

Figure 3.3 Plant cell anatomy.

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

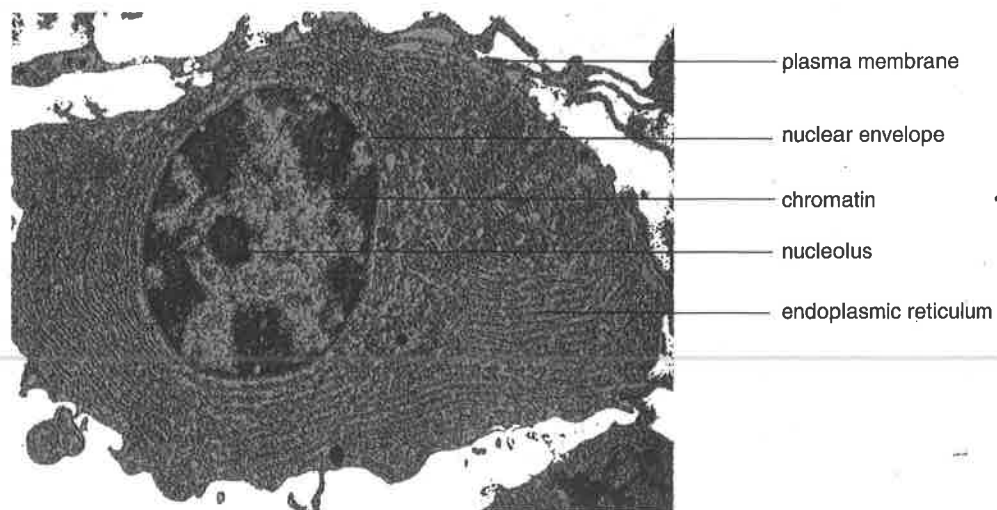
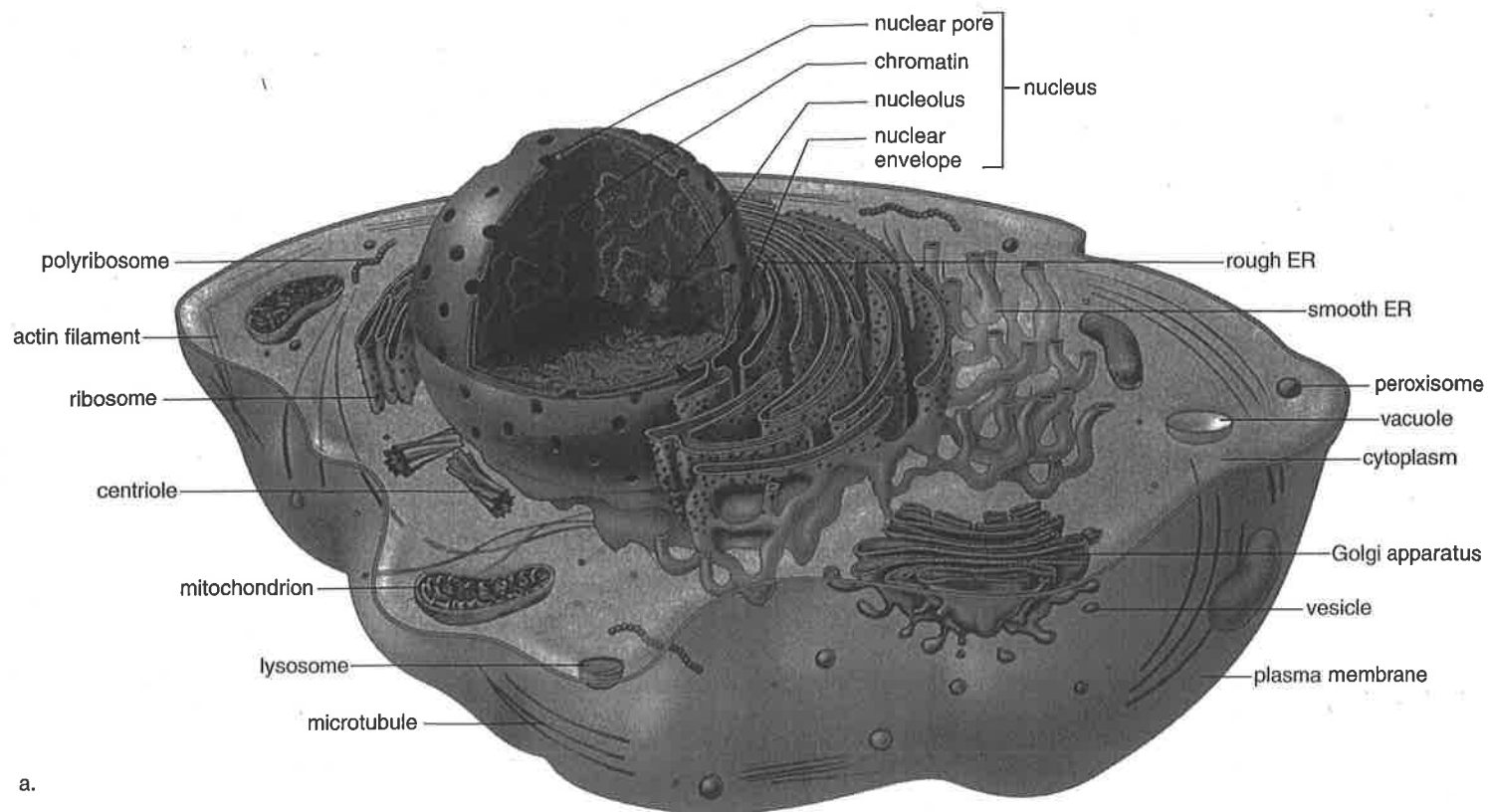


Figure 3.2 Animal cell anatomy.

a. Generalized drawing. b. Transmission electron micrograph. See Table 3.1 for a description of these structures, along with a listing of their functions.

