What is the largest organism? The answer depends on your definition of “largest.” Among animals, the blue whale is the largest animal on earth, and possibly the largest animal ever. This sea mammal can weigh in at over 100 metric tons and extend up to 35 meters from head to fluke. Blue whales feed on krill, which look like miniature shrimp. By the early 1960s, blue whales had nearly gone extinct due to whaling. They were hunted for their large stores of blubber, a lipid used for lighting and lubrication before the oil age. Luckily, many nations outlawed the hunting of blue whales, and they are slowly rebounding.

In terms of area, the largest organism is a newly discovered fungus, *Armillaria ostoyae*. One fungal individual covers 10 square kilometers of Oregon forest floor. By mass, the largest organism is the giant sequoia (*Sequoia sempervirens*), a tree native to California’s humid coastal forests. Giant sequoias can reach 110 meters in height, with a mass of about 2,500 metric tons. Like the blue whale, the giant sequoia has been threatened (it makes good lumber) but some reserves have been set aside for protection from the chainsaw.

Ironically, these giants are a stunning example of the success of the smallest unit of life—the cell.
Cells are the building blocks of life. Every living thing is composed of cells, from the smallest bacterium to the blue whale or the giant sequoia. These giants have can be as large as an ostrich egg or smaller than a dust speck (a typical liter of blood, for example, contains more than $5.9 \times 10^{12}$ red blood cells). Because most cells are microscopic, you need lots to make up a typical mammal: the human body contains trillions of cells, and virtually all but one are invisible without a microscope (see I Wonder… box on page 64). Our egg, the only human cell visible to the naked eye, is approximately as big as this period:. All cells share these characteristics, they can be remarkably different in shape and size. Cells can be defined by a barrier called the plasma membrane (in animals) or cell wall (in plants and bacteria). Inside the plasma membrane is a fluid called cytosol, which supports the life of the cell.

The cell is a highly organized structure that is defined by a barrier called the plasma membrane (in animals) or cell wall (in plants and bacteria). Inside the plasma membrane is a fluid called cytosol, which supports the life of the cell.

Cellular organization is evident with a quick glance at a magnified cell. Inside the cell, membrane-bound compartments can be seen. These compartments are organelles, small structures whose overall goal is to maintain cellular homeostasis. Some organelles break down nutrients, others are tiny factories that churn out structural and functional proteins, and still others extend through the plasma membrane to the surface of the cell and circulate the surrounding fluid so that waste materials and nutrients can diffuse into or out of the cell.

Cytosol contains water, dissolved compounds, and small molecules called inclusions. These molecules vary by the type of cell, and many include keratin for waterproofing, melanin for absorbing ultraviolet light, and carotenoids which are precursors to vitamin A.

**Learning Objectives**

- Outline the cell theory
- Relate the size of cells to the instrument used to view them.
- Describe the difference between organelles and cytoplasm.
- Compare the size of cells to the instrument used to view them.
- Relate the division of cells to cell division.
- Compare the size of cells to the instrument used to view them.
- Relate the diversity of cells to the role played by cells.
- Describe the diversification of responses of cells to the role played by cells.
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I WONDER ...

How Can You See Cells?

Most cells are microscopic, meaning you literally cannot see them without a microscope. Microscopes make images of “objects,” and are measured by their magnification and resolution. Magnification is a factor comparing image size to object size. Resolution measures the size of objects that can be distinguished from each other.

Cytologists use several types of microscopes to see cells and their organelles. A compound light microscope uses a series of lenses to focus rays of light that pass through an object. The maximum magnification of a light microscope is about 1000 (written 1000X), enough to see cells and some larger organelles. Images taken with a light microscope are called photomicrographs.

Light microscope
You may have the opportunity to use a compound light microscope such as this one in your laboratory class. The microscope enables you to view human cells, such as your own cheek cells.

Scanning electron microscope
The scanning electron microscope achieves high resolution, but can only be used for nonliving samples.

Transmission electron microscope

The microscope can resolve objects 0.2 micrometers apart (one thousand times closer). An electron microscope can distinguish rows of protein molecules. Other electron microscopes can resolve objects only half an angstrom apart! Microscopes have played a heroic role in the development of biology. The Dutch lens maker Anton van Leeuwenhoek started building compound microscopes around 1660. With no scientific training but an open mind, Leeuwenhoek discovered bacteria, sperm, and other basic cells.

In terms of magnification, compound light microscopes are the least powerful microscopic tool discussed. Electron microscopes are far more powerful, and TEM microscopes have the highest resolution of any tool currently available. A TEM microscope built in 2000 at Hitachi’s Advanced Research Laboratory is capable of distinguishing rows of atoms only half an angstrom apart.

Microscopes have a heroic role in the development of biology. The Dutch lens maker Anton van Leeuwenhoek started building compound microscopes around 1660. With no scientific training but an open mind, Leeuwenhoek discovered bacteria, sperm, and other basic cells. At about the same time, English scientist Robert Hook built compound microscopes, and made astonishingly detailed drawings of insects, feathers, and other life forms. Hook made the key discovery of cells as the basis for life.

Later, as biology turned to treating disease, pioneering German biologist Robert Koch used a microscope to view the bacteria that cause tuberculosis and cholera. These images helped cement the germ theory of disease. More recently, electron microscopes have shown that biology’s phenomenal degree of organization extends down to the smallest scale imaginable—the molecular scale.

