# 2.1 Cell Structures

**organelle** an internal functional structure that is located within the cytosol of a cell

LEARNING **TIP**

**Cytoplasm versus Cytosol**
The term “cytoplasm” is often used to refer to the liquid portion of the cell, but the more precise term is “cytosol.” Cell biologists use “cytoplasm” to refer to *all* of the internal components of the cell, other than the nucleus.

**plasma membrane** a dynamic barrier that surrounds the cytosol of the cell

The internal structures of a cell interact and complement each other in both form and function. In eukaryotic cells, internal structures, or **organelles**, carry out specialized functions. Some organelles isolate toxic or harmful substances from the rest of the cell or provide a favourable environment for a reaction that could not occur in the cytosol. Other organelles transport substances through the cytosol, maintaining the fluid balance. The shapes of some organelles are quite elaborate, because each organelle is adapted to perform a specific function.

In this section, you will focus on the organelles inside eukaryotic plant and animal cells. Plant cells differ from animal cells because plants and animals have very different requirements for obtaining food and energy. Although fungi are not discussed in this section, they have many of the same organelles that plants and animals have. Fungi-like animals are heterotrophic, while the protist kingdom includes both heterotrophs and photosynthetic autotrophs. The most complex of all cells are those of some single-celled protists.

The cell itself, and many organelles within it, are bounded by membranes that control the amounts and types of substances that move in and out of the cell or organelle. The **plasma membrane** forms a barrier around the cytosol of the cell. The membrane surrounding an organelle maintains an internal environment that allows the organelle to carry out its particular function.

An organelle rarely works alone. Just as your organ systems work together to keep your body functioning, it takes a team of organelles to keep a cell running. Substances move between different organelles and the plasma membrane. Some metabolic pathways take place in a series of different organelles. At the same time, the cell needs to reproduce itself to generate more cells. **Figure 1** and **Table 1** (next page) show the common components of a eukaryotic cell. You can refer back to Figure 1 and Table 1 as you read about the specific organelles.

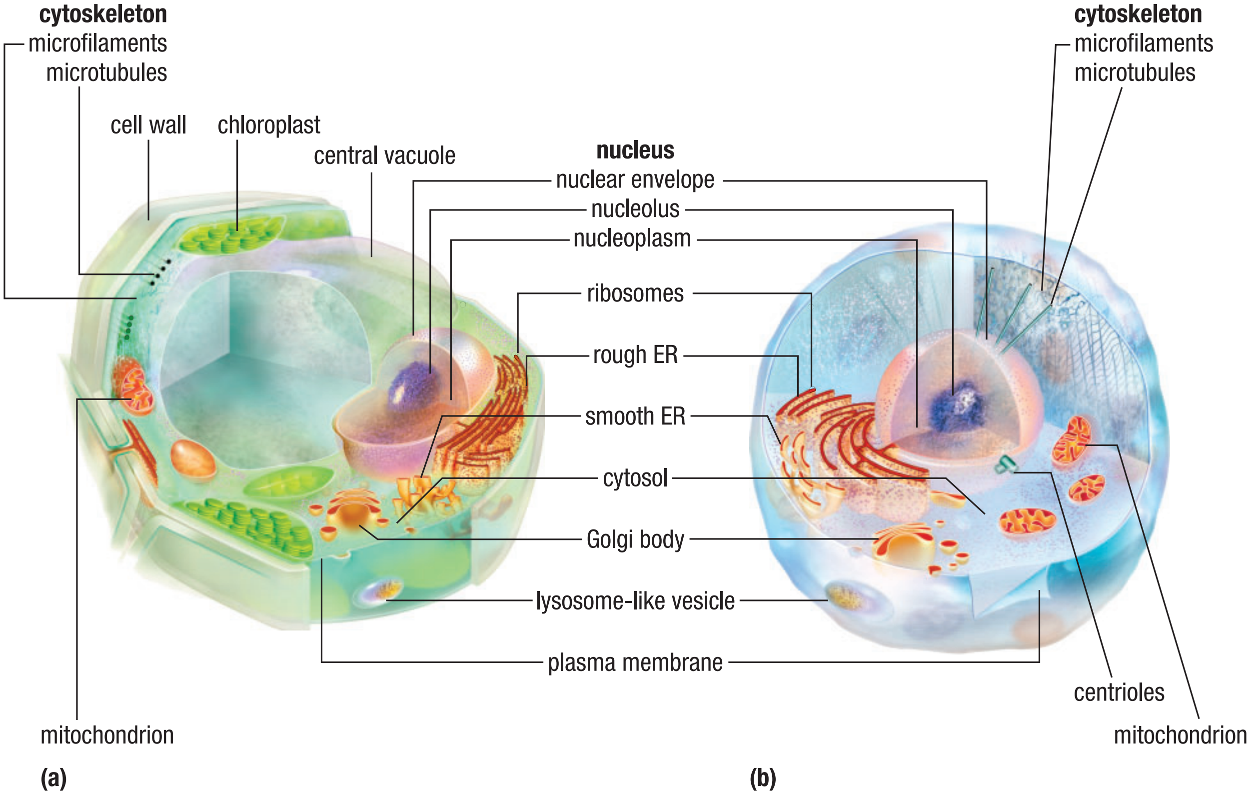



**Figure 1** The functions of the organelles of (a) a typical plant cell and (b) a typical animal cell are described in Table 1.

