CK-12 Biology Concepts

ABHS Q4 Biology I Flexbook

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Foreword

The study of biology is the study of life. Concept Biology presents biology as a set of 13 concepts, with each concept centered around a specific category, such as cell biology or human biology. Each concept is comprised of a series of lessons, with each lesson focusing on one specific topic. The complete Concept Biology is comprised of over 327 lessons.

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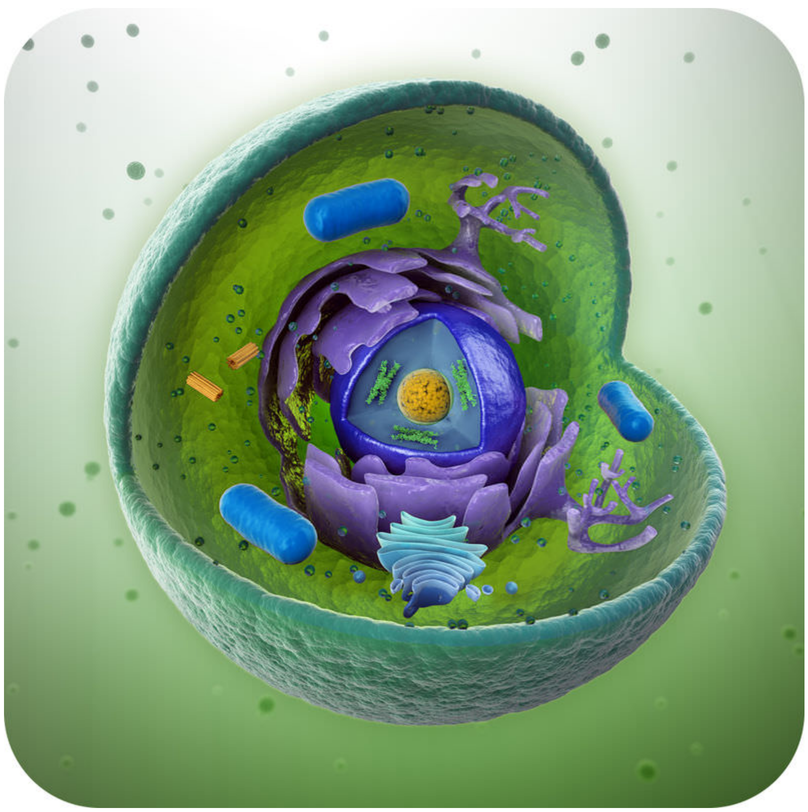
Chapter Outline

Introduction

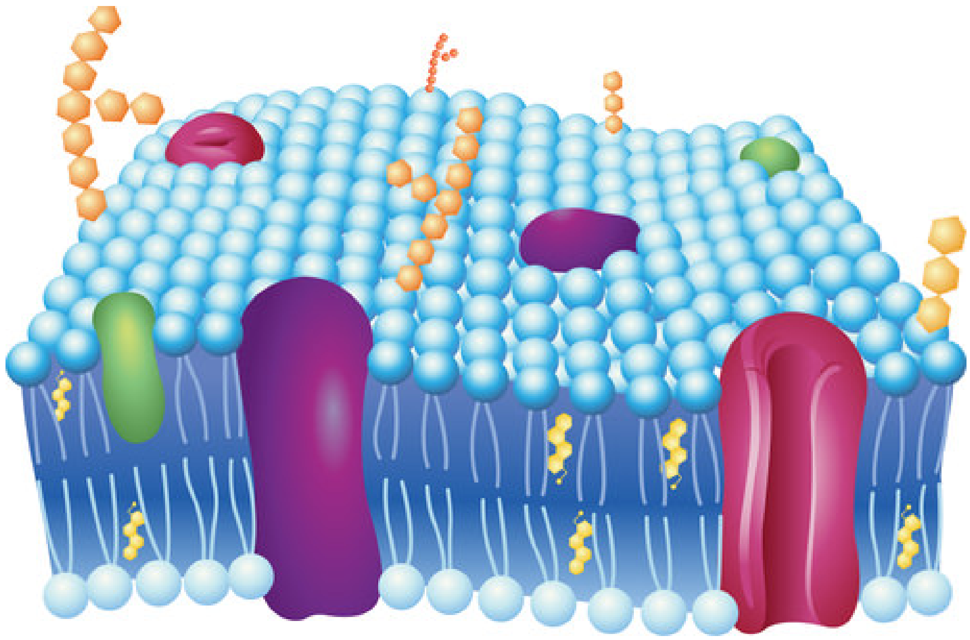


What is a cell?

It could easily be said that a cell is the fundamental unit of life, the smallest unit capable of life or the structural and functional unit necessary for life. But whatever it is, a cell **is** necessary for life. This chapter will discuss some of the fundamental properties of the cell, with lessons that include the cell structure, transport in and out of the cell, energy metabolism, and cell division and reproduction.

1.1 Phospholipid Bilayers

- Describe the structure and function of the plasma membrane.



All cells have a plasma membrane. This membrane surrounds the cell. So what is its role?

Can molecules enter and leave the cell? Yes. Can anything or everything enter or leave? No. So, what determines what can go in or out? Is it the nucleus? The DNA? Or the plasma membrane?

The Plasma Membrane

The **plasma membrane** (also known as the **cell membrane**) forms a barrier between the cytoplasm inside the cell and the environment outside the cell. It protects and supports the cell and also controls everything that enters and leaves the cell. It allows only certain substances to pass through, while keeping others in or out. The ability to allow only certain molecules in or out of the cell is referred to as selective permeability or **semipermeability**. To understand how the plasma membrane controls what crosses into or out of the cell, you need to know its composition.

The plasma membrane is discussed at http://www.youtube.com/watch?v=-aSfoB8Cmic (6:16).

A Phospholipid Bilayer

The plasma membrane is composed mainly of phospholipids, which consist of fatty acids and alcohol. The phospholipids in the plasma membrane are arranged in two layers, called a **phospholipid bilayer**. As shown in **Figure** 1.1, each phospholipid molecule has a head and two tails. The head "loves" water (**hydrophilic**) and the tails "hate" water (**hydrophobic**). The water-hating tails are on the interior of the membrane, whereas the water-loving heads point outwards, toward either the cytoplasm or the fluid that surrounds the cell.

Molecules that are hydrophobic can easily pass through the plasma membrane, if they are small enough, because they are water-hating like the interior of the membrane. Molecules that are hydrophilic, on the other hand, cannot pass through the plasma membrane—at least not without help—because they are water-loving like the exterior of the membrane.