Leukocytes: cells and their organelles. A compound light microscope enables you to view human cells, such as your own cheek cells.

Figure 3.2

The Cell Membrane Isolates the Cell

LEARNING OBJECTIVES

Discuss the structure of the cell membrane.

Define osmosis and relate it to the actions of hypotonic and hypertonic solutions.

Compare the subtle differences in the main categories of active transport.

Figure 3.2: The cell membrane

The cell membrane

The obvious place to start studying cellular anatomy is with the plasma membrane, the structure that separates the cell from the extracellular fluid. This membrane is composed of two layers of phospholipids, interspersed with proteins, fats, and sugars (see Figure 3.2). The phospholipids are arranged in a double layer, or bilayer, with the hydrophilic, water-loving heads (the charged, phosphate ends of the molecule) oriented toward the aqueous environment both inside and outside the cell. The hydrophobic, water-fearing, non-polar, lipid portion of the molecules are sandwiched in the center.
Some of the proteins and lipids associated with the cell membrane have sugars attached to their external surface, and are called **glycoproteins** and **glycolipids**.

The **glycoproteins** and **glycolipids** form a layer called the **glycocalyx**; these are particular enough to define the cell as belonging to a specific organism. Both blood type and tissue type are defined by the specific structures on the glycocalyx. For example, each person’s white blood cells carries a group of identifying proteins called the human leukocyte antigens (HLA) as that serve as markers indicating that our cells belong to us. HLA is used to match tissues before organ transplants. Because HLA is inherited, if we need a transplant, we can often find a close tissue match within our immediate family.

The cell membrane is not a static structure. At any given time, the phospholipids are liquid, not solid, so the basic structure of the membrane is a continually snuffling fluid. (Cholesterol, a necessary component of the cell membrane, helps to maintain this fluidity.) The proteins embedded in the membrane are in constant motion, floating around in the fluid phospholipid bilayer. Picture a beach ball covered in Vaseline and rolled in the sand. As the Vaseline warms in the sun, it will begin to flow around the ball (inner cytosol of the cell) causing the embedded sand grains to swirl with it. Similarly, the glycocalyx and embedded proteins in the fluid phospholipid bilayer swirl around the cell membrane.

**MOVEMENT ACROSS THE MEMBRANE CAN BE PASSIVE OR ACTIVE**

The phospholipid bilayer defines the cell and protects it from the aqueous environment. Without membrane lipids, the cell would literally disintegrate, much like a cracker dropped into a glass of juice. But the plasma membrane cannot maintain cellular homeostasis unless it allows some compounds in and out of the cell.

In fact, rather than being a simple plastic bag, the membrane is a semipermeable barrier that allows nutrients to enter the cell and waste and secretory products to exit it. Some ions and molecules cross freely; others can be moved across the membrane with the expenditure of some energy, and still others cannot cross at all. Movement across the membrane can be either passive or active.

Passive movement includes **filtration**, **diffusion**, and **facilitated diffusion**. None of these activities requires the cell to expend energy. **Diffusion** is the movement of solutes in response to fluid pressure. Your kidneys separate waste products from the blood via filtration.

**DIFFUSION MOVES MOLECULES FROM HIGH CONCENTRATIONS TO LOW CONCENTRATIONS**

Diffusion is the movement of a substance toward an area of lower concentration. Open a perfume bottle and set it in the corner of a room. Within a short time, the perfume will diffuse from the bottle and permeate the room. Warm the room, and the diffusion speeds up. Diffusion results from the random movement of the molecules, which eventually tends to balance out the molecule’s concentrations (see Figure 3.3).

The same phenomenon occurs continuously in your cells. Lipid-soluble compounds and gases can diffuse across the cell membrane as if it weren’t there, traveling right through the phospholipid bilayer. The driving force for the movement of oxygen from the atmosphere into the deepest tissues of the body is merely diffusion.

While lipid-soluble molecules can diffuse freely through it, the phospholipid bilayer completely blocks the diffusion of aqueous, or water soluble, solutes. This is a potential problem, as many aqueous solutes, such as glucose, are essential compounds that must be able to penetrate the cell membrane. To solve this problem, the lipid bilayer has **integral and peripheral proteins** that serve as channels and receptors for aqueous solutes to enter and exit the cell.

The most abundant compound in the body is water. To maintain homeostasis, cells must allow water to move between the intracellular fluid (ICF) and the extracellular fluid (ECF). Diffusion of water across a semipermeable membrane such as the cell membrane is termed osmosis. In osmosis, water moves in a direction that tends to equalize solute concentration on each side of the membrane. In effect, locations with high solute concentrations seem to “pull” water toward them.

Water cannot cross the phospholipid bilayer, so it must travel through proteins. Usually, the extracellular fluid is isotonic to the cells, and water flows equally in and out of the cell through transport proteins. If you place a cell in a hypertonic solution (water with a lower concentration of solutes than the cytosol), the cell will take in water and may even burst. In contrast, a hypertonic solution (with a higher concentration of solutes), will remove water from the cell, and cause it to shrivel up (see Figure 3.4).

**FACILITATED DIFFUSION**

When solutes are transported across the membrane down their concentration gradients (from high concentration to low concentration) by transport proteins, no energy is expended. This type of movement is called facilitated diffusion and is the main avenue through which glucose is moved into cells. After a meal, blood glucose is higher than cellular glucose. However, in order to diffuse into the cell, glucose needs a “doorway”
CHAPTER 3
Cells, Organization, and Communication

The Cell Membrane Isolates the Cell

Facilitated diffusion Figure 3.5

Through the phospholipid bilayer. It would make very little sense to expend energy just to get glucose into the cell to make energy (see Figure 3.5).