# The Nucleus

Almost all eukaryotic cells have a nucleus. The nucleus is an organelle that contains almost all the DNA in a eukaryotic cell. Small amounts of DNA are present in two other organelles that you will learn about later—chloroplasts and mitochondria. The nucleus protects the DNA, or genetic material, in the cell. Isolated in its own compartment, the DNA stays separated from the activity of the cytosol and from the metabolic reactions that might damage it.

## Nuclear Envelope

The nucleus is surrounded by a double membrane called the nuclear membrane or **nuclear envelope**. It consists of two lipid bilayers that are folded together. The outer bilayer of the membrane is continuous with the membrane of another organelle, the endoplasmic reticulum (ER). Different kinds of membrane proteins are embedded in the two lipid bilayers. Some are receptors and transporters. Others collect in tiny pores that span the membrane (**Figure 2**). The membrane proteins work with the lipid bilayers, as a system, to transport various molecules across the nuclear membrane.

Like other membranes, the nuclear envelope allows water and gases to cross freely. Other substances can only enter and exit the nucleus with the help of a system of transporters and pumps that span the nuclear envelope. The system of transporters and pumps controls the passage of molecules between the nucleus and the cytosol. For example, cells access their DNA when they make RNA and proteins, so various molecules that are involved in this process must pass into and out of the nucleus. The nuclear membrane allows only certain molecules to cross it, at certain times and in certain amounts. This control is another measure of safety for the DNA, as well as a way for the cell to regulate the production of RNA and proteins.

Proteins that attach to the inner surface of the nuclear envelope anchor the DNA molecules and keep them organized. During cell division (mitosis), these proteins help the cell pass DNA to its two daughter cells. You will learn more about transport across membranes in Section 2.4.

**nuclear envelope** a two-layer membrane that encloses the nucleus of a eukaryotic cell

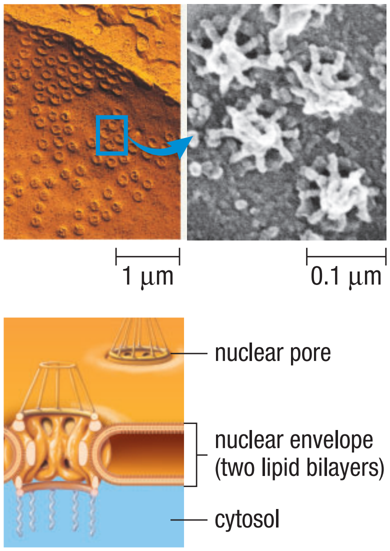



**Figure 2** The structure of a nuclear pore

**Table 1** Organelles of Eukaryotic Cells

| Category | Name | Primary function(s) |
|---|---|---|
| Organelles with a membrane | nucleus | protects and controls access to the DNA; makes ribosome subunits |
| | endoplasmic reticulum (ER) | routes and modifies new polypeptide chains; synthesizes lipids |
| | Golgi body | modifies new polypeptide chains; sorts and ships proteins and lipids |
| | transport/secretory vesicle | transports substances within a cell and or releases them from the cell |
| | mitochondrion | generates ATP and other molecules |
| | chloroplast | produces sugars using light energy, carbon dioxide, and water |
| | lysosome | carries out intracellular digestion |
| | peroxisome | inactivates toxins |
| | vacuole | provides storage and contains waste; in plants, maintains cell size and shape |
| Organelles without a membrane | ribosome | assembles polypeptide chains that are used to form proteins |
| | centriole | makes microtubules for the cytoskeleton; involved in cell division |

## Nucleolus

Enclosed by the nuclear envelope, the nucleus contains nucleoplasm, which is a viscous fluid that is similar to cytosol. The nucleus also contains at least one nucleolus (plural: nucleoli), a dense irregularly shaped region where subunits of ribosomes are assembled from proteins and RNA. **Figure 3** shows the components of the nucleus.