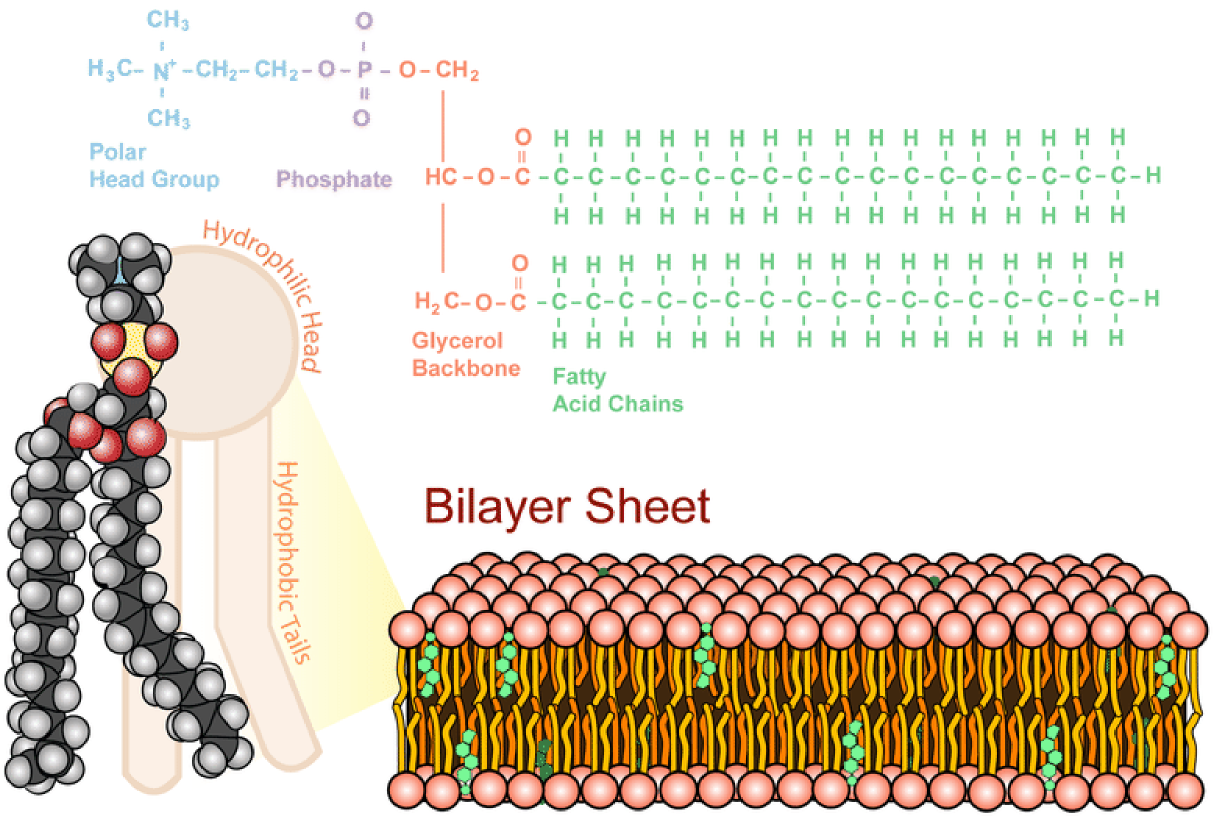


FIGURE 1.1

Phospholipid Bilayer. The phospholipid bilayer consists of two layers of phospholipids, with a hydrophobic, or water-hating, interior and a hydrophilic, or water-loving, exterior. The hydrophilic (polar) head group and hydrophobic tails (fatty acid chains) are depicted in the single phospholipid molecule. The polar head group and fatty acid chains are attached by a 3-carbon glycerol unit.

See *Insights into cell membranes via dish detergent* at http://ed.ted.com/lessons/insights-into-cell-membranes-via-dish-detergent-ethan-perlstein for additional information on the cell membrane.

Summary

- The plasma membrane forms a barrier between the cytoplasm and the environment outside the cell. The plasma membrane has selective permeability.
- The plasma membrane is primarily composed of phospholipids arranged in a bilayer, with the hydrophobic tails on the interior of the membrane, and the hydrophilic heads pointing outwards.

Practice

Use these resources to answer the questions that follow.

- **Construction of the Cell Membrane** at http://www.wisc-online.com/Objects/ViewObject.aspx?ID=AP1101 .

1. What are the two main components of the cell membrane?
2. Describe the types of proteins that live in the cell membrane.
3. Describe the orientation of the phospholipid molecule in the cell membrane.

- **Cell Membranes** at http://johnkyrk.com/cellmembrane.html .

1. Are *all* cells surrounded by a membrane?
2. Why are phospholipids considered an amphipathic molecule?
3. What is a glycolipid?
4. Describe the role of cholesterol in the cell membrane.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Plasma Membrane Structure**

1. What are the roles of the plasma membrane?
2. What is the difference between hydrophilic and hydrophobic?
3. What are the functions of proteins associated with the cell membrane?
4. Why is the structure of the cell membrane described as "fluid mosaic"?

Review

1. Describe the role of the plasma membrane.

2. Describe the composition of the plasma membrane.

3. Explain why hydrophobic ("water-hating") molecules can easily cross the plasma membrane, while hydrophilic ("water-loving") molecules cannot.

1.2 Diffusion

- Describe different types of passive transport.

What will eventually happen to these dyes?

They will all blend together. The dyes will move through the water until an even distribution is achieved. The process of moving from areas of high amounts to areas of low amounts is called diffusion.

Passive Transport

Probably the most important feature of a cell's phospholipid membranes is that they are **selectively permeable** or **semipermeable**. A membrane that is selectively permeable has control over what molecules or ions can enter or leave the cell, as shown in **Figure** 1.2. The permeability of a membrane is dependent on the organization and characteristics of the membrane lipids and proteins. In this way, cell membranes help maintain a state of homeostasis within cells (and tissues, organs, and organ systems) so that an organism can stay alive and healthy.

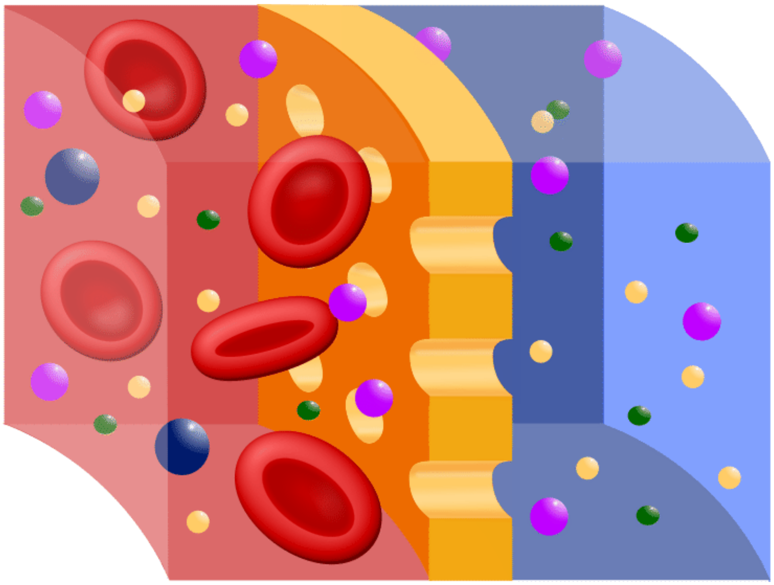


FIGURE 1.2
A selectively permeable membrane allows certain molecules through, but not others.