During osmosis, as water diffuses toward areas of lower water concentration (and higher solute concentration), across the semipermeable membrane, it creates osmotic pressure. The Greek letter \( \psi \) (psi) stands for water potential. This is a calculation of the osmotic pressure of resting cells in an isotonic solution. The two components of water potential are the pressure exerted on the cell by its environment and the solute concentration of the cells, so \( \psi = \psi_{\text{osmotic}} + \psi_{\text{solute concentration}} \).

Water potential is useful for calculating the concentration of an isotonic solution, and is used most often by botanists to predict water movement in and out of plant cells.

ACTIVE TRANSPORT USES ENERGY TO MOVE MOLECULES ACROSS MEMBRANES

When energy is consumed to move a molecule or ion against the concentration gradient, we call the process active transport, or solute pumping. Osmosis and other forms of diffusion move molecules “down” their concentration gradients without additional energy. Active transport is used to concentrate molecules inside cells at levels that exceed the extracellular concentration, using energy derived from the breakdown of ATP into ADP. Active transport accounts for the almost complete uptake of digested nutrients from the lumen of the intestine, the sequestering of iodine in thyroid gland cells, and the return to the blood of the vast majority of sodium ions filtered from the blood by the kidneys.

Active transport can move atoms, ions, or molecules into the cell (endocytosis) or out of it (exocytosis). In endocytosis, extracellular molecules and particles are taken into the cell via vesicle formation. Just as punching a partially inflated balloon caves in the balloon wall, endocytosis begins with depression of the cell membrane. Particles in the extracellular fluid flow into the new dimple, and get trapped within the vesicle that forms when the two sides touch and are pinched off inside the cell. The two forms of endocytosis are pinocytosis and phagocytosis (see Figure 3.6).

Exocytosis is used to remove secretory products or waste products from the cell. Vesicles form within the cell, usually from one of two organelles, the Golgi apparatus or a lysosome. They travel to the inner wall of the cell membrane, and fuse with it (think of two soap bubbles fusing into one larger bubble where they touch). This fusion releases the vesicle’s contents into the extracellular fluid (see Figure 3.7).

During phagocytosis the cell surrounds and ingests a large particle. In this image, the cell on the left is in the act of engulfing the round bacterium on the right.
Often small molecules or ions are moved by intramembrane pumps, as transport proteins are sometimes called. These protein structures may transport ions or small molecules in either direction across the plasma membrane. Pumps often have reciprocal functions—pumping one molecule or ion into the cell while simultaneously removing a second chemical species from the cell. For example, sodium/potassium ATPase is a common reciprocal pump, moving two potassium ions into the cell while pumping three sodium ions out of it (see Figure 3.8). We will discuss this pump again when we cover neurophysiology.

**Figure 3.8**

*Na+/K+ ATPase*  
The sodium potassium pump transfers two potassium ions into the cell for every three sodium ions it removes. The movement of ions happens simultaneously.

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**The Science of Intravenous Fluids**

Few visits to the hospital seem complete without some form of intravenous (IV) therapy. Intravenous (“within a vein”) treatment allows doctors to place medicine right inside your bloodstream. IV treatment can convey vitamins, glucose, coenzymes, antivirus drugs, antibiotics, and electrolytes.

These medicines and agents are commonly added to a carrier called IV solution. Have you ever wondered why so much IV solution is marked “0.9% saline,” or “5% dextrose”? The answer is rooted in osmosis, the diffusion of water through a semi permeable membrane. Molecules diffusing from areas of high concentration to areas of lower concentration. Water diffuses, or osmoses, toward areas with higher solute concentration (where the water concentration is lower).

Diffusion explains the focus on solute concentration in IV solution. Blood plasma is normally isotonic, and doctors usually want IV solution to be isotonic as well, which is why they use 0.9% saline or 5% dextrose IV solution. The total solute (salt or sugar) concentration in these IV bags is the same as in human plasma. In some cases, other IV solutions are more appropriate. A less concentrated (“hypotonic”) solution would, according to the principles of diffusion, move water across the plasma membrane into cells, helping to reverse dehydration.

A hypertonic IV solution (with a higher solute concentration than the cytosol) will cause osmotic pressure to reduce blood pressure. In cerebral edema, for example, hypertonic IV treatment is often the first line of treatment. If it does not reduce swelling of the brain, physicians may take drastic steps like surgically removing part of the skull to relieve the pressure.

Osmotic pressure plays a key role in two common conditions: diabetes and hypertension (high blood pressure). Diabetes results from either a shortage of insulin or a failure to respond to insulin. In either case, glucose fails to enter the cells, and the blood becomes hypertonic, which tends to remove water from the cells. Such an alteration in solute concentration can cause some of the widespread changes in cellular metabolism seen in diabetes.

Osmosis also plays a key role in many cases of hypertension, which affects 50 million Americans and is implicated in heart disease and stroke, two of the top three killers. Excess sodium ions in the blood change the osmotic conditions and reduce the kidney’s ability to excrete water, resulting in an increase in blood pressure. The exact role of salt in hypertension is debated, however, as reducing salt intake does not always reduce blood pressure among hypertensive people. Clearly, the homeostatic mechanisms to regulate blood pressure are so important that many other factors are involved.