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 contains a complex copy of 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 during protein synthesis. 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 but you can see chromatin (Fig. 3.4). **Chromatin** looks grainy, but actually it is a threadlike material that undergoes coiling into rodlike structures called **chromosomes**, just before the cell divides. Chemical analysis shows that chromatin, and therefore chromosomes, contains DNA and much protein, and some RNA. Chromatin is immersed in a semifluid medium called the **nucleoplasm**. A difference in pH between the nucleoplasm and 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

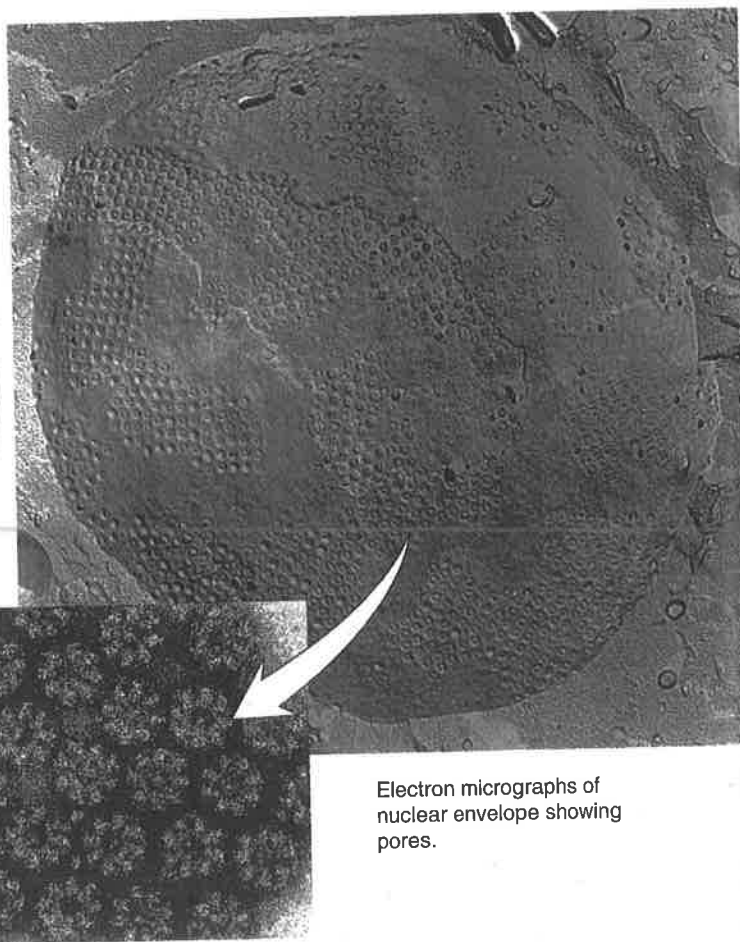
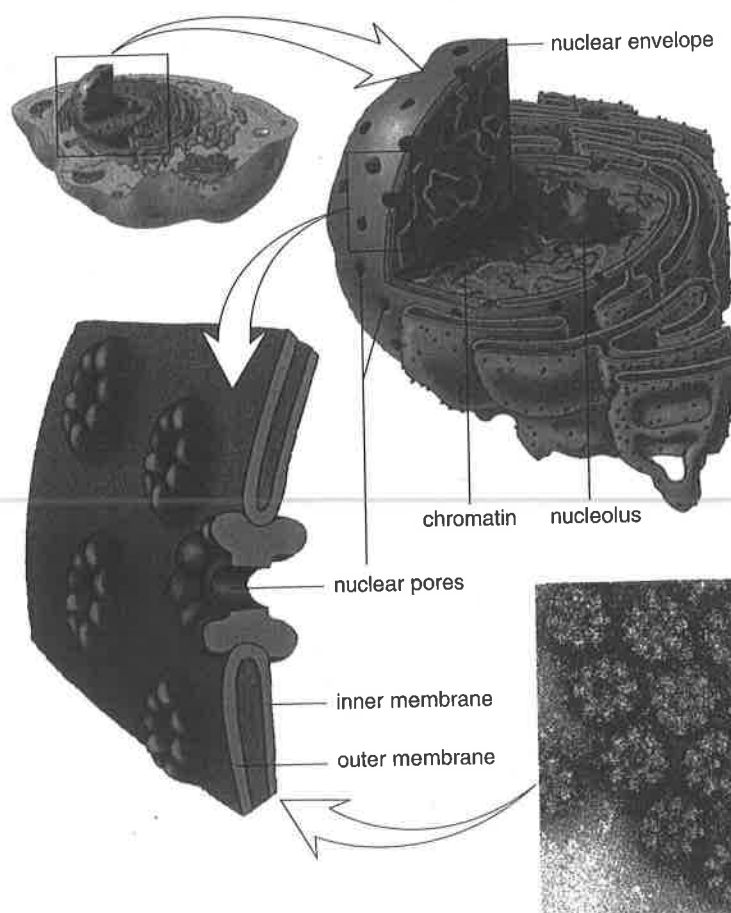


Figure 3.4 The nucleus and the nuclear envelope.