Transport Across Membranes

The molecular make-up of the phospholipid bilayer limits the types of molecules that can pass through it. For example, **hydrophobic** (water-hating) molecules, such as carbon dioxide (CO_2) and oxygen (O_2), can easily pass through the lipid bilayer, but ions such as calcium (Ca^{2+}) and polar molecules such as water (H_2O) cannot. The hydrophobic interior of the phospholipid bilayer does not allow ions or polar molecules through because these molecules are **hydrophilic**, or water loving. In addition, large molecules such as sugars and proteins are too big to pass through the bilayer. Transport proteins within the membrane allow these molecules to pass through the membrane, and into or out of the cell. This way, polar molecules avoid contact with the nonpolar interior of the membrane, and large molecules are moved through large pores.

Every cell is contained within a membrane punctuated with transport proteins that act as channels or pumps to let in or force out certain molecules. The purpose of the transport proteins is to protect the cell's internal environment and to keep its balance of salts, nutrients, and proteins within a range that keeps the cell and the organism alive.

There are three main ways that molecules can pass through a phospholipid membrane. The first way requires no energy input by the cell and is called passive transport. The second way requires that the cell uses energy to pull in or pump out certain molecules and ions and is called active transport. The third way is through vesicle transport, in which large molecules are moved across the membrane in bubble-like sacks that are made from pieces of the membrane.

Passive transport is a way that small molecules or ions move across the cell membrane without input of energy by the cell. The three main kinds of passive transport are diffusion, osmosis, and facilitated diffusion.

Diffusion

Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration. The difference in the concentrations of the molecules in the two areas is called the **concentration gradient**. Diffusion will continue until this gradient has been eliminated. Since diffusion moves materials from an area of higher concentration to the lower, it is described as moving solutes "down the concentration gradient." The end result of diffusion is an equal concentration, or **equilibrium**, of molecules on both sides of the membrane.

If a molecule can pass freely through a cell membrane, it will cross the membrane by diffusion (**Figure** 1.3).

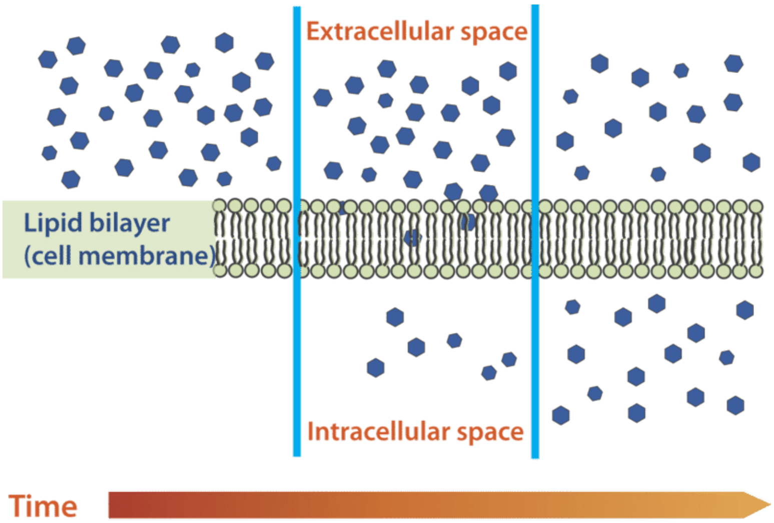


FIGURE 1.3

Molecules move from an area of high concentration to an area of lower concentration until an equilibrium is met. The molecules continue to cross the membrane at equilibrium, but at equal rates in both directions.

Summary

- The cell membrane is selectively permeable, allowing only certain substances to pass through.
- Passive transport is a way that small molecules or ions move across the cell membrane without input of energy by the cell. The three main kinds of passive transport are diffusion, osmosis, and facilitated diffusion.
- Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Is simple diffusion a form of passive transport? Explain your answer.
2. What is a concentration gradient?
3. Give an example of a molecule that can enter a cell by simple diffusion.

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport .

Review

1. What is diffusion?
2. What is a concentration gradient?
3. What is meant by passive transport?

1.3 Osmosis

- Describe osmosis and discuss its effects on cells.

Saltwater Fish vs. Freshwater Fish?

Fish cells, like all cells, have semi-permeable membranes. Eventually, the concentration of "stuff" on either side of them will even out. A fish that lives in salt water will have somewhat salty water inside itself. Put it in the freshwater, and the freshwater will, through osmosis, enter the fish, causing its cells to swell, and the fish will die. What will happen to a freshwater fish in the ocean?

Osmosis

Imagine you have a cup that has 100ml water, and you add 15g of table sugar to the water. The sugar dissolves and the mixture that is now in the cup is made up of a **solute** (the sugar) that is dissolved in the **solvent** (the water). The mixture of a solute in a solvent is called a **solution**.

Imagine now that you have a second cup with 100ml of water, and you add 45 grams of table sugar to the water. Just like the first cup, the sugar is the solute, and the water is the solvent. But now you have two mixtures of different solute concentrations. In comparing two solutions of unequal solute concentration, the solution with the higher solute concentration is **hypertonic**, and the solution with the lower solute concentration is **hypotonic**. Solutions of equal solute concentration are **isotonic**. The first sugar solution is hypotonic to the second solution. The second sugar solution is hypertonic to the first.

You now add the two solutions to a beaker that has been divided by a selectively permeable membrane, with pores that are too small for the sugar molecules to pass through, but are big enough for the water molecules to pass through. The hypertonic solution is on one side of the membrane and the hypotonic solution on the other. The hypertonic solution has a lower water concentration than the hypotonic solution, so a concentration gradient of water now exists across the membrane. Water molecules will move from the side of higher water concentration to the side of lower concentration until both solutions are isotonic. At this point, **equilibrium** is reached.

Osmosis is the diffusion of water molecules across a selectively permeable membrane from an area of higher concentration to an area of lower concentration. Water moves into and out of cells by osmosis. If a cell is in a hypertonic solution, the solution has a lower water concentration than the cell cytosol, and water moves out of the cell until both solutions are isotonic. Cells placed in a hypotonic solution will take in water across their membrane until both the external solution and the cytosol are isotonic.