**Concept Check**

Describe the structure of a typical cell membrane. Which type of solution (hypotonic, isotonic, or hypertonic) causes red blood cells to burst? What is the difference between diffusion and osmosis? List the two main types of active transport, and explain how they differ.
CHAPTER 3

Cells, Organization, and Communication

The Components of a Cell Are Called Organelles

LEARNING OBJECTIVES

- List and describe the function of the main organelles of a typical animal cell.
- Compare eukaryotic and prokaryotic cells.
- Identify the organelles specific to plant cells.

CYTOSKELETON IS THE POWER BEHIND THE MEMBRANE

Cytologists used to view the cytosol as a watery bath, but it is actually a highly organized chemical soup pervaded by a support structure called the cytoskeleton. The cytoskeleton lies directly underneath the plasma membrane, and is attached to it in many places. Composed mainly of three types of filament, the cytoskeleton extends throughout the cytosol, providing shape, support, and a scaffold for suspending and moving organelles. Unlike your bony skeleton, the cytoskeleton is continuously changing shape, forming and breaking down. This gives cells a plasticity, or fluid resiliency, that allows them to change shape or move organelles quickly.

The cytoskeleton has three types of protein structure: microfilaments, intermediate filaments, and microtubules. Microfilaments, the thinnest elements, are responsible for cellular locomotion, muscle contractions, and movement during cell division. They also establish the basic shape and strength of the cell. Intermediate filaments are much stronger than microfilaments and protect the cell from mechanical stresses. Microtubules are long strings of the globular protein tubulin, coiled tightly into a tube. Microtubules are used as tracks for organelle movement, and are instrumental in chromosome movement during cell division. The proteins of these cytoskeletal elements are what give each their characteristic functions. The microfilaments are composed mostly of actin, a protein that, under the proper conditions, will cause movement in a predictable fashion. We discuss this protein far more extensively when looking at skeletal muscle contraction. Intermediate filaments are composed of extremely tough, support proteins found nowhere else in the cell.

FLAGELLA AND CILIA KEEP THINGS MOVING

Many cells have projections from their surface that can move either the entire cell or the extracellular fluid. Flagella are single, long whip-like structures that propel the cell forward. The only human cell that moves by flagellum is the sperm. Cilia are shorter extensions that look like hairs or eyelashes, and they are far more common in the human body (see Figure 3.9). They beat synchronously in what is referred to as a "power stroke" to move mucus across the surface of the cell, or to circulate the extracellular fluid to increase diffusion. Cilia line the upper respiratory tract, moving mucus upward and sweeping out debris and pathogens. Cilia lining the fallopian tubes move the egg from the ovary to the uterus.

ENDOPLASMIC RETICULUM: PROTEIN AND HORMONE MANUFACTURING SITE

Within the cytosol of many cells lie networks of folded membranes, called the endoplasmic reticulum or ER (literally "within fluid network"). The membranes of the ER are directly connected to the double membrane surrounding the cell nucleus. Human cells have two types of ER, rough or smooth. Rough endoplasmic reticulum (RER) is a processing and sorting area for proteins synthesized by the ribosomes that stud its outer membrane (see Figure 3.10). Ribosomes are small nonmembrane-bound organelles composed of protein and ribosomal RNA. They serve as protein factories, synthesizing proteins that may be included in other organelles or in the plasma membrane itself, or are exocytosed through secretory vesicles.

GOLGI COMPLEX: COMPLICATED CHEMICAL FACTORY

This organelle is one of the few to retain the name of its discoverer, Camillo Golgi, who discovered it in 1898. The Golgi complex, or Golgi apparatus, is usually found in secretory cells, such as those of the liver, that produce complex molecules, such as proteins or polysaccharides. The Golgi complex is a stack of membrane-bound sacs that acts as a polishing station for proteins and lipids. "Glycoproteins" are proteins and carbohydrates that combine to form a complex molecule. These molecules are then transported out of the cell. The Golgi complex is involved in the transport of all glycoproteins. The Golgi complex is made up of many sacs, or cisternae, that may be included in other organelles or in the plasma membrane itself, or are exocytosed through secretory vesicles.

Smooth endoplasmic reticulum, or SER, is responsible for the synthesis of fatty acids and steroid hormones, such as testosterone. SER has no ribosomes. In the liver, enzymes that break down drugs and alcohol are stored in the SER.

In both RER and SER, the end product is a vesicle filled with product ready for the next step in processing. These vesicles form from the ER, and usually move substances from the ER to the cell membrane for exocytosis, or to the Golgi complex for further packaging.

The cell in this image is packed with ER. The thin tubules without ribosomes studding their surface are the channels of the SER. The RER is concentrated in the lower left of the image. As can be seen in the inset, RER is found immediately outside the cell nucleus, while SER is a continuation of the RER tubules.
near the end of the SER and resembles a stack of pancakes called saccules (see Figure 3.11). Saccules are slightly curved, with concave and convex faces. The concave portions usually face the ER, and the convex portions face the plasma membrane. Vesicles are found at the edges of these saccules.