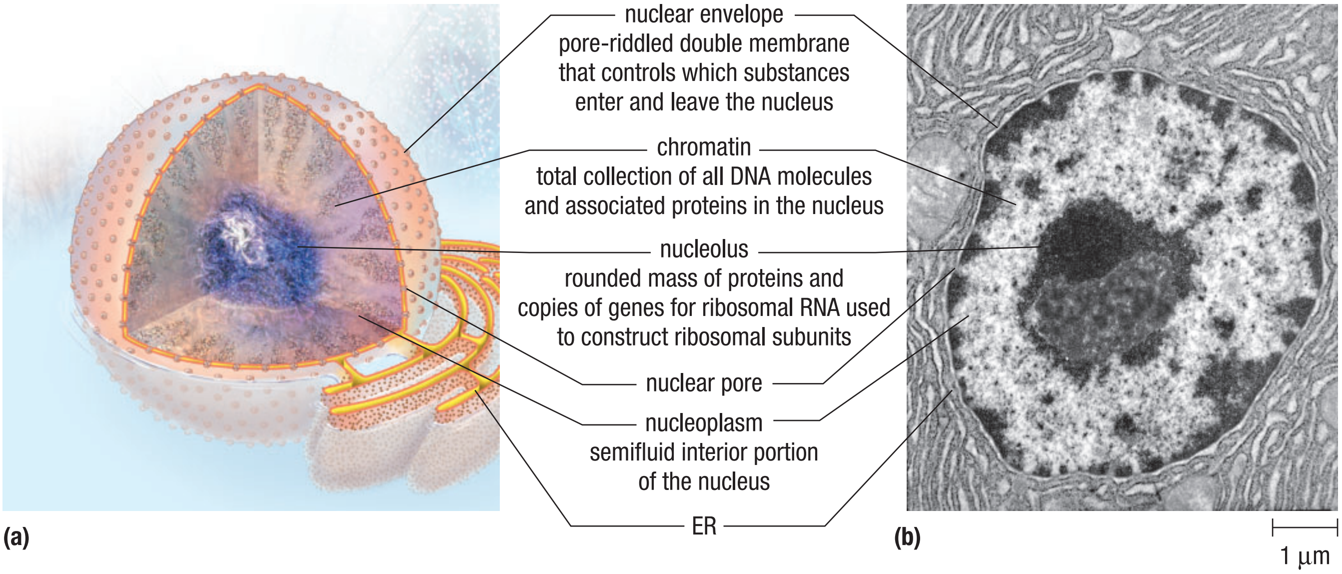



**Figure 3** (a) A diagram of a nucleus and (b) transmission electron microscopy (TEM) showing the nucleus of a cell from the pancreas of a mouse

## The Endomembrane System

**endomembrane system** a group of interacting organelles between the nucleus and the plasma membrane

The **endomembrane system** is a group of interacting organelles between the nucleus and the plasma membrane (**Figure 4**). Its main function is to make lipids, enzymes, and other proteins for secretion or insertion into cell membranes. It also has other specialized functions, such as destroying toxins and recycling wastes. The components of the endomembrane system vary among different types of cells, but the most common components are described in the following text and in **Figure 5**.

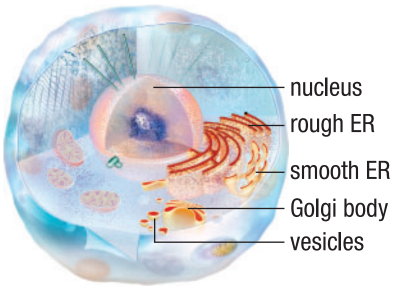



**Figure 4** Components of the endomembrane system

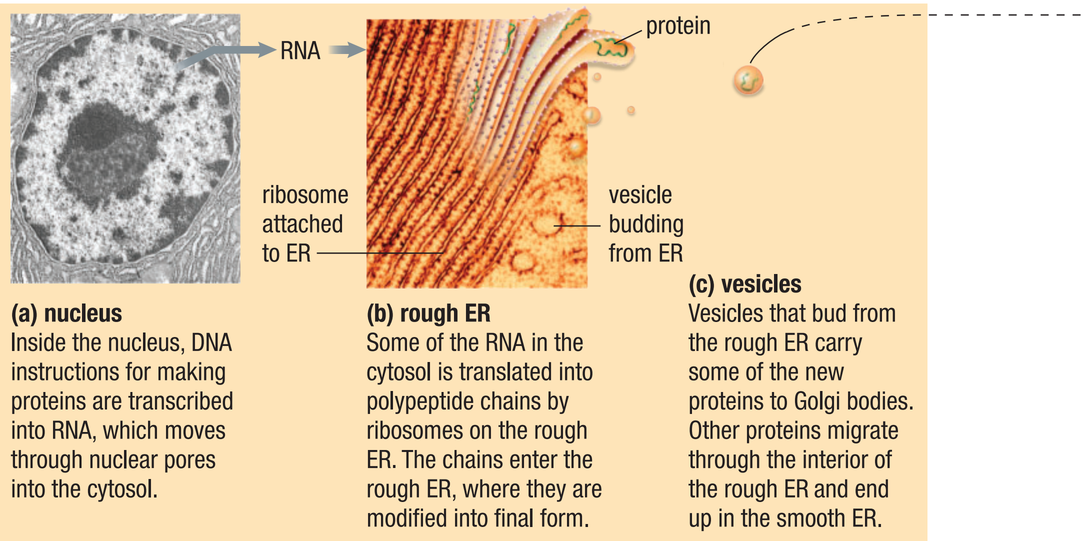



**Figure 5** The endomembrane system builds lipids and many proteins, which are transported to other cellular destinations or to the plasma membrane.

## Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** is an extension of the nuclear envelope (Figure 5(a)). It forms a continuous compartment that folds repeatedly into flattened sacs and tubes. Two kinds of ER—rough ER and smooth ER—are named for their appearance in electron micrographs. Many thousands of ribosomes are attached to the outer surface of **rough ER** (Figure 5(b)). The ribosomes synthesize polypeptide chains, which are released into the interior of the ER. Inside the ER, the proteins fold and take on their complex structure. Some of the proteins become part of the ER membrane itself, whereas other proteins are carried to different destinations in the cell. Cells that make, store, and secrete a lot of proteins have a lot of rough ER. For example, ER-rich gland cells in the pancreas make and secrete enzymes that help to digest food in the small intestine.

**endoplasmic reticulum (ER)** a membrane-bound organelle that is folded into flattened sacs and tubes, and is often an outgrowth of the nuclear envelope in a eukaryotic cell

**rough ER** areas of endoplasmic reticulum with ribosomes attached to the surface

**Smooth ER** has no ribosomes, so it does not make proteins. Some of the polypeptides that are made in the rough ER end up in the smooth ER as enzymes (Figure 5(d)). These enzymes produce most of the cell's membrane lipids. They also break down carbohydrates, fatty acids, and some drugs and poisons.

**smooth ER** areas of the endoplasmic reticulum without attached ribosomes

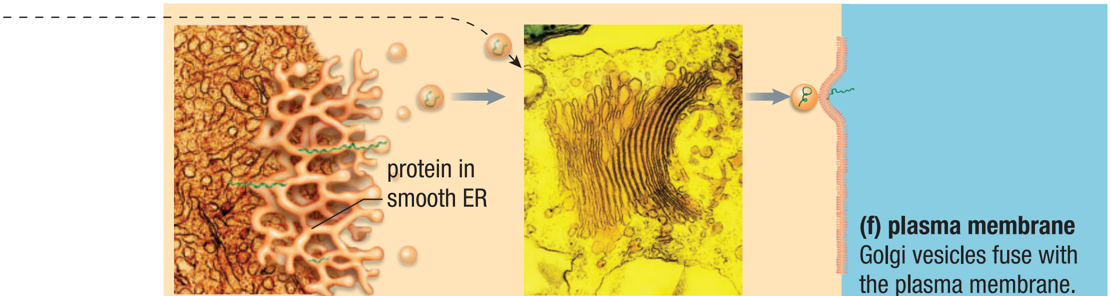
## Vesicles

**Vesicles** are membrane-enclosed, saclike organelles (Figure 5(c)). They form in great numbers, either on their own or by budding from other organelles or from the plasma membrane. There are many types of vesicles with many different functions. Some types transport proteins from one organelle to another, or to and from the plasma membrane. Another type, called a peroxisome, contains enzymes that digest fatty acids and amino acids. Peroxisomes form and divide on their own and have a variety of functions, such as inactivating hydrogen peroxide, a toxic by-product of fatty acid breakdown. Enzymes, such as catalase, in the peroxisomes convert hydrogen peroxide to water and oxygen, or they use hydrogen peroxide in reactions that break down alcohol and other toxins.

**vesicle** a small, membrane-bound organelle that may transport, store, or digest substances within a cell

Plant and animal cells contain vesicles called **vacuoles**. Although vacuoles appear empty under a microscope, they serve an important function—they are like trash cans. They isolate and dispose of wastes, debris, and toxic materials. A large central vacuole is present in plant cells. Amino acids, sugars, ions, wastes, and toxins accumulate in the water-filled interior of the central vacuole. Fluid pressure in the central vacuole keeps the plant cell, and therefore structures such as stems and leaves, firm. Usually, the central vacuole takes up 50 to 90 % of the cell's interior, with the cytosol confined to the narrow area between this large organelle and the plasma membrane.

**vacuole** a liquid-filled organelle that stores waste and aids in cellular metabolism and water balance




**(d) smooth ER**
Some proteins from the rough ER are packaged into new vesicles and shipped to the Golgi bodies. Others become enzymes of the ER that assemble lipids or inactivate toxins.

**(e) Golgi body**
Proteins arriving in vesicles from the ER are modified into final form and sorted. New vesicles carry them to the plasma membrane or to lysosomes.

**(f) plasma membrane**
Golgi vesicles fuse with the plasma membrane. Lipids and proteins of a vesicle's membrane fuse with the plasma membrane, and the vesicle's contents are released to the exterior of the cell.

**lysosome** a small, membrane-bound organelle that contains digestive enzymes that aid in waste disposal

**Lysosomes** are vesicles that contain powerful digestive enzymes. They fuse with vacuoles that carry particles or molecules for disposal, such as worn-out cell components. Lysosomal enzymes empty into these vacuoles and digest their contents.