A cell that does not have a rigid cell wall, such as a red blood cell, will swell and lyse (burst) when placed in a hypotonic solution. Cells with a cell wall will swell when placed in a hypotonic solution, but once the cell is turgid (firm), the tough cell wall prevents any more water from entering the cell. When placed in a hypertonic solution, a cell without a cell wall will lose water to the environment, shrivel, and probably die. In a hypertonic solution, a cell with a cell wall will lose water too. The plasma membrane pulls away from the cell wall as it shrivels, a process called **plasmolysis**. Animal cells tend to do best in an isotonic environment, plant cells tend to do best in a hypotonic environment. This is demonstrated in **Figure** 1.4.

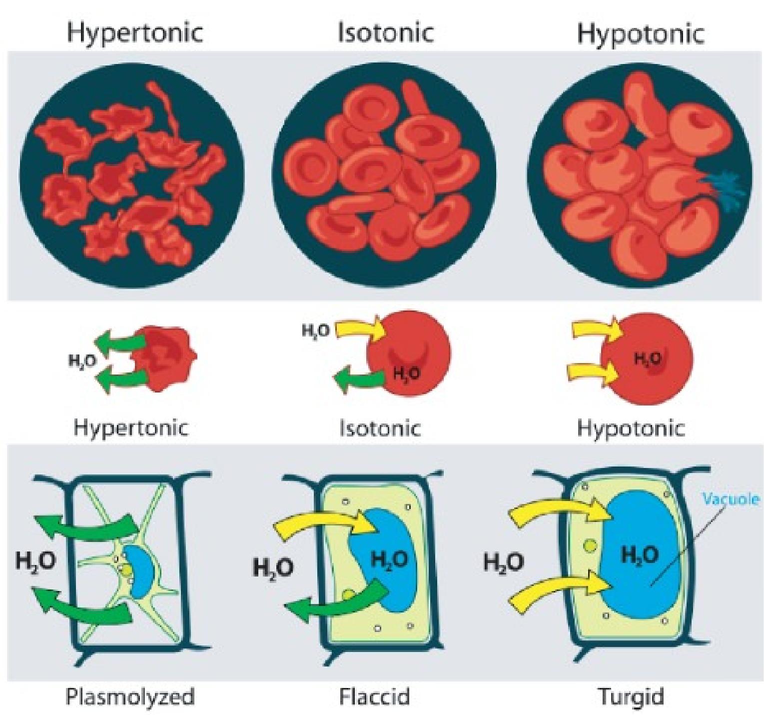


FIGURE 1.4

Unless an animal cell (such as the red blood cell in the top panel) has an adaptation that allows it to alter the osmotic uptake of water, it will lose too much water and shrivel up in a hypertonic environment. If placed in a hypotonic solution, water molecules will enter the cell, causing it to swell and burst. Plant cells (bottom panel) become plasmolyzed in a hypertonic solution, but tend to do best in a hypotonic environment. Water is stored in the central vacuole of the plant cell.

Osmotic Pressure

When water moves into a cell by osmosis, osmotic pressure may build up inside the cell. If a cell has a cell wall, the wall helps maintain the cell's water balance. **Osmotic pressure** is the main cause of support in many plants. When a plant cell is in a hypotonic environment, the osmotic entry of water raises the turgor pressure exerted against the cell wall until the pressure prevents more water from coming into the cell. At this point the plant cell is turgid. The effects of osmotic pressures on plant cells are shown in **Figure** 1.5.

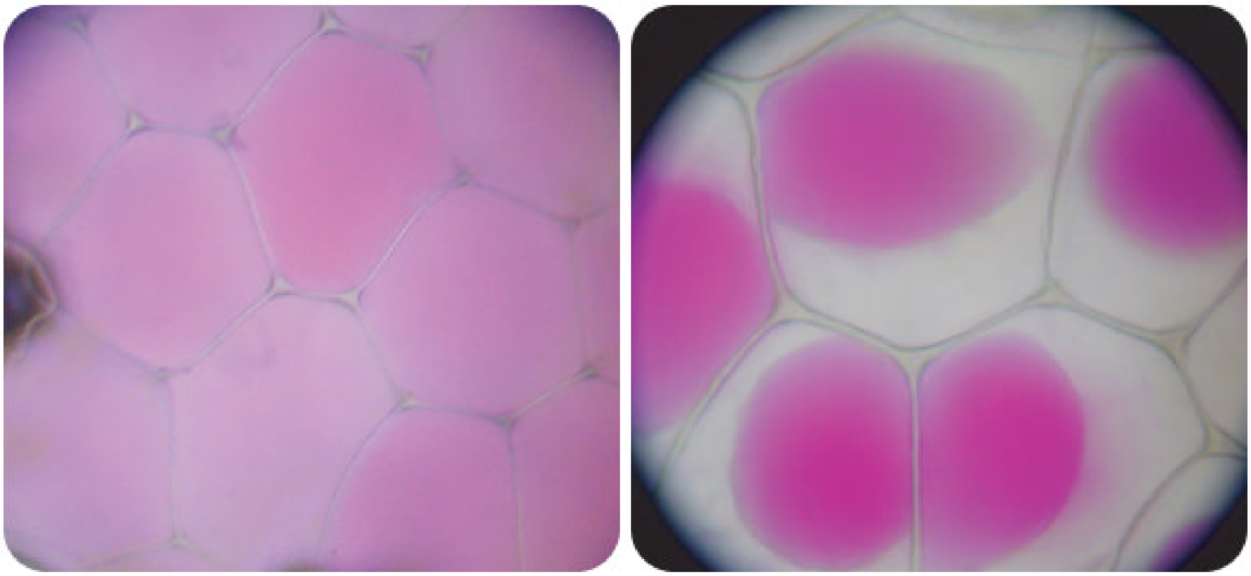
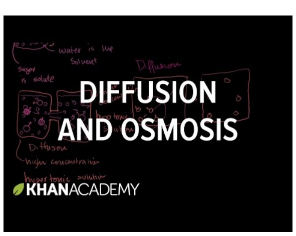


FIGURE 1.5

The central vacuoles of the plant cells in the left image are full of water, so the cells are turgid. The plant cells in the right image have been exposed to a hypertonic solution; water has left the central vacuole and the cells have become plasmolysed.

The action of osmosis can be very harmful to organisms, especially ones without cell walls. For example, if a saltwater fish (whose cells are isotonic with seawater), is placed in fresh water, its cells will take on excess water, lyse, and the fish will die. Another example of a harmful osmotic effect is the use of table salt to kill slugs and snails.

Diffusion and osmosis are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/34/aubZU0iWtgI (18:59).



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Controlling Osmosis

Organisms that live in a hypotonic environment such as freshwater, need a way to prevent their cells from taking in too much water by osmosis. A **contractile vacuole** is a type of vacuole that removes excess water from a cell. Freshwater protists, such as the paramecium shown in **Figure** 1.6, have a contractile vacuole. The vacuole is surrounded by several canals, which absorb water by osmosis from the cytoplasm. After the canals fill with water, the water is pumped into the vacuole. When the vacuole is full, it pushes the water out of the cell through a pore.