The precise role of the Golgi complex is debated. Clearly it is involved with processing of proteins and fatty acids, but exactly how does it do that? Some scientists believe that vesicles from the ER fuse with the lowest saccule of the Golgi complex, and then the saccules “move up” in ranking toward the upper saccule. From there, the Golgi complex membrane reforms the vesicle, which transports completed proteins or fatty acids to their destination (see Figure 3.12). Other scientists believe that the original vesicles from the ER fuse with the top saccule right from the start. The enzymes within this top saccule complete the processing of the proteins or fatty acids in the vesicle, which are then transported to their functional areas.

In either case, the vesicles that leave the Golgi complex migrate all over the cell. Some fuse with the cell membrane, others fuse with lysosomes, and still others become lysosomes. It seems that the Golgi complex completes the processing of proteins and fatty acids, readying the products for use in other organelles or in the cell membrane.

**LYSOSOMES: SAFE CHEMICAL PACKAGES**

Lysosomes are chemical packages produced by the Golgi complex that contain hydrolytic enzymes powerful enough to digest an entire cell from the inside. The lysosome sequesters these digestive enzymes for use in decomposing macromolecules that have entered the cell via endocytosis (see Figure 3.13). When a lysosome ("lyse" means to break open or break up) fuses with the endocytosed material, the enclosed material is digested by the enzymes in the lysosome. This process is called autolysis.

Membrane is constantly cycling through the cell. New membrane is being made in the ER, transported through the Golgi complex, and finally fused with the plasma membrane. The membrane is constantly being replaced. Lysosomes are sequestered digestive enzymes that help decompose compounds by splitting bonds with water molecules.
is lost not by developmental changes in DNA processing, but rather by lysosomes bursting and digesting cells in the tail.

THE CELL’S LIBRARY IS THE NUCLEUS

The nucleus contains a cell’s genetic library, and is usually the largest organelle in a cell (see Figure 3.14). (Mature human red blood cells, however, have no nucleus.) This organelle is approximately 5 micrometers in diameter in most human cells. It is covered, like the cell itself, by two layers of membrane, called the nuclear envelope. The envelope is punctuated by nuclear pores, which allow molecules to enter and exit the nucleus. The DNA in the nucleus is the cell’s library, which is “read” by molecules called RNA. After RNA makes a perfect impression of the DNA, it leaves the nucleus and serves as templates for proteins. The process of forming RNA is called transcription, which means to “write elsewhere” (see Figure 3.15A).

Once RNA is formed within the nucleus, it leaves via the nuclear pores. In the cytoplasm, this message is “read” by ribosomes. The single strand of mRNA is fed into the center of a ribosome, where transfer RNA matches up to it in three-base pair sections. Each tRNA carries an amino acid, specified by those same three base pairs that are matching up to the mRNA. As the mRNA is passed through the ribosome, the mes-
During protein synthesis the ribosomal subunits join, but they separate when the process is complete. During protein synthesis the ribosomal subunits join, but they separate when the process is complete.

Summary of movement of ribosome along mRNA

During protein synthesis the ribosomal subunits join, but they separate when the process is complete.

A chromosome is a highly coiled and folded DNA molecule that is combined with proteins. The two arms of the chromosome are identical pieces of DNA.
Mitochondria break down glucose to produce ATP. This process is completed in four steps, the first of which happens outside the mitochondrial walls. The formation of ATP occurs on the inner walls of the mitochondria. Chapter 13: Digestion will discuss these processes in more detail.

Mitochondrial Reactions Figure 3.18

1. Glucose is brought into the cell via facilitated diffusion, where it is broken down in a series of chemical reactions called glycolysis. Glycolysis releases energy in two ATP molecules, and two molecules of pyruvic acid.
2. Pyruvic acid then gets taken into the mitochondrion, where it is converted to acetyl co-A.
3. Acetyl co-A feeds into the Krebs cycle, another series of biochemical reactions that release energy from the acetyl co-A in the form of ATP, NADH, and FADH2.
4. In the final step of the mitochondrial reactions, the NADH and FADH2 formed during glycolysis and the Krebs cycle are transported to the inner membrane of the mitochondrion. There they are used to drive a final series of reactions called the electron transport chain. This final series converts the energy stored in the NADH and FADH2 into usable ATP for the cell.

The mitochondria convert digested nutrients into usable energy for the body, in the form of ATP. Virtually every move you make, every step you take, can be traced to mitochondria. Each cell has many mitochondria, all undergoing cellular respiration producing the ATP your cells need to survive. ATP forms within the inner membrane of the mitochondrion (see Figure 3.18). Mitochondria require oxygen, and produce carbon dioxide, in their endless production of ATP. In the final analysis, we inhale oxygen to serve our mitochondria, and we exhale the carbon dioxide they produce while generating ATP.

Mitochondria can divide, replicating these energy-producing organelles when our cells need more ATP. Cells in active tissues, like skeletal muscle and liver, have more mitochondria than cells in less-active tissue. This ability to reproduce has long intrigued cellular biologists. Mitochondria resemble bacteria in size and chemical composition, and in their use of DNA to pattern their proteins. Some scientists hypothesize that these organelles were once free-living bacteria that evolved from a symbiotic relationship into a type of ultimate, intimate symbiosis. Perhaps billions of years ago, a bacterial cell traded a free-living existence for a safe and constant environment in which to carry out its life processes. In this “you scratch my back and I’ll scratch yours” arrangement, the sheltering cell receives a supply of ATP in return for protecting the mitochondria, delivering oxygen to it and disposing of its waste carbon dioxide. Mitochondria have their own DNA. Because they are outside the nucleus, they are not constantly reshuffled through sexual reproduction, and are inherited through the maternal lineage. The relatively stable DNA in mitochondria means they can help trace human migrations and evolution.