The nucleoplasm contains chromatin. Chromatin has a special region called the nucleolus, which is 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 on the ribosomes. Ribosomes occur free within the cytoplasm either singly or in groups called **polyribosomes**. Ribosomes are often attached to the endoplasmic reticulum, a membranous system of saccules and channels discussed in the next section. Proteins synthesized by cytoplasmic ribosomes are used in the cell, such as in the mitochondria and chloroplasts. Those produced by ribosomes attached to endoplasmic reticulum may eventually be secreted from the cell.

Ribosomes are small organelles where protein synthesis occurs. Ribosomes occur in the cytoplasm, both singly and in groups (i.e., polyribosomes). Numerous ribosomes are 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. Membranes that make up the endomembrane system are connected by direct physical contact and/or by the transfer of vesicles from one part to the other.

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. 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 large molecules are transported to other parts of the cell. Often these vesicles are on their way to the plasma membrane or the Golgi apparatus.

ER is involved in protein synthesis (rough ER) and various other processes such as lipid synthesis (smooth ER). Molecules that are produced or modified in the ER are eventually enclosed in vesicles that often transport them to the Golgi apparatus.

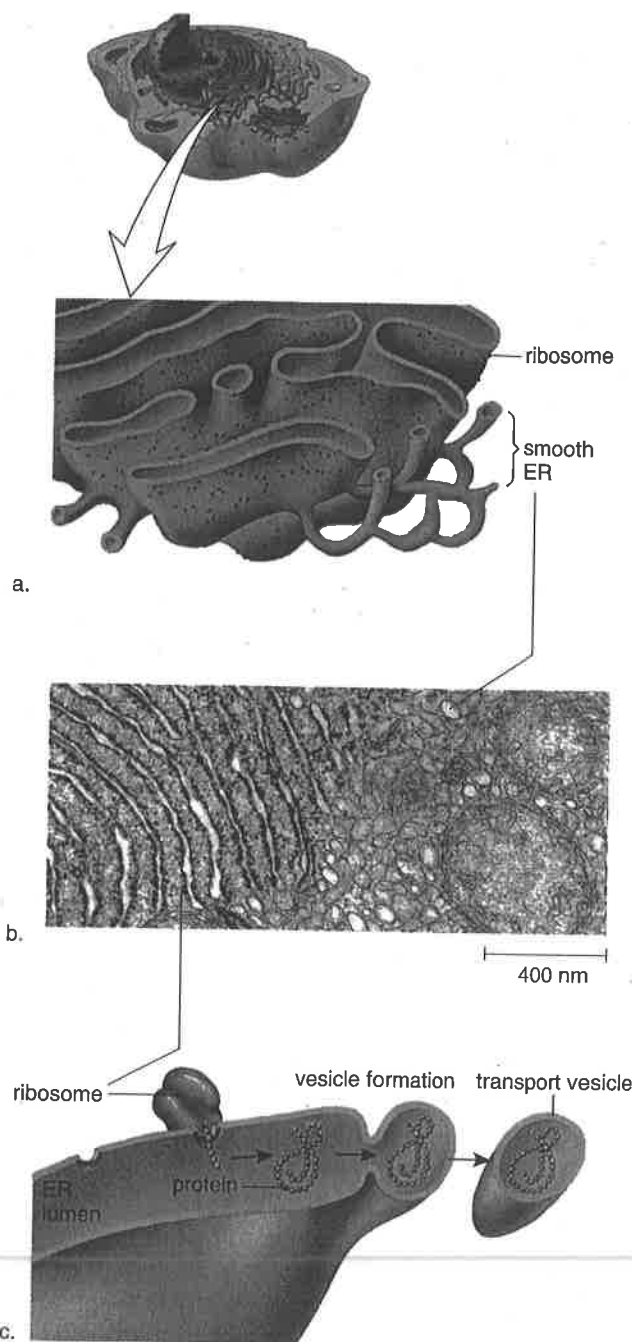


Figure 3.5 The endoplasmic reticulum (ER).

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 on a ribosome moves into the lumen of the system and eventually is packaged in a transport vesicle for distribution inside the cell.

