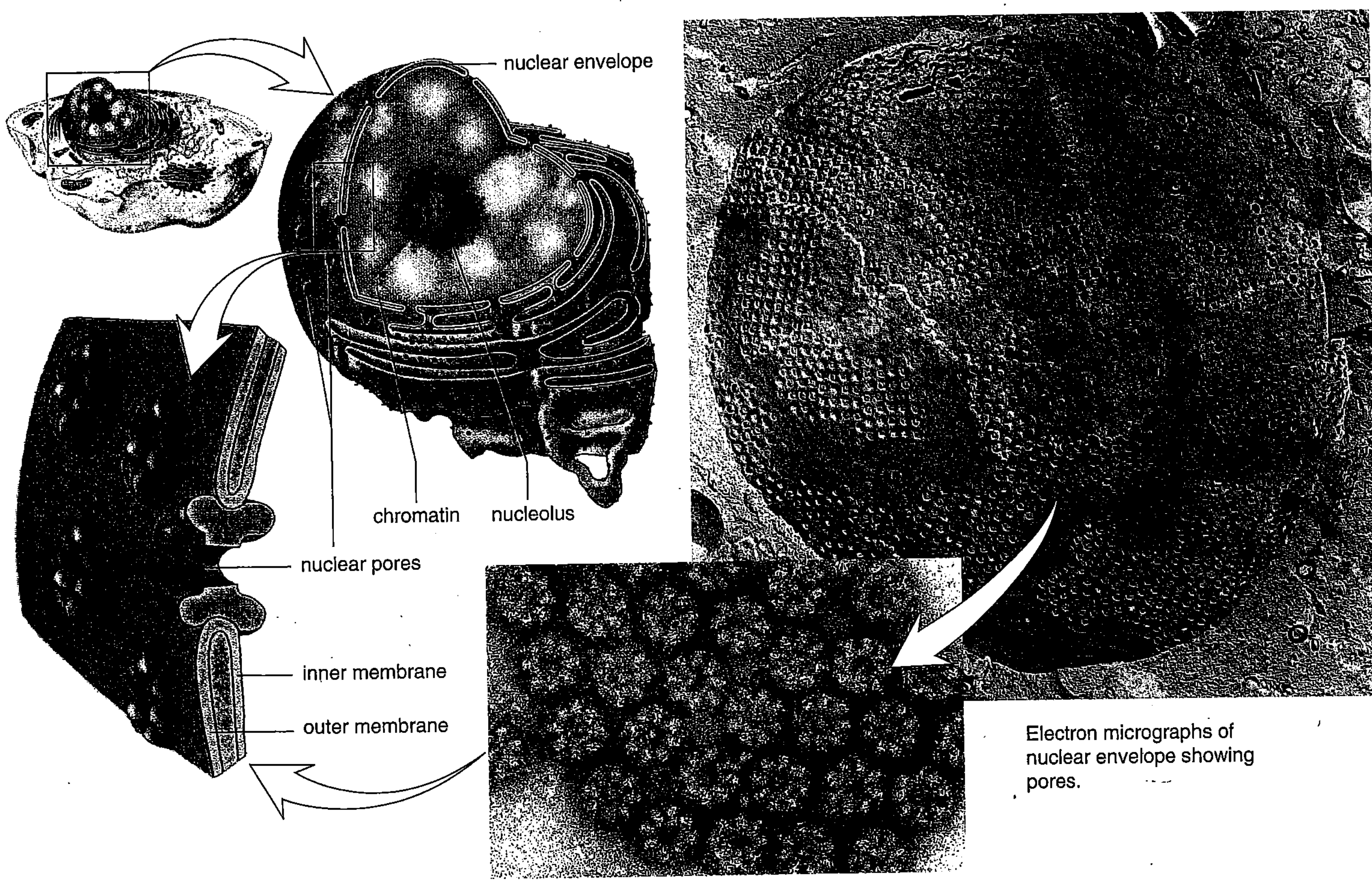


Figure 3.4 The nucleus and the nuclear envelope.
The nucleoplasm contains chromatin. Chromatin has a special region called the nucleolus, where rRNA is produced and ribosomal subunits are assembled. The nuclear envelope, consisting of two membranes separated by a narrow space, contains pores. The electron micrographs show that the pores cover the surface of the envelope.

Ribosomes

Ribosomes are composed of two subunits, one large and one small. Each subunit has its own mix of proteins and rRNA. Protein synthesis occurs at the ribosomes. Ribosomes can be found free within the cytoplasm, either singly or in groups called **polyribosomes.** Ribosomes can also be found attached to the endoplasmic reticulum, a membranous system of saccules and channels discussed in the next section. Proteins synthesized at cytoplasmic ribosomes are used in the cell, such as in the mitochondria and chloroplasts. Those proteins produced at ribosomes attached to endoplasmic reticulum are eventually secreted from the cell or become a part of its external surface.