See Table 3.1 for a summary of all organelles.

**Plant cells**

Plant cells, composed of tough cellulose, provide rigid support immediately superficial to the cell membrane. The large, membrane-bound organelle called the central vacuole (not found in animal cells) maintains cell turgor. Many plant cells also have chloroplasts, organelles where photosynthesis occurs. These are similar in structure to mitochondria in that they have an inner and an outer membrane, and they are responsible for producing energy and making simple sugars from carbon dioxide. Like mitochondria, chloroplasts may have originated as bacteria that were “adopted” by the plant cell.

**Symbiotic**

Intimate co-existing of two organisms in a mutually beneficial relationship.
### Table 3.1: Cell parts and their functions

<table>
<thead>
<tr>
<th>Part</th>
<th>Structure</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Membrane</td>
<td>Composed of a lipid bilayer consisting of phospholipids and glycoproteins with proteins inserted, mitochondria visible.</td>
<td>Protects cellular contents, makes contact with other cells, contains channels, receptors, and cell-identity markers, mediates the entry and exit of substances.</td>
</tr>
<tr>
<td>Cytoplasm</td>
<td>Cellular contents between the plasma membrane and nucleus, including cytosol and organelles.</td>
<td>Site of all intracellular activities except those occurring in the nucleus.</td>
</tr>
<tr>
<td>Organelles</td>
<td>Specialized cellular structures with characteristic shapes and specific functions.</td>
<td>Each organelle has one or more specific functions.</td>
</tr>
<tr>
<td>Cytoskeleton</td>
<td>Network composed of three protein filaments (microfilaments, intermediate filaments, and microtubules).</td>
<td>Maintains shape and general organization of cellular curvature, responsible for cell movements.</td>
</tr>
<tr>
<td>Centrioles</td>
<td>Paired centrioles.</td>
<td>Organizing center for microtubules and centrosomes.</td>
</tr>
<tr>
<td>Cilia and flagella</td>
<td>Mobile cell-surface projections with inner core of microtubules.</td>
<td>Cilia move fluids over a cell's surface, a flagellum moves an entire cell.</td>
</tr>
<tr>
<td>Ribosome</td>
<td>Composed of two subunits containing ribosomal RNA and proteins, may be free in cytosol or attached to rough ER.</td>
<td>Protein synthesis.</td>
</tr>
<tr>
<td>Endoplasmic reticulum (ER)</td>
<td>Membranous network of folded membranes. Rough ER is studded with ribosomes and is attached to the nuclear membrane; smooth ER lacks ribosomes.</td>
<td>Rough ER is the site of synthesis of glycoproteins and phospholipids; smooth ER is the site of fatty acid and steroid synthesis.</td>
</tr>
<tr>
<td>Golgi complex</td>
<td>A stack of 3-20 flattened membranous sacs called cisterns.</td>
<td>Accepts proteins from rough ER, stores, packages, and exports proteins.</td>
</tr>
<tr>
<td>Lysosome</td>
<td>Vesicle formed from Golgi complex, contains digestive enzymes.</td>
<td>Bases with and digests contents of vacuoles, digests receptor organelles, entire cells, and extracellular materials.</td>
</tr>
<tr>
<td>Peroxisome</td>
<td>Vesicle containing oxidase enzymes.</td>
<td>Detoxifies harmful substances.</td>
</tr>
<tr>
<td>Mitochondria</td>
<td>Consists of an outer and inner membranes, cristae, and matrix.</td>
<td>Site of reactions that produce most of a cell's ATP.</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Consists of nuclear envelope with genes, nucleoli, and chromatin (or chromosomes).</td>
<td>Contains genes, which control and direct most cellular activities.</td>
</tr>
</tbody>
</table>

### Learning Objectives

- **Explain** cellular signaling as it relates to the human body.
- **Define** hormone.
- **Identify** the steps necessary before mitosis can begin.
- **Trace** the steps in mitotic cellular division.

### Cell Communication and Cell Division

Cell Communication and Cell Division are the Keys to Cellular Success. Not all life forms are eukaryotic. Bacteria, for example, do not have membrane-bound organelles. They have no chloroplasts, no mitochondria, no ER, no Golgi complex, and no nuclei (see Fig. 3.20). These prokaryotic cells do not compartmentalize functions like eukaryotic cells, and their genetic material is loose within the cytoplasm.

### Prokaryote

Prokaryote Figure 3.20

Note the smaller size of these bacterial cells. No compartmentalization is seen in these cells: no nucleus, no organelles of any sort.
1. Circulating hormones can be released into the bloodstream, potentially reaching every cell.

2. Local hormones, called paracines, can be released to affect only cells in the vicinity. Neurons use paracines to stimulate nearby nerve, muscle, or glandular cells by releasing short-lived chemicals called neurotransmitters.

3. Cells of epithelial and muscular tissues can interact with other cells directly through a physical connection at cell-to-cell junctions.

The differences in these types of signals lie mostly in the speed and distance of signal transmission, and the selectivity of reaching the target cells. Much hormonal communication is long-distance, carrying information to distant cells that will alter their functioning. The target cells are often remote from the secreting cells. For example, the pituitary gland in the center of the brain secretes a hormone that stimulates reproductive organs in the pelvic cavity.