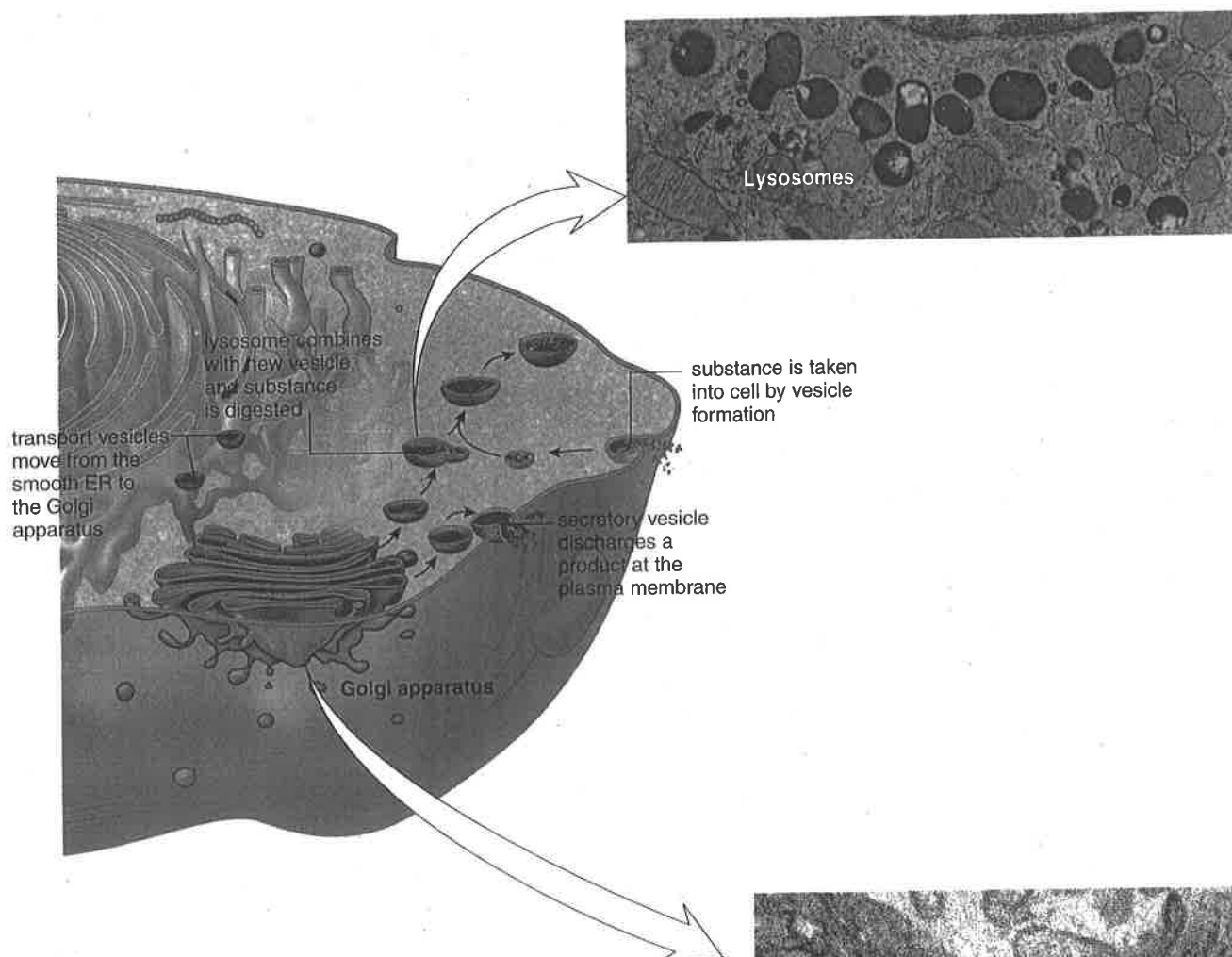


Figure 3.6 The Golgi apparatus.

The Golgi apparatus receives transport vesicles containing proteins from smooth ER. After modifying the proteins, it repackages them in either secretory vesicles or in lysosomes. When lysosomes combine with newly formed vesicles, their contents are digested. Lysosomes also break down cellular components.

The Golgi Apparatus

The **Golgi apparatus** is named for Camillo Golgi, who discovered its presence in cells in 1898. The Golgi apparatus consists of a stack of three to twenty slightly curved saccules whose appearance can be compared to a stack of pancakes (Fig. 3.6). In animal cells, one side of the stack (the inner face) is directed toward the ER, and the other side of the stack (the outer face) is directed toward the plasma membrane. Vesicles can frequently be seen at the edges of the saccules.

The Golgi apparatus receives protein and/or lipid-filled vesicles that bud from the ER. Some biologists believe that these fuse to form a saccule at the inner face and that this saccule remains as a part of the Golgi apparatus until the molecules are repackaged in new vesicles at the outer face. Others believe that the vesicles from the ER proceed directly to the outer face of the Golgi apparatus, where processing and packaging occurs within its saccules.

The Golgi apparatus contains enzymes that modify proteins and lipids. For example, it can add a chain of sugars to proteins, thereby making them glycoproteins and glycolipids, which are molecules found in the plasma membrane.

The vesicles that leave the Golgi apparatus move to different locations in the cell. Some vesicles proceed to the plasma membrane, where they discharge their contents. Because this is **secretion**, it is often said that the Golgi apparatus is involved in processing, packaging, and secretion. Other vesicles that leave the Golgi apparatus are lysosomes.

The Golgi apparatus processes, packages, and distributes molecules about or from the cell. It is also said to be involved in secretion.

Lysosomes

Lysosomes are membrane-bounded vesicles produced by the Golgi apparatus in animal cells and plant cells. Lysosomes contain hydrolytic digestive enzymes.