FIGURE 1.6
The contractile vacuole is the star-like structure within the paramecium (at center-right)

Summary

- Osmosis is the diffusion of water.
- In comparing two solutions of unequal solute concentration, the solution with the higher solute concentration is hypertonic, and the solution with the lower concentration is hypotonic. Solutions of equal solute concentration are isotonic.
- A contractile vacuole is a type of vacuole that removes excess water from a cell.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Define osmosis.
2. Is osmosis a form of diffusion? Explain your answer.
3. Why is osmosis important in biology?

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport

- **Osmosis**

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Review

1. What is osmosis? What type of transport is it?
2. How does osmosis differ from diffusion?

1.4 Facilitated Diffusion

- Describe passive transport using membrane proteins.

Can you help me move?

What is one of the questions no one likes to be asked? Sometimes the cell needs help moving things as well, or facilitating the diffusion process. And this would be the job of a special type of protein.

Facilitated Diffusion

Facilitated diffusion is the diffusion of solutes through transport proteins in the plasma membrane. Facilitated diffusion is a type of passive transport. Even though facilitated diffusion involves transport proteins, it is still passive transport because the solute is moving down the concentration gradient.

Small nonpolar molecules can easily diffuse across the cell membrane. However, due to the hydrophobic nature of the lipids that make up cell membranes, polar molecules (such as water) and ions cannot do so. Instead, they diffuse across the membrane through transport proteins. A **transport protein** completely spans the membrane, and allows certain molecules or ions to diffuse across the membrane. Channel proteins, gated channel proteins, and carrier proteins are three types of transport proteins that are involved in facilitated diffusion.

A **channel protein**, a type of transport protein, acts like a pore in the membrane that lets water molecules or small ions through quickly. Water channel proteins allow water to diffuse across the membrane at a very fast rate. Ion channel proteins allow ions to diffuse across the membrane.

A **gated channel protein** is a transport protein that opens a "gate," allowing a molecule to pass through the membrane. Gated channels have a binding site that is specific for a given molecule or ion. A stimulus causes the "gate" to open or shut. The stimulus may be chemical or electrical signals, temperature, or mechanical force, depending on the type of gated channel. For example, the sodium gated channels of a nerve cell are stimulated by a chemical signal which causes them to open and allow sodium ions into the cell. Glucose molecules are too big to diffuse through the plasma membrane easily, so they are moved across the membrane through gated channels. In this way glucose diffuses very quickly across a cell membrane, which is important because many cells depend on glucose for energy.

A **carrier protein** is a transport protein that is specific for an ion, molecule, or group of substances. Carrier proteins "carry" the ion or molecule across the membrane by changing shape after the binding of the ion or molecule. Carrier proteins are involved in passive and active transport. A model of a channel protein and carrier proteins is shown in **Figure** 1.7.

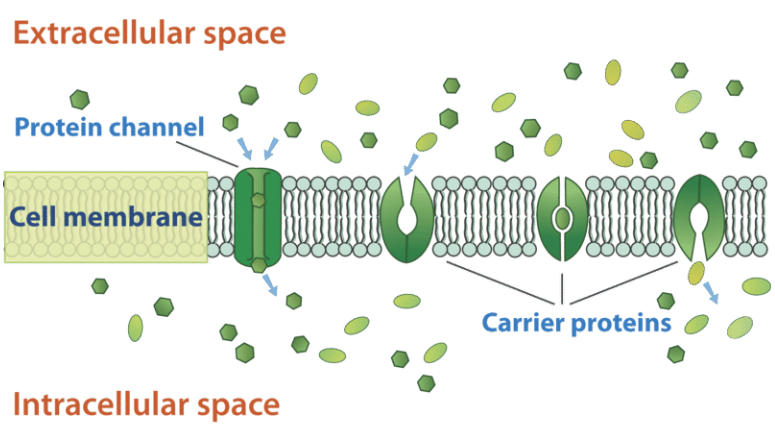
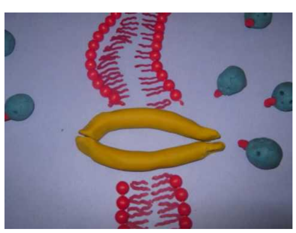


FIGURE 1.7
Facilitated diffusion through the cell membrane. Channel proteins and carrier proteins are shown (but not a gated-channel protein). Water molecules and ions move through channel proteins. Other ions or molecules are also carried across the cell membrane by carrier proteins. The ion or molecule binds to the active site of a carrier protein. The carrier protein changes shape, and releases the ion or molecule on the other side of the membrane. The carrier protein then returns to its original shape.

An animation depicting facilitated diffusion can be viewed at http://www.youtube.com/watch?v=OV4PgZDRTQw&feature=related (1:36).



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Ion Channels

Ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and chloride (Cl^-), are important for many cell functions. Because they are polar, these ions do not diffuse through the membrane. Instead they move through ion channel proteins where they are protected from the hydrophobic interior of the membrane. **Ion channels** allow the formation of a concentration gradient between the extracellular fluid and the cytosol. Ion channels are very specific, as they allow only certain ions through the cell membrane. Some ion channels are always open, others are "gated" and can be opened or closed. Gated ion channels can open or close in response to different types of stimuli, such as electrical or chemical signals.

Summary

- Facilitated diffusion is the diffusion of solutes through transport proteins in the plasma membrane. Channel proteins, gated channel proteins, and carrier proteins are three types of transport proteins that are involved in facilitated diffusion.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Describe the structure of a transport protein.
2. Give an example of a molecule transported by a transport protein.
3. What is carrier-mediated diffusion? How does this process function?

Practice II

- **Membrane Channels** at http://phet.colorado.edu/en/simulation/membrane-channels .

Multimedia

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Review

1. Assume a molecule must cross the plasma membrane into a cell. The molecule is a very large protein. How will it be transported into the cell? Explain your answer.

2. Compare and contrast simple diffusion and facilitated diffusion. For each type of diffusion, give an example of a molecule that is transported that way.

1.5 Active Transport

- Explain how different types of active transport occur.

Need to move something really heavy?

If you did, it would take a lot of energy. Sometimes, moving things into or out of the cell also takes energy. How would the cell move something against a concentration gradient? It starts by using energy.

Active Transport

In contrast to facilitated diffusion, which does not require energy and carries molecules or ions down a **concentration gradient**, active transport pumps molecules and ions against a concentration gradient. Sometimes an organism needs to transport something against a concentration gradient. The only way this can be done is through active transport, which uses energy that is produced by respiration (ATP). In active transport, the particles move across a cell membrane from a lower concentration to a higher concentration. **Active transport** is the energy-requiring process of pumping molecules and ions across membranes "uphill" - against a concentration gradient.