Ribosomes are small organelles where protein synthesis occurs. Ribosomes occur in the cytoplasm, both singly and in groups (i.e., polyribosomes). Numerous ribosomes are also attached to the endoplasmic reticulum.

The Endomembrane System

The endomembrane system consists of the nuclear envelope, the endoplasmic reticulum, the Golgi apparatus, and several **vesicles** (tiny membranous sacs). This system compartmentalizes the cell so that particular enzymatic reactions are restricted to specific regions. Organelles that make up the endomembrane system are connected either directly or by transport vesicles.

The Endoplasmic Reticulum

The **endoplasmic reticulum** (ER), a complicated system of membranous channels and saccules (flattened vesicles), is physically continuous with the outer membrane of the nuclear envelope. Rough ER is studded with ribosomes on the side of the membrane that faces the cytoplasm (Fig. 3.5). Here proteins are synthesized and enter the ER interior where processing and modification begin. Most of them are modified by the addition of a sugar chain, which makes them a **glycoprotein.**

Smooth ER, which is continuous with rough ER, does not have attached ribosomes. Smooth ER synthesizes the phospholipids that occur in membranes and has various other functions depending on the particular cell. In the testes, it produces testosterone, and in the liver it helps detoxify drugs. Regardless of any specialized function, smooth ER also forms vesicles in which proteins are transported to the Golgi apparatus.

ER is involved in protein synthesis (rough ER) and various other processes such as lipid synthesis (smooth ER). Vesicles transport proteins from the ER to the Golgi apparatus.

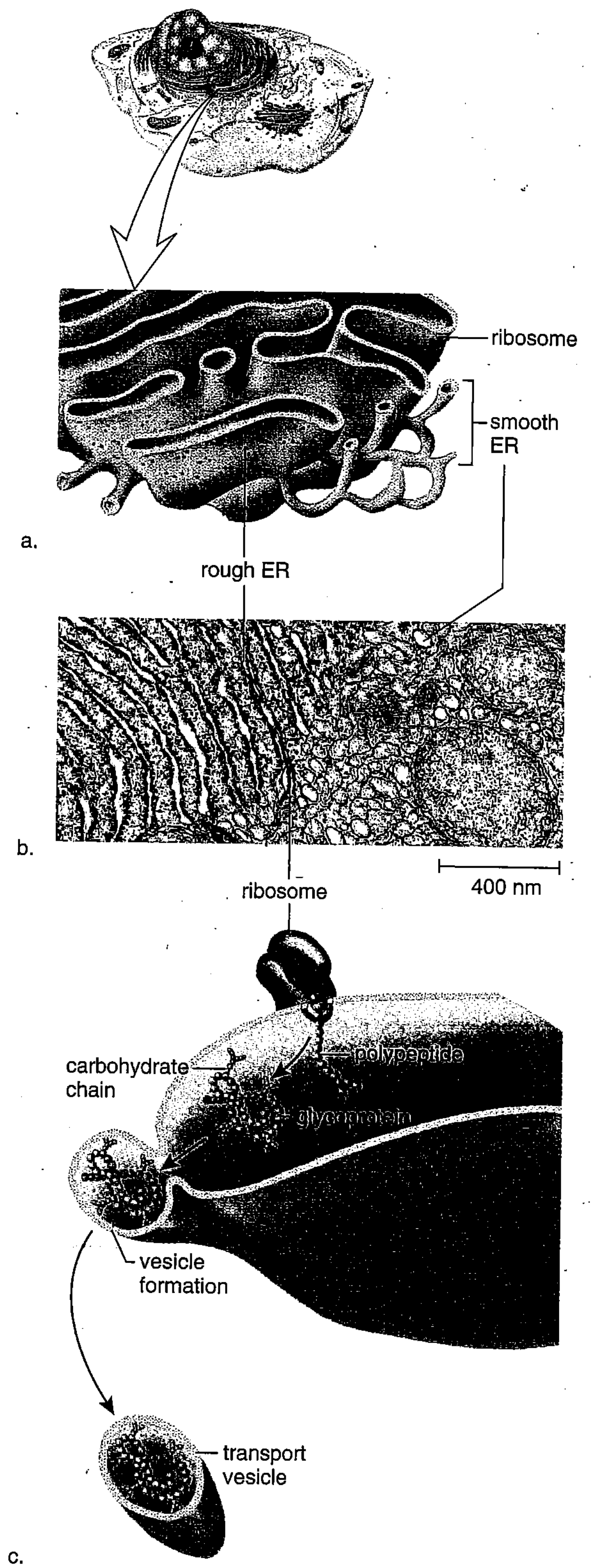


Figure 3.5 The endoplasmic reticulum (ER).
a. Rough ER has attached ribosomes, but smooth ER does not.
b. Rough ER appears to be flattened saccules, while smooth ER is a network of interconnected tubules. **c.** A protein made at a ribosome moves into the lumen of the system, is modified, and is eventually packaged in a transport vesicle for distribution to the Golgi apparatus.