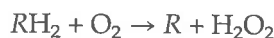
Sometimes macromolecules are brought into a cell by vesicle formation at the plasma membrane (Fig. 3.6). When a lysosome fuses with such a vesicle, its contents are digested by lysosomal enzymes into simpler subunits that then enter the cytoplasm. Some white blood cells defend the body by engulfing bacteria that are then enclosed within vesicles. When lysosomes fuse with these vesicles, the bacteria are digested. It should come as no surprise, then, that even parts of a cell are digested by its own lysosomes (called autodigestion). Normal cell rejuvenation most likely takes place in this manner, but programmed cell destruction occurs during development. For example, when a tadpole becomes a frog, lysosomes digest away the cells of the tail. The fingers of a human embryo are at first webbed, but they are freed from one another as a result of lysosomal action.

Occasionally, a child is born with a metabolic disorder involving a missing or inactive lysosomal enzyme. In these cases, the lysosomes fill to capacity with macromolecules that cannot be broken down. The cells become so full of these lysosomes that the child dies. Someday soon it may be possible to provide the missing enzyme for these children.

Lysosomes are produced by a Golgi apparatus, and their hydrolytic enzymes digest macromolecules from various sources.

Peroxisomes

Peroxisomes, similar to lysosomes, are membrane-bounded vesicles that enclose enzymes (Fig. 3.7). These enzymes were synthesized by free ribosomes and imported directly into a peroxisome. Peroxisomes contain enzymes for oxidizing certain organic substances with the formation of hydrogen peroxide (H_2O_2):



Hydrogen peroxide, a toxic molecule, is immediately broken down to water and oxygen by another peroxisomal enzyme called catalase. Peroxisomes are abundant in cells that metabolize lipids and in liver cells that metabolize alcohol. They help detoxify alcohol.

Peroxisomes play additional roles in plants. In germinating seeds, they oxidize fatty acids into molecules that can be converted to sugars needed by the growing plant. In leaves, peroxisomes can carry out a reaction that is opposite to photosynthesis—the reaction uses up oxygen and releases carbon dioxide.

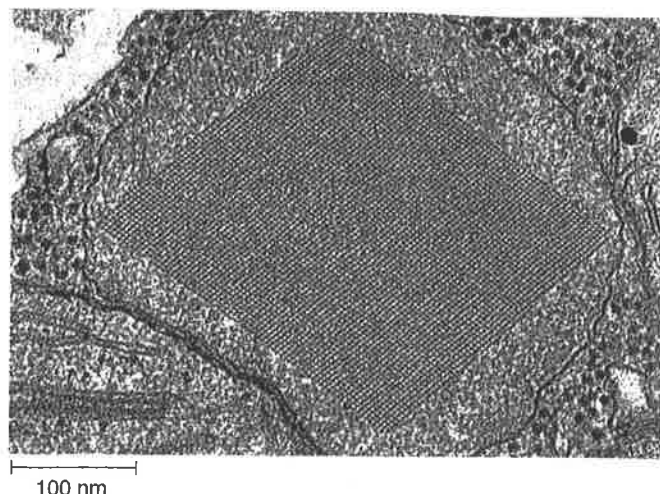


Figure 3.7 Peroxisome in a tobacco leaf.

Peroxisomes are vesicles that oxidize organic substances with a resulting build-up of hydrogen peroxide. The crystalline, squarelike core of a peroxisome contains the enzyme catalase, which breaks down hydrogen peroxide (H_2O_2) to water and oxygen.

Vacuoles

A **vacuole** is a large membranous sac. A vesicle is smaller than a vacuole. Animal cells have vacuoles, but they are much more prominent in plant cells. Typically, plant cells have a large central vacuole so filled with a watery fluid that it gives added support to the cell (see Fig. 3.3).

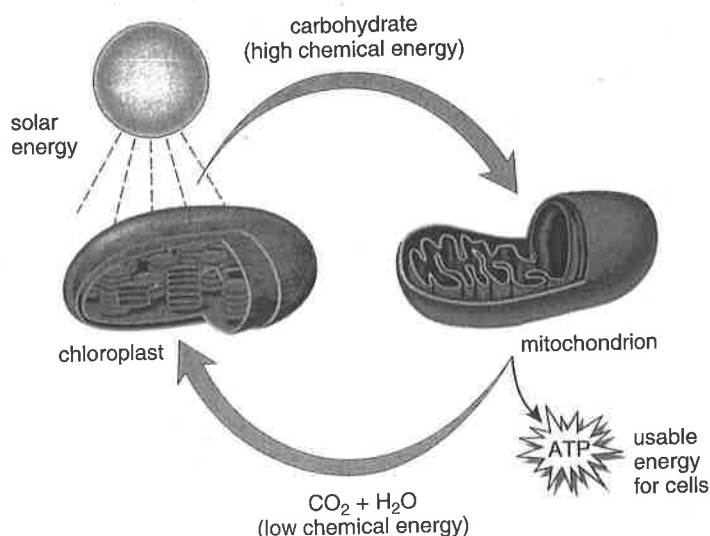
Vacuoles store substances. Plant vacuoles contain not only water, sugars, and salts but also pigments and toxic molecules. The pigments are responsible for many of the red, blue, or purple colors of flowers and some leaves. The toxic substances help protect a plant from herbivorous animals. The vacuoles present in unicellular protozoans are quite specialized, and they include contractile vacuoles for ridding the cell of excess water and digestive vacuoles for breaking down nutrients.