- The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins that are found in the membrane.
- Larger molecules such as starch can also be actively transported across the cell membrane by processes called endocytosis and exocytosis.

Homeostasis and Cell Function

Homeostasis refers to the balance, or equilibrium, within the cell or a body. It is an organism's ability to keep a constant internal environment. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. The adjusting of systems within a cell is called homeostatic regulation. Because the internal and external environments of a cell are constantly changing, adjustments must be made continuously to stay at or near the set point (the normal level or range). Homeostasis is a dynamic equilibrium rather than an unchanging state. The cellular processes discussed in both the "Passive Transport" and "Active Transport" concepts all play an important role in homeostatic regulation. You will learn more about homeostasis in other concepts.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- Active transport processes help maintain homeostasis.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. What is the main difference between active transport and diffusion?
2. What is cotransport?
3. What molecule is required in active transport?

Practice II

- **Diffusion, Osmosis and Active Transport** at http://www.concord.org/activities/diffusion-osmosis-and-active-transport .

- **Active Transport**

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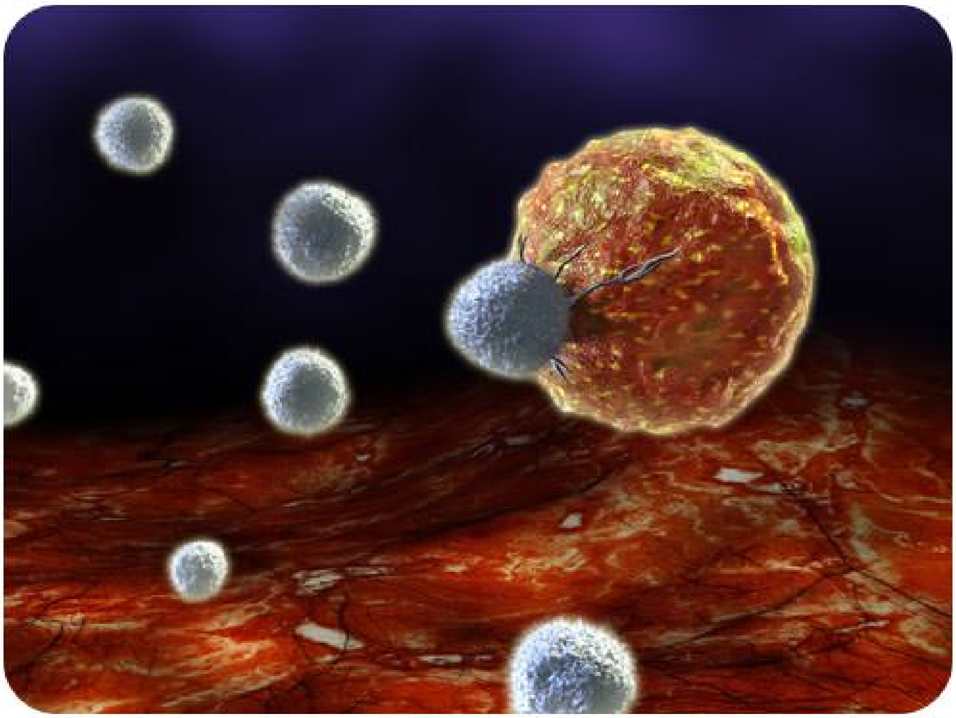
Review

1. What is active transport?

2. Explain how cell transport helps an organism maintain homeostasis.

1.6 Exocytosis and Endocytosis

- Explain how different types of active transport occur.



What does a cell "eat"?

Is it possible for objects larger than a small molecule to be engulfed by a cell? Of course it is. This image depicts a cancer cell being attacked by a cell of the immune system. Cells of the immune system consistently destroy pathogens by essentially "eating" them.

Vesicle Transport

Some molecules or particles are just too large to pass through the plasma membrane or to move through a transport protein. So cells use two other active transport processes to move these macromolecules (large molecules) into or out of the cell. Vesicles or other bodies in the cytoplasm move macromolecules or large particles across the plasma membrane. There are two types of vesicle transport, endocytosis and exocytosis. Both processes are **active transport** processes, requiring energy.

Endocytosis and Exocytosis

Endocytosis is the process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane. The membrane folds over the substance and it becomes completely enclosed by the membrane. At this point a membrane-bound sac, or vesicle, pinches off and moves the substance into the cytosol. There are two main kinds of endocytosis:

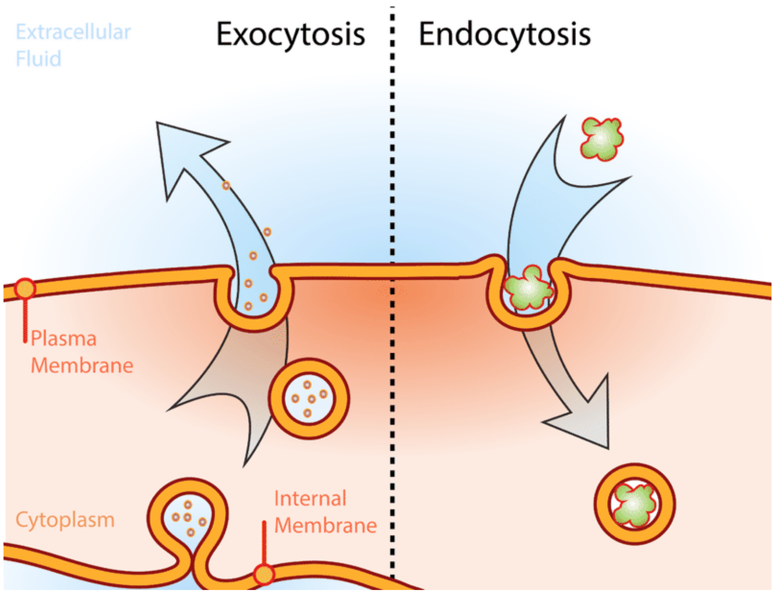


FIGURE 1.8
Illustration of the two types of vesicle transport, exocytosis and endocytosis.

- **Phagocytosis**, or *cellular eating,* occurs when the dissolved materials enter the cell. The plasma membrane engulfs the solid material, forming a phagocytic vesicle.
- **Pinocytosis**, or *cellular drinking,* occurs when the plasma membrane folds inward to form a channel allowing dissolved substances to enter the cell, as shown in **Figure** 1.9. When the channel is closed, the liquid is encircled within a pinocytic vesicle.

FIGURE 1.9
Transmission electron microscope image of brain tissue that shows pinocytotic vesicles. Pinocytosis is a type of endocytosis.