Paracrine communication is mostly used when quick responses are required. Cells that are infected with a virus, for example, may secrete the paracrine interferon. Interferon alerts the surrounding cells, warning them of the viral invasion, and ideally helping them to avoid it. Neurons must respond instantly to information; therefore, they secrete neurotransmitters directly into the space between cells. Sending neurotransmitters into the bloodstream would be too slow and ineffective.

Gap junctions, such as those described above between neurons, are used for instantaneous communication. They occur across very small distances, and are extremely specific. Unlike endocrine communication, whose effects are long-lasting, gap junction communications are immediate and short-lived.

Cell-to-cell junctions occur in tissues like your skin, where cells are in direct contact with one another. Skin cells are knit tightly together, so any change in one cell will be immediately passed to the next. Muscular tissue has similar cell-to-cell junctions, allowing the entire muscle to contract as one organ.

Endocrine cell

Circulating hormone

Blood capillary

Hormone receptor

Distant target cells

Paracrine receptor

Paracrine

Neuro target cell

Autocrine cell

Autocrine receptor

Local hormones (paracines and autocrines)

Cell signaling comparison (Figure 3.21)
Interphase is the "resting" phase. The cell is not dividing, but rather carrying out its normal duties. The nuclear membrane is intact, the DNA is loose and unwound in chromatin threads, and nucleoli are present. In a cell that is destined to divide (some, like skeletal muscle and nerve cells, do not divide), the DNA doubles during the interphase, but interphase is not considered part of mitosis.

In prophase, the nuclear membrane disappears; the chromatin condenses and becomes visible in the cell as chromosomes; the centrioles (which also doubled during interphase) separate and migrate to opposite ends of the cell. As the centrioles migrate, the spindle apparatus is formed. This is a network of microtubules that attach to the centromeres. Prophase is the longest phase of mitosis.

In metaphase, the middle phase of mitosis, the chromosomes are lined up on the central axis of the cell. As soon as the chromosomes are aligned, anaphase begins.

In anaphase, the spindle apparatus shortens, pulling the two arms of the chromosome from the centromeres. As the spindle fibers shorten, the chromosome breaks apart at the centromere, and the two arms are pulled away from each other. Anaphase is very quick, but it is here that the doubled genetic material separates into the DNA needed for each daughter cell.

Telophase is the final phase of mitosis. The chromosomes, now separated into two equal groups, de-condense into chromatin, and the DNA returns to the thread-like appearance. Nuclear envelopes form around these chromatin groups. The center of the cell pinches to form a cleavage furrow. The furrow deepens, eventually separating the cell into two separate cells, each with a nucleus containing the same amount of DNA as the parent cell.

The two daughter cells contain identical genetic material, and are clones of the single parent cell. Once division is completed, the daughter cells are in interphase, meaning they have begun a new growth phase. Eventually they will each reach the size of the original cell. They may undergo mitosis as well, individually moving through the cycle again.
CHAPTER SUMMARY

1. The Cell Is Highly Organized

According to the cell theory, all life is composed of cells. Cells come from pre-existing cells, they contain hereditary material, and they are composed of similar chemical compounds. These cells have a membrane that separates them from the environment, as well as internal compartments designed to carry out specific functions. The cell membrane (or plasma membrane) is composed of a phospholipid bilayer. It is vital to cellular function, allowing some ions to pass freely and requiring energy expenditure to transport others.

The membrane has embedded proteins and surface proteins that help distinguish a particular organism’s immune identity. Osmosis and diffusion both transport molecules across the cell membrane, as do the active transport processes of endocytosis and exocytosis.

2. The Cell Membrane Isolates the Cell

The cell membrane is composed of a phospholipid bilayer, studded with proteins and covered on the surface with the glycocalyx. This liquid membrane is selectively permeable, allowing some substances free access to the cell while others are excluded. Passive transport across the membrane requires no energy, and includes filtration, diffusion, and facilitated diffusion. Osmosis describes the movement of water across the cell membrane. Solutions can be defined as isotonic, hypertonic, or hypotonic, depending on the amount of water relative to that found in the cell. Active transport requires ATP, and involves moving substances into the cell (endocytosis) and out of the cell (exocytosis) against their concentration gradients.

3. The Components of a Cell Are Called Organelles

A typical animal cell has the following organelles: nucleus, nucleolus, RER, SER, ribosomes, Golgi apparatus, lysosomes, centrioles, cytoskeleton, and mitochondria. Cilia are found on cells that must move fluid past them, and sperm carry a flagellum. The cell is a dynamic place, where membrane is constantly being created and used. New membrane made at the RER is processed while moving to the Golgi apparatus and then to a transport vesicle destined to leave the cell. When the vesicles fuse with the cell membrane, the new phospholipid bilayer is spliced into place.

4. Cell Communication and Division are the Keys to Cellular Success

Cells communicate with one another through chemicals. Hormones carry information long distances in the body, while paracrine convey information locally. Some cells, such as those of the skin or muscles, interact through direct physical contact as well. Cells divide through a regulated process called mitosis. In a cell destined for mitosis, the DNA is replicated during interphase. The steps in mitosis are:

1. Prophase where the nuclear membrane breaks down, the chromatins condense into visible chromosomes, the centrioles separate, the spindle apparatus forms, and the spindle fibers attach to the centers of the chromosomes.