The organelles of the endomembrane system are as follows:

- Endoplasmic reticulum (ER): synthesis and modification and transport of proteins and other substances
 - Rough ER: protein synthesis
 - Smooth ER: lipid synthesis in particular
 - Golgi apparatus: processing, packaging, and distribution of protein molecules
 - Lysosomes: intracellular digestion
 - Peroxisomes: various metabolic tasks
 - Vacuoles: storage areas
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Energy-Related Organelles

Life is possible only because of a constant input of energy used for maintenance and growth. Chloroplasts and mitochondria are the two eukaryotic membranous organelles that specialize in converting energy to a form that can be used by the cell. **Chloroplasts** use solar energy to synthesize carbohydrates, and carbohydrate-derived products are broken down in mitochondria (sing., **mitochondrion**) to produce ATP molecules.

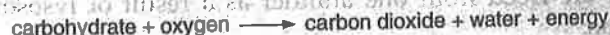


Photosynthesis, which occurs in chloroplasts, is the process by which solar energy is converted to chemical energy within carbohydrates. Photosynthesis can be represented by this equation:



Here the word *energy* stands for solar energy, the ultimate source of energy for cellular organization. Only plants, algae, and cyanobacteria are capable of carrying on photosynthesis in this manner.

Cellular respiration is the process by which the chemical energy of carbohydrates is converted to that of ATP (adenosine triphosphate), the common carrier of chemical energy in cells. Aerobic cellular respiration can be represented by this equation:



Here the word *energy* stands for ATP molecules. When a cell needs energy, ATP supplies it. The energy of ATP is used for synthetic reactions, active transport, and all energy-requiring processes in cells. All organisms carry on cellular respiration, and all organisms except bacteria complete the process of aerobic cellular respiration in mitochondria.

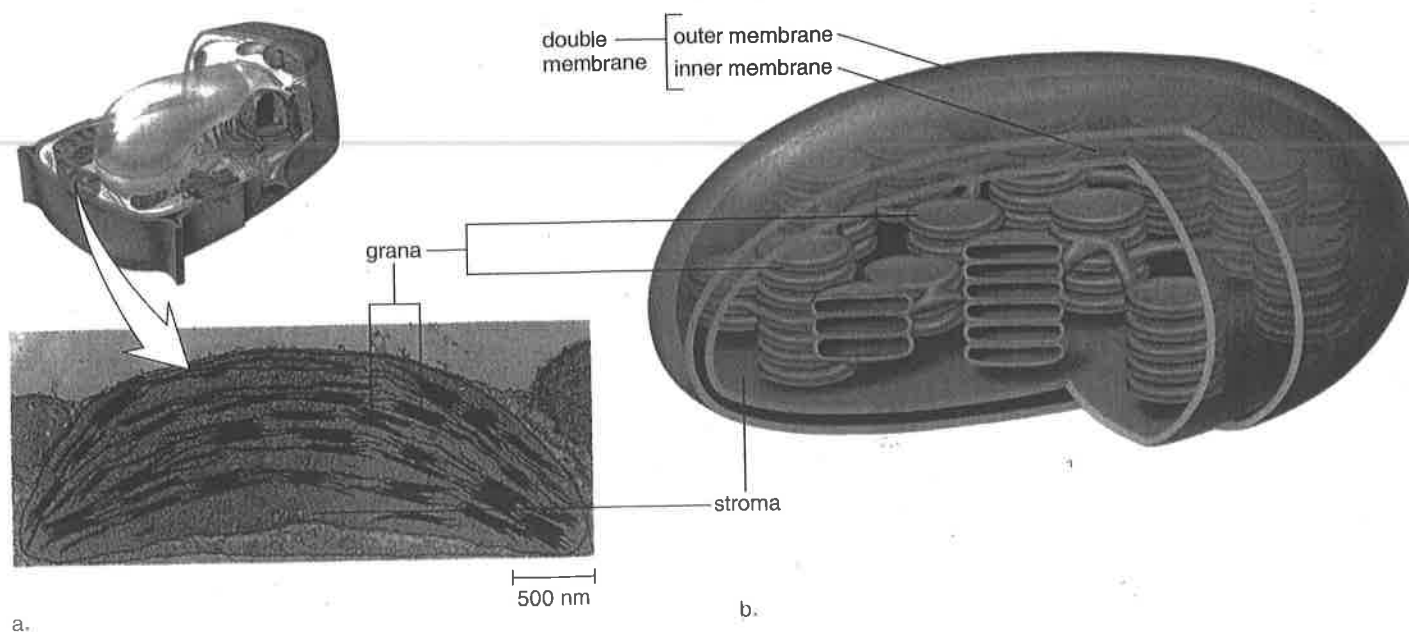


Figure 3.8 Chloroplast structure.

a. Electron micrograph. b. Generalized drawing in which the outer and inner membranes have been cut away to reveal the grana.

Chloroplasts

Plant cells contain chloroplasts, the organelles that allow them to produce their own organic food. Chloroplasts are about 4–6 μm in diameter and 1–5 μm in length; they belong to a group of organelles known as plastids. Among the plastids are also the *amyloplasts*, common in roots, which store starch; and the *chromoplasts*, common in leaves, which contain red and orange pigments. A chloroplast is green, of course, because it contains the green pigment chlorophyll.