### Golgi Bodies

**Golgi body** an organelle with folded membranes where the final packaging of proteins occurs

Many vesicles fuse with and empty their contents into a **Golgi body** (Figure 5(e)). This organelle has a folded membrane that usually looks like a stack of pancakes. Enzymes in a Golgi body put finishing touches on polypeptide chains and lipids that have been delivered from the ER. They attach phosphate groups or sugars, and they cleave certain polypeptide chains. The end products—membrane proteins, proteins for secretion, and enzymes—are sorted and packaged into new vesicles that carry them to the plasma membrane or to lysosomes (Figure 5(f)).

## Other Organelles

Eukaryotic cells have other organelles, in addition to those described above. For example, nearly all eukaryotic cells make most of their ATP in mitochondria. In addition, plants and some types of algae have special organelles called plastids that are used for storage and photosynthesis.

### Mitochondria

**mitochondrion** an organelle with two membranes; the site of most ATP synthesis during aerobic cellular respiration

The **mitochondrion** (plural: mitochondria) is a type of organelle that specializes in making ATP (**Figure 6**). Nearly all eukaryotic cells have mitochondria, but prokaryotes do not. In plants and animals, most ATP is produced in a series of reactions that occur inside the mitochondria and require oxygen (Chapter 4). These reactions can extract more energy from organic compounds than any other metabolic pathway. With each breath, you take in oxygen that is used by the mitochondria in your trillions of energy-demanding cells.

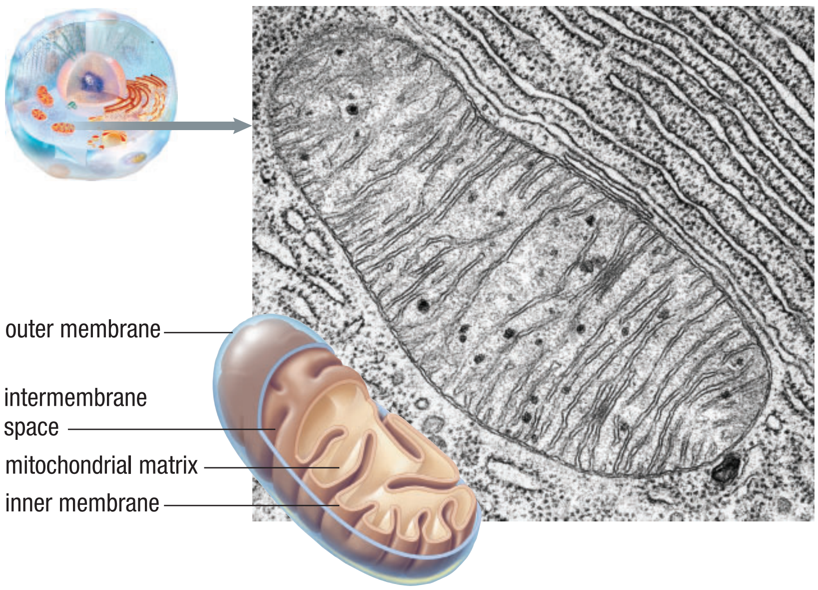



**Figure 6** A sketch and a transmission electron micrograph of a mitochondrion. This organelle specializes in producing large quantities of ATP.

The number of mitochondria varies based on the type of cell and the type of organism. For example, a single-celled yeast (a type of fungus) may have only one mitochondrion, whereas a human skeletal muscle cell may have a thousand or more. Cells that have a very high demand for energy tend to have many mitochondria.

Typical mitochondria are between 1 and 4 μm in length, but a few are as long as 10 μm. Some mitochondria are branched. These organelles can change shape, split in two, and fuse together. A mitochondrion has two membranes, one highly folded inside the other. This arrangement creates two compartments: the mitochondrial matrix (the interior of the mitochondrion) and the intermembrane space (the space between the two mitochondrial membranes).

Mitochondria resemble bacteria in size, form, and biochemistry. They have their own DNA, which is similar to bacterial DNA. They divide independently of the cell and have their own ribosomes. Such clues led to the now widely accepted theory of endosymbiosis. According to this theory, mitochondria evolved from aerobic bacteria that took up permanent residence inside a host cell.

## Plastids

**Plastids** are membrane-enclosed organelles that are used for photosynthesis or storage in plants and algal cells. Chloroplasts, chromoplasts, and amyloplasts are common types of plastids. Photosynthetic cells of plants and many protists contain **chloroplasts**, which are organelles that are specialized for photosynthesis (Chapter 5). Most chloroplasts are an oval or disk shape. Two outer membranes enclose a semifluid interior called the stroma (**Figure 7**). The stroma contains enzymes and the chloroplast's DNA. Inside the stroma, a third highly folded membrane forms a single compartment. In many ways, chloroplasts resemble photosynthetic bacteria. Like mitochondria, they may have evolved by endosymbiosis.