2. Metaphase during which the chromosomes are aligned on the central plane of the cell.

3. Anaphase which is the fastest phase of mitosis. During anaphase the sister chromosomes are pulled apart and separated, one to each pole of the cell.

4. Telophase concludes mitosis. The chromosomes de-condense; two nuclear membranes now appear; one surrounding each group of separated chromosomes; the spindle apparatus dissolves; and a cleavage furrow appears.

Cytokinesis marks the end of mitosis, resulting in two identical daughter cells.

KEY TERMS

- organelle p. 53
- meiosis p. 53
- melanin p. 53
- cistern p. 53
- SM p. 54
- TSM p. 54
- phosphophoryl p. 56
- glycoprotein p. 56
- glycolipid p. 56
- integral protein p. 57
- peripheral protein p. 57
- solute p. 57
- isotonic p. 57
- pancytotic p. 58
- phagocytosis p. 58
- cilium p. 58
- cytokeratin p. 58
- actin p. 58
- succinylic p. 58
- hydrolytic enzymes p. 64
- nucleoplasm p. 65
- symbiotic p. 71
- glycosyl p. 71
- turgor p. 71
- prokaryotic p. 79
- hormone p. 74

CRITICAL AND CREATIVE THINKING QUESTIONS

1. As a research assistant in a cytology lab, you are handed a stack of photographs from an electron microscope. Each represents a different type of cell. You are asked to identify photos of animal cells that secrete large amounts of protein, do not divide, and include a mechanism for moving their secretions along their surface. What organelles would be required by this cell? Which organelles would you not expect to see?

2. Assume you are now a lead scientist in a cytology lab, studying membrane proteins. You have placed a radioactive marker on an embedded membrane protein immediately after the DNA was transcribed. Trace the pathway this membrane protein would likely take while moving from its formation to its destination in the cell membrane. What organelles will it pass through? Where will it be located within these organelles?

3. Mutations are permanent changes in the nucleotide sequence in DNA. A point mutation is the loss or gain of a single nucleotide. If a base was lost from the DNA sequence, how would this affect subsequent transcription and translation of that gene?
### SELF TEST

1. Which of the following is NOT a part of the cell theory?
   - All living things are composed of cells
   - Cells cannot arise from preexisting cells.
   - Chemically all cells are quite similar
   - Metabolism occurs within cells.

2. An organelle can be defined as
   - a dissolved compounds in the cytosol
   - a structure within the cytosol that performs one vital cellular function
   - a phospholipids bilayer
   - the smallest unit of life

3. Within a human cell, it is common to find
   - Cytosol
   - Melanin
   - Ribosomes
   - All of the above

4. Movement across the cell membrane can be passive or active. Which of the following is an example of active transport?
   - Diffusion
   - Filtration
   - Osmosis
   - Sodium potassium ATPase

5. Putting a cell in a hypotonic solution will result in that cell
   - Shrinking as water passes out of the cell membrane
   - Expanding as water moves into the cell
   - Remaining static, with no net water movement across the membrane
   - Expanding as proteins move in the cell

6. The process of ________ removes secretory products or wastes from a cell.
   - Endocytosis
   - Pinocytosis
   - Exocytosis
   - Phagocytosis

7. Using the same figure, what is the function of structure E?
   a. ATP production
   b. Protein packaging and processing
   c. Housing the DNA
   d. Digesting worn out organelles

8. The functions of the cytoskeleton include
   a. Providing cellular shape
   b. Supporting organelles within the cytosol
   c. Cellular locomotion
   d. All of the above are correct

9. The largest organelle in most human cells is the organelle that houses the DNA of the cell.

10. The process of ________ removes secretory products or wastes from a cell.
    a. Endocytosis
    b. Pinocytosis
    c. Exocytosis
    d. Phagocytosis

11. Identify the organelles indicated on this figure by matching the structure on the figure with the names below:
    - Mitochondrion
    - Flagella
    - Ribosomes
    - SER
    - Lysosome
    - Golgi Complex
    - Nucleus

12. What is the function of lysosomes?
    - ATP production
    - Protein packaging and processing
    - Housing the DNA
    - Digesting worn out organelles

13. The functions of the cytoskeleton include
    a. Providing cellular shape
    b. Supporting organelles within the cytosol
    c. Cellular locomotion
    d. All of the above are correct

14. Which organelle is thought to have been bacterial symbionts that are now permanently incorporated into eukaryotic cells?
    - Mitochondrion
    - Golgi complex
    - Ribosomes
    - Nucleus

15. The organelles responsible for moving fluid past the surface of a cell are
    - Mitochrondion
    - Flagella
    - Cilia
    - Nucleus

16. When a protein is formed, it moves from the ribosome to the RER and then on to the ________ where it is processed for use either in the cell or in the extracellular matrix.
    - SER
    - Golgi Complex
    - Compartment
    - Nucleus

17. True or False: The largest organelle in most human cells is the organelle that houses the DNA of the cell.

18. Some cells communicate with one another through paracrinnes, which can be defined as
    a. cell to cell contact
    b. long range hormones
    c. local hormones
    d. gap junctions

19. What stage of mitosis is indicated by the number 15 below?
    - Prophase
    - Metaphase
    - Anaphase
    - Telophase
    - Interphase

20. Of the stages seen above, in which one does the DNA duplicate?
    - Prophase
    - Metaphase
    - Anaphase
    - Telophase
    - Interphase

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### Chapter Summary

90 CHAPTER 3 Cells, Organization, and Communication