A chloroplast is bounded by two membranes that enclose a fluid-filled space called the **stroma**. A membrane system within the stroma is organized into interconnected flattened sacs called **thylakoids**. In certain regions, the thylakoids are stacked up in structures called grana (sing., **granum**). There can be hundreds of grana within a single chloroplast (Fig. 3.8). Chlorophyll, which is located within the thylakoid membranes of grana, captures the solar energy that is needed to allow chloroplasts to produce carbohydrates. The stroma contains DNA, ribosomes, and enzymes that synthesize carbohydrates from carbon dioxide and water.

Mitochondria

All eukaryotic cells, including plant cells, contain mitochondria. This means that plant cells contain both chloroplasts and mitochondria. Most mitochondria are usually 0.5–1.0 μm in diameter and 2–5 μm in length.

Mitochondria, like chloroplasts, are bounded by a double membrane (Fig. 3.9). In mitochondria the inner fluid-filled space is called the **matrix**. The matrix contains DNA, ribosomes, and enzymes which break down carbohydrate products, releasing energy that is used for ATP production.

The inner membrane of a mitochondrion invaginates to form **cristae**. Cristae provide a much greater surface area to accommodate the protein complexes and other participants that produce ATP.

Mitochondria and chloroplasts are able to make some proteins, but others are imported from the cytoplasm.

Chloroplasts and mitochondria are membranous organelles whose structure lends itself to the processes that occur within them.

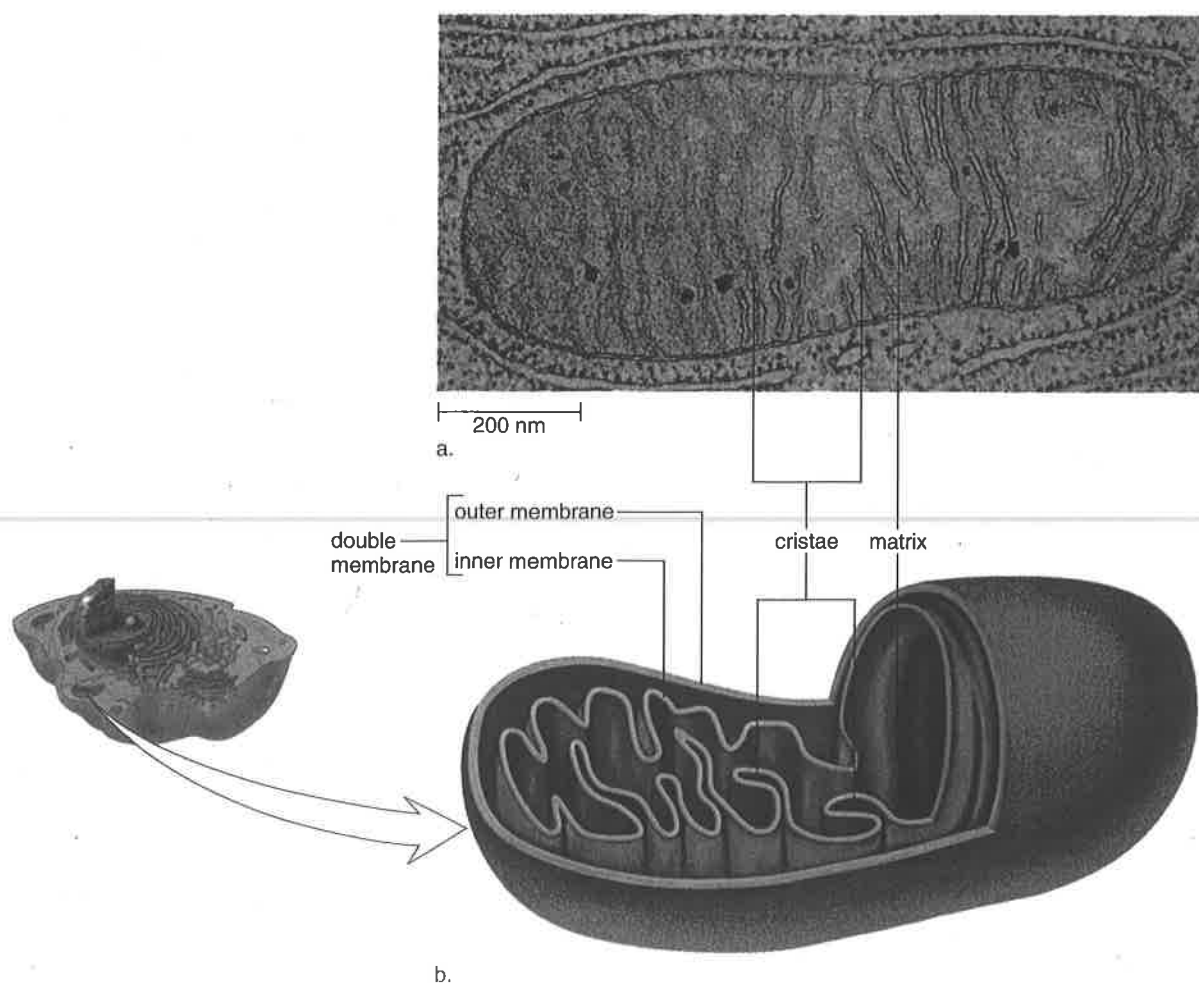


Figure 3.9 Mitochondrion structure.

a. Electron micrograph. **b.** Generalized drawing in which the outer membrane and portions of the inner membrane have been cut away to reveal the cristae.