**plastid** a membrane-bound organelle that is involved in photosynthesis and storage in plants and algae

**chloroplast** a double-membrane-bound organelle that contains enzymes and pigments that are used to perform photosynthesis in eukaryotic cells

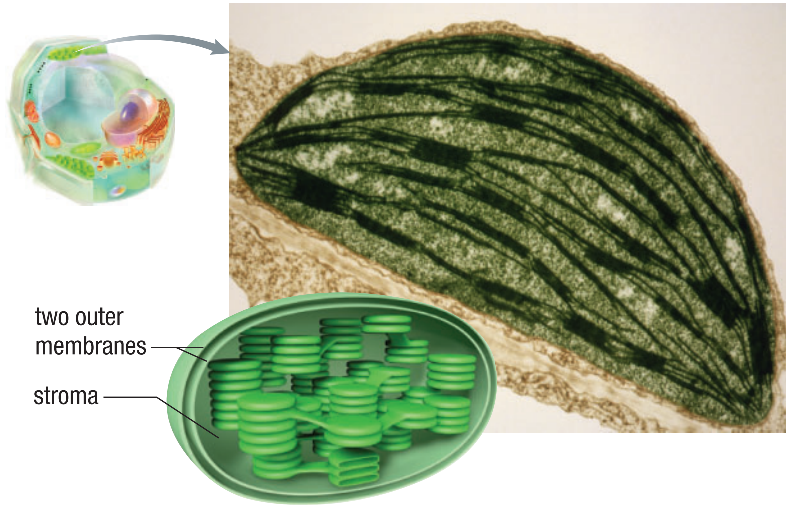



**Figure 7** The chloroplast is a defining component in photosynthetic eukaryotic cells. This transmission electron micrograph shows a chloroplast from a tobacco leaf (*Nicotiana tabacum*). The lighter patches are nucleoids, where DNA is stored.

**Chromoplasts** make and store pigments other than chlorophyll. They have an abundance of orange and red carotenoids, the pigments that colour many flowers, leaves, fruits, and roots. These colourful pigments are revealed in the autumn, when the chlorophyll in some plant leaves is broken down and the bright fall colours of yellows, oranges, and reds are visible. The carotenoids are also visible in fruits. For example, as a tomato ripens, its green chloroplasts are converted to red chromoplasts, and its colour changes. **Amyloplasts** are unpigmented plastids that often store starch grains. They are abundant in the cells of stems, tubers (underground stems), and seeds. In some plant cells, amyloplasts function as gravity-sensing organelles.

**chromoplast** an organelle that makes and stores pigments other than chlorophyll

**amyloplast** an organelle that stores starch

# The Dynamic Cytoskeleton

Between the nucleus and plasma membrane of a eukaryotic cell is a **cytoskeleton**: an interconnected system of many protein filaments. Parts of the cytoskeleton reinforce, organize, and move cell structures, and often the whole cell. Some cytoskeleton structures are permanent, whereas others only form at certain times.

**cytoskeleton** a dynamic system of filaments that provides cell structure, helps with cell division, and enables the cell and inner organelles to move around

## Microtubules and Microfilaments

A microtubule is a long, hollow cylinder that consists of subunits of the protein tubulin. Microtubules form a dynamic scaffolding for many cellular processes, rapidly assembling when they are needed and disassembling when they are not. For example, some microtubules assemble before a eukaryotic cell divides, separate the cell's duplicated chromosomes, and then disassemble.

**microfilament** a fibre structure made from actin that is part of the cytoskeleton and is located in the cytosol of cells

A **microfilament** is a fibre that consists primarily of subunits of the protein actin. Microfilaments strengthen or change the shape of eukaryotic cells. Actin microfilaments, which form at the edge of a cell, drag or extend it in a certain direction (**Figure 8**). In muscle cells, microfilaments of myosin and actin interact to bring about contraction.

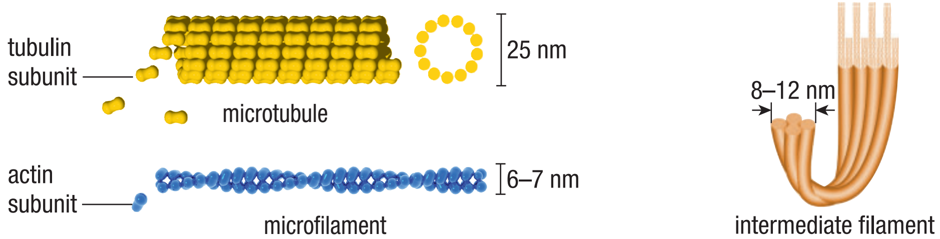



**Figure 8** Components of the cytoskeleton

Intermediate filaments are the most stable part of a cell's cytoskeleton. They consist of fibrous proteins, each with a globular head and tail and a rodlike centre. Intermediate filaments strengthen and maintain cell and tissue structures and are the toughest of the cytoskeleton filaments. They are in the cytosol and nucleus of most animal cells.

## Cilia, Flagella, and Pseudopods

**flagellum** a whiplike tail that is used in propulsion of both prokaryotic and eukaryotic cells

**cilia** tiny hairlike structures that move water and mucus in eukaryotes; used for movement of prokaryotic cells

Organized arrays of microtubules are found in eukaryotic flagella (singular: flagellum) and cilia (singular: cilium) (**Figure 9(a)** and **(b)**). **Flagella**, whiplike structures that propel cells such as sperm through fluid, tend to be longer and less abundant than cilia. The coordinated beating of **cilia** propels motile cells through fluid and stirs fluid around stationary cells. For example, the coordinated motion of cilia on the thousands of cells that line your airways sweeps particles away from your lungs.