Exocytosis describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell, as shown in **Figure** 1.10. Exocytosis occurs when a cell produces substances for export, such as a protein, or when the cell is getting rid of a waste product or a toxin. Newly made membrane proteins and membrane lipids are moved on top the plasma membrane by exocytosis. For a detailed animation of cellular secretion, see http

://vcell.ndsu.edu/animations/constitutivesecretion/first.htm .

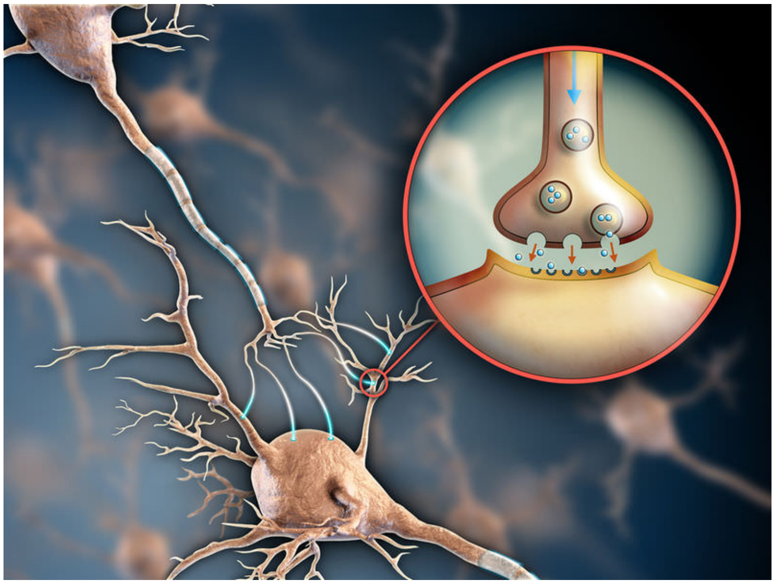


FIGURE 1.10
Illustration of an axon releasing dopamine by exocytosis.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- Endocytosis is the process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane, and bringing it into the cell.
- Exocytosis describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell.
- Both endocytosis and exocytosis are active transport processes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Transport Mechanisms**

1. Compare endocytosis to exocytosis.
2. Describe the process of endocytosis.
3. What are the differences between phagocytosis, pinocytosis, and receptor-mediated endocytosis?
4. How are hormones released from a cell?

Review

1. What is the difference between endocytosis and exocytosis?

2. Why is pinocytosis a form of endocytosis?

3. Are vesicles involved in passive transport? Explain.

Summary

The cell is the smallest unit of structure and function of all living organisms. Cell Biology focuses on significant aspects of the cell from its structure to its division. Some organisms contain just one cell, and others contain trillions. Some have a nucleus with DNA, others do not. Some have many organelles, others do not. But all cells are surrounded by a cell membrane. And it is this semipermeable membrane that determines what can enter and leave the cell. All cells need energy, and for many organisms, this energy comes from photosynthesis and cellular respiration. All cells come from preexisting cells through the process of cell division, which can produce a new prokaryotic organism. The cell cycle, which includes mitosis, defines the life of an eukaryotic cell.

1.7 References

1. LadyofHats for the CK-12 Foundation. . CC-BY-NC-SA 3.0
2. [Wikimedia: Pidalka44]. . Public Domain
3. Mariana Ruiz Villarreal [Wikimedia: LadyofHats]. . CC-BY-NC-SA 3.0
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CHAPTER 2 Human Biology

Chapter Outline

Introduction

Human Biology provides an overview of the physiology of humans, from the skin inward. In addition to the skin, the skeletal, muscular, nervous, endocrine, circulatory, respiratory, digestive, excretory, immune and reproductive systems are described.

2.1 Sodium-Potassium Pump

- Explain how different types of active transport occur.
- Explain how the sodium-potassium pump functions.

What is this incredible object?

Would it surprise you to learn that it is a human cell? The image represents an active human nerve cell. How nerve cells function will be the focus of another concept. However, active transport processes play a significant role in the function of these cells. Specifically, it is the sodium-potassium pump that is active in the axons of these nerve cells.

The Sodium-Potassium Pump

Active transport is the energy-requiring process of pumping molecules and ions across membranes "uphill" - against a concentration gradient. To move these molecules against their concentration gradient, a carrier protein is needed. Carrier proteins can work with a concentration gradient (during passive transport), but some carrier proteins can move solutes against the concentration gradient (from low concentration to high concentration), with an input of energy. As in other types of cellular activities, ATP supplies the energy for most active transport. One way ATP powers active transport is by transferring a phosphate group directly to a carrier protein. This may cause the carrier protein to change its shape, which moves the molecule or ion to the other side of the membrane. An example of this type of active transport system, as shown in **Figure** 2.1, is the **sodium-potassium pump,** which exchanges sodium ions for potassium ions across the plasma membrane of animal cells.

As is shown in **Figure** 2.1, three sodium ions bind with the protein pump inside the cell. The carrier protein then gets energy from ATP and changes shape. In doing so, it pumps the three sodium ions out of the cell. At that point, two potassium ions move in from outside the cell and bind to the protein pump. The sodium-potassium pump is

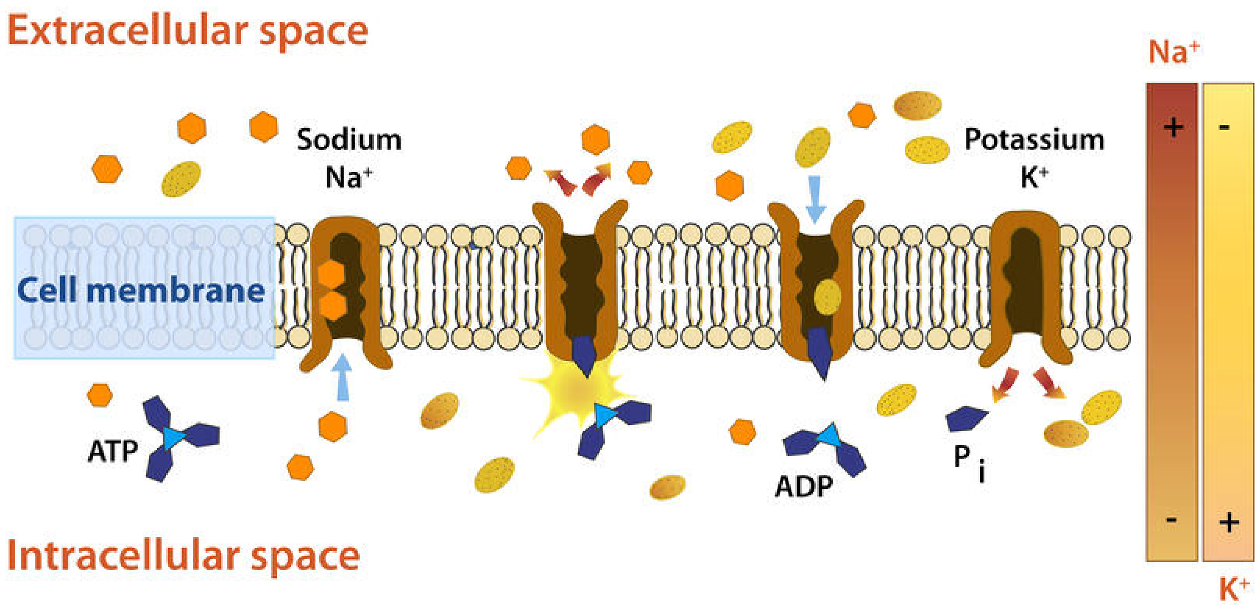

FIGURE 2.1
The sodium-potassium pump system moves sodium and potassium ions against large concentration gradients. It moves two potassium ions into the cell where potassium levels are high, and pumps three sodium ions out of the cell and into the extracellular fluid.

found in the plasma membrane of almost every human cell and is common to all cellular life. It helps maintain cell potential and regulates cellular volume.