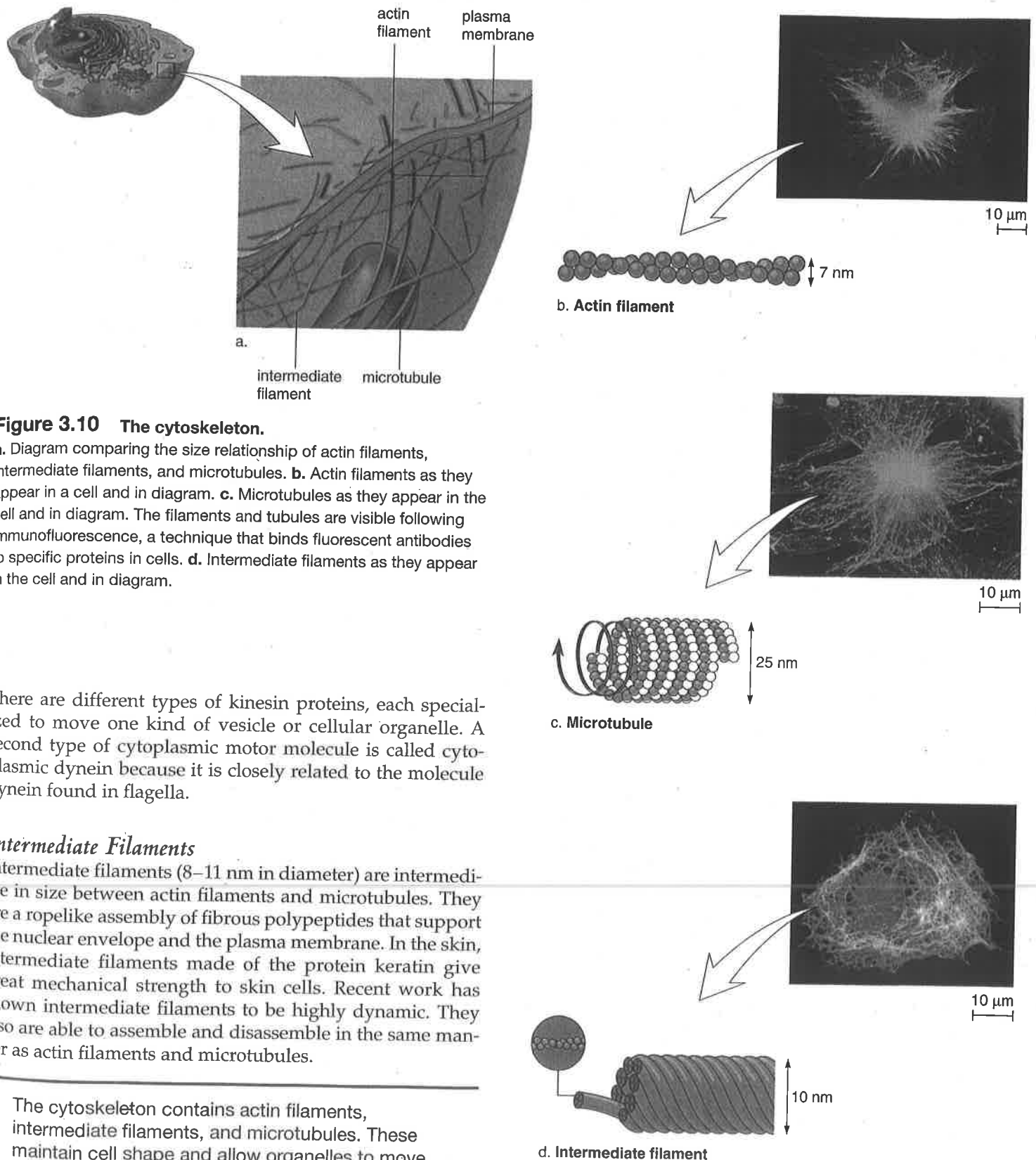


Figure 3.10 The cytoskeleton.

a. Diagram comparing the size relationship of actin filaments, intermediate filaments, and microtubules. **b.** Actin filaments as they appear in a cell and in diagram. **c.** Microtubules as they appear in the cell and in diagram. The filaments and tubules are visible following immunofluorescence, a technique that binds fluorescent antibodies to specific proteins in cells. **d.** Intermediate filaments as they appear in the cell and in diagram.

There are different types of kinesin proteins, each specialized to move one kind of vesicle or cellular organelle. A second type of cytoplasmic motor molecule is called cytoplasmic dynein because it is closely related to the molecule dynein found in flagella.

Intermediate Filaments

Intermediate filaments (8–11 nm in diameter) are intermediate in size between actin filaments and microtubules. They are a ropelike assembly of fibrous polypeptides that support the nuclear envelope and the plasma membrane. In the skin, intermediate filaments made of the protein keratin give great mechanical strength to skin cells. Recent work has shown intermediate filaments to be highly dynamic. They also are able to assemble and disassemble in the same manner as actin filaments and microtubules.

The cytoskeleton contains actin filaments, intermediate filaments, and microtubules. These maintain cell shape and allow organelles to move within the cytoplasm. Sometimes they are also involved in movement of the cell itself.