A special array of microtubules extends lengthwise through a flagellum or a cilium. Protein spokes and links stabilize the array. The microtubules grow from a barrel-shaped organelle called a centriole, which remains located below the array after it forms. Amoebas and other types of eukaryotic cells form lobes called pseudopods or "false feet" (**Figure 9(c)**). As these temporary irregular lobes bulge outward, they move the cell and engulf a target, such as prey. Elongated microfilaments force the lobes to advance in a steady direction.

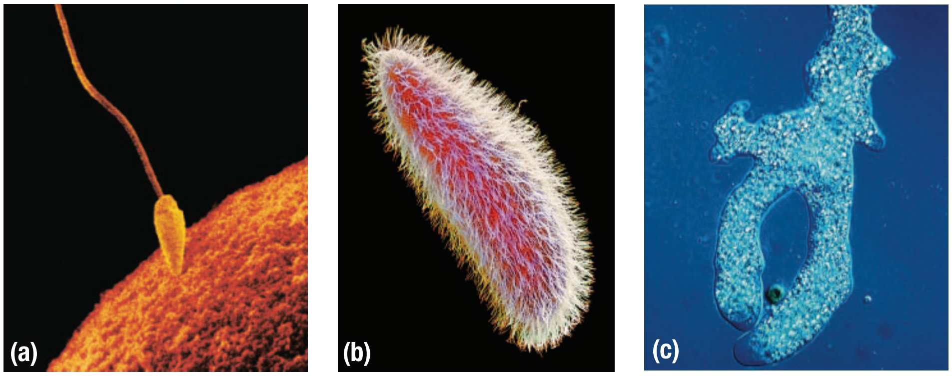



**Figure 9** (a) The flagellum of a human sperm, which is about to penetrate an egg; (b) a paramecium with cilia; and (c) a predatory amoeba (*Chaos carolinense*) extending two pseudopods around its hapless meal, a single-celled green alga (*Pandorina*)

## The Cell Surface

Like most prokaryotic cells, many types of eukaryotic cells have a **cell wall** around the plasma membrane. Animal cells do not have a cell wall, but plant cells and many protist and fungal cells do. The cell wall is a porous structure that protects, supports, and gives shape to the cell. Water and many solutes easily cross it on the way to and from the plasma membrane.

The cell wall is the outer barrier of a plant cell. It surrounds the plasma membrane and gives structure to the cell, and ultimately the plant (**Figure 10**). The cell wall has a **primary wall** and develops a **secondary wall** during later stages of growth. The primary wall is thin and pliable, which allows the growing plant cell to enlarge. At maturity, the cells in some plant tissues stop enlarging and start secreting a material onto the inner surface of the primary wall. This material forms a firm secondary wall. In addition, some plant cells are covered in an outer waxy cuticle. The cuticle helps to protect exposed surfaces of soft parts of the plant and limits water loss on hot, dry days.

**cell wall** the outer barrier of a plant cell; the cell wall surrounds the plasma membrane and gives structure to the plant

**primary wall** a cellulose coating that surrounds a plant cell

**secondary wall** a coating that is added to a plant cell wall; it is more rigid and often thicker than the primary cell wall

**extracellular matrix (ECM)** a molecular system that supports and protects a cell; a cell's environment

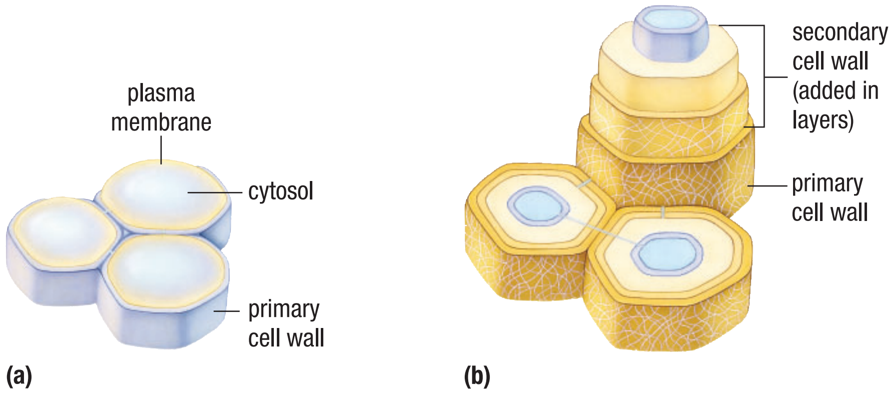



**Figure 10** **(a)** Plant cell secretions form the middle layer that cements adjoining cells together. **(b)** In many plant tissues, cells also secrete materials that are deposited in layers on the inner surface of their primary wall. These layers strengthen the wall and maintain its shape.

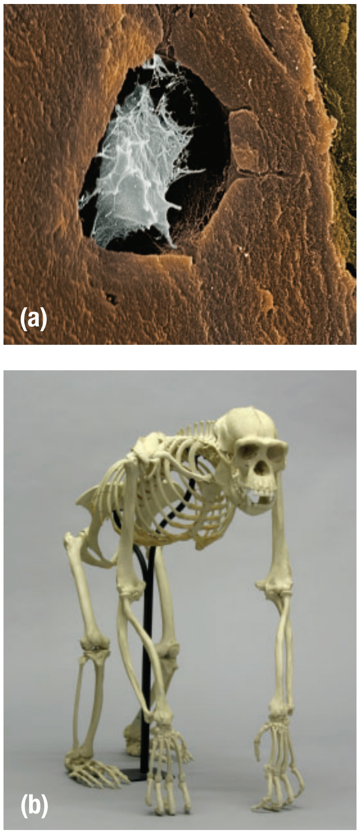



**Figure 11** (a) A living cell surrounded by hardened bone tissue, which is the main structural material in the skeleton of most vertebrates (b)

Most cells of multicellular organisms are surrounded and organized by an **extracellular matrix (ECM)**. This non-living, complex mixture of fibrous proteins and polysaccharides is secreted by cells and varies with the type of tissue. It supports and anchors cells, separates tissues, and functions in cell signalling. The primary cell wall is a type of ECM, which is mostly cellulose in plants. The ECM of fungi is mainly chitin. In most animals, the ECM consists of various kinds of carbohydrates and proteins. The ECM is the basis of tissue organization, and it provides structural support. For example, bone is mostly ECM (**Figure 11**). Bone ECM is mostly collagen, which is a fibrous protein, and it is hardened by mineral deposits. Other protective structures, such as an insect exoskeleton or a bivalve shell, are also examples of ECM.

A cell that is surrounded by a wall or secretions is not isolated. It can still interact with other cells and with its surroundings via **cell junctions**. In multicellular organisms, cell junctions are structures that connect a cell to other cells and to the environment. Cells send and receive ions, molecules, and signals through some junctions. Other junctions help cells recognize and stick to each other and to the ECM.

**cell junction** a structure that allows cells to interact with each other and the surrounding environment

## 2.1 Review

### Summary


- Eukaryotic cells have many different internal components, called organelles. Each organelle has a specific role in cellular activities.
- Plant cells and animal cells have many of the same organelles. Plant cells also have a cell wall, plastids, and a large central vacuole.
- The nucleus isolates and protects most of the cell's DNA.
- The endomembrane system produces lipids, enzymes, and other proteins that are secreted out of the cell or become part of cell membranes.
- Mitochondria produce ATP.
- Eukaryotic cells have an extensive and dynamic framework called a cytoskeleton. The cytoskeleton is used for cell shape, internal structure, movement, and cell division.
- Many cells are surrounded by and supported by a complex extracellular matrix and are able to interact with adjacent cells and the environment via cell junctions.


### Questions

1. What is the main difference between eukaryotic cells and prokaryotic cells? Why is this difference significant? K/U
2. Describe the relationship between the following cellular structures and contents. K/U
   (a) endoplasmic reticulum and the nuclear envelope
   (b) the centriole and microtubules
   (c) ribosomes and the nucleolus
   (d) plastids and pigments
3. The nuclear envelope is much more than a simple capsule that contains chromosomes. Describe the structure and function of this dynamic component of a cell. K/U
4. (a) What is the endomembrane system?
   (b) What organelles does it include?
   (c) What does each organelle do? K/U
5. Compare and contrast the structure and the functions of the smooth and rough endoplasmic reticulum. K/U
6. How do lysosomes and peroxisomes differ functionally? K/U
7. Your lab partner is looking at a micrograph of an organelle and is trying to identify it. Your partner tells you that it has a folded membrane that looks like a stack of pancakes. K/U
   (a) What organelle are they observing?
   (b) What is the function of this organelle?
8. Compare and contrast the functions of vesicles and vacuoles. K/U
9. (a) What are mitochondria?
   (b) Describe the structure of mitochondria.
   (c) Why are mitochondria sometimes referred to as the "power plants" of cells? K/U
10. What are the various roles of plastids? How can knowing the colour of a plastid reveal something about its function? K/U
11. Structurally, how are chloroplasts and mitochondria well adapted for energy transfer? Explain your answer for each organelle. K/U
12. What important roles are played by microtubules and microfilaments? K/U
13. Use the Internet and other sources to investigate the functions of the following organelles. What types of cells would you expect to contain them? T/I
    (a) acrosome
    (b) eyespot
    (c) proteasomes
14. Use the Internet and other sources to learn more about red blood cells, which are among the smallest of all human cells. T/I
    (a) How many molecules of hemoglobin does a typical human red blood cell contain?
    (b) The human red blood cell does not have a nucleus. Is this true of the red blood cells in all animals?
    (c) What is the benefit of not having a nucleus?

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