A more detailed look at the sodium-potassium pump is available at http://www.youtube.com/watch?v=C_H-ONQFjpQ (13:53) and http://www.youtube.com/watch?v=ye3rTjLCvAU (6:48).

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The Electrochemical Gradient

The active transport of ions across the membrane causes an electrical gradient to build up across the plasma membrane. The number of positively charged ions outside the cell is greater than the number of positively charged ions in the cytosol. This results in a relatively negative charge on the inside of the membrane, and a positive charge on the outside. This difference in charges causes a voltage across the membrane. Voltage is electrical potential energy that is caused by a separation of opposite charges, in this case across the membrane. The voltage across a membrane is called **membrane potential**. Membrane potential is very important for the conduction of electrical impulses along nerve cells.

Because the inside of the cell is negative compared to outside the cell, the membrane potential favors the movement of positively charged ions (cations) into the cell, and the movement of negative ions (anions) out of the cell. So, there are two forces that drive the diffusion of ions across the plasma membrane—a chemical force (the ions' concentration gradient), and an electrical force (the effect of the membrane potential on the ions' movement). These two forces working together are called an **electrochemical gradient**, and will be discussed in detail in "Nerve Cell" and "Nerve Impulses" concepts.

Summary

- Active transport is the energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
- The sodium-potassium pump is an active transport pump that exchanges sodium ions for potassium ions.

Practice

Use this resource to answer the questions that follow.

- **Sodium Potassium Pump (ATPase)** at http://www.youtube.com/watch?v=Z9tPTDRjCYU&feature=fvwrel

1. Why is the size difference between a sodium and potassium ion important?
2. Are there more sodium ions on the outside of cells or the inside?
3. Are there more potassium ions on the outside of cells or the inside?
4. Describe the role of ATP in active transport.

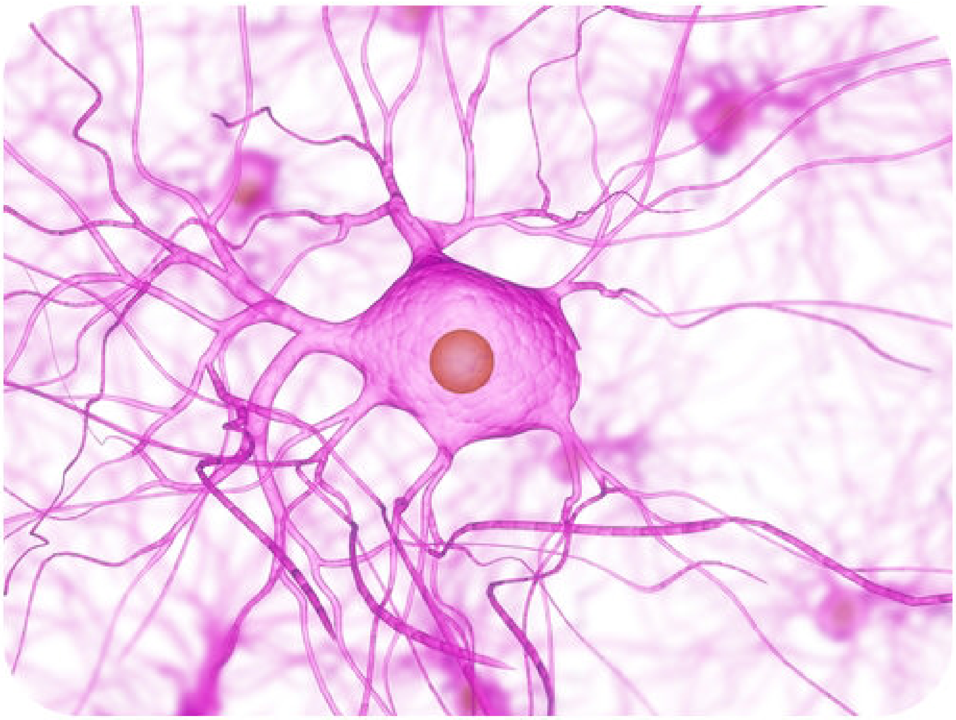
Review

1. What is active transport?

2. Describe how the sodium-potassium pump functions.

2.2 Nerve Cells

- Describe the structure of a neuron, and identify types of neurons.



A close-up view of a spider web? Some sort of exotic bacteria? What do you think this is?

This is actually a nerve cell, the cell of the nervous system. This cell sends electrical "sparks" that transmit signals throughout your body.

The Nervous System

A small child darts in front of your bike as you race down the street. You see the child and immediately react. You put on the brakes, steer away from the child, and yell out a warning, all in just a split second. How do you respond so quickly? Such rapid responses are controlled by your nervous system. The **nervous system** is a complex network of nervous tissue that carries electrical messages throughout the body. It includes the brain and spinal cord, the **central nervous system**, and nerves that run throughout the body, the **peripheral nervous system** (see **Figure** 2.2). To understand how nervous messages can travel so quickly, you need to know more about nerve cells.

Nerve Cells

Although the nervous system is very complex, nervous tissue consists of just two basic types of nerve cells: neurons and glial cells. **Neurons** are the structural and functional units of the nervous system. They transmit electrical signals, called **nerve impulses. Glial cells** provide support for neurons. For example, they provide neurons with nutrients and other materials.

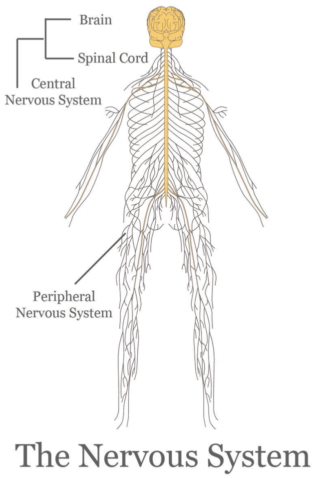


FIGURE 2.2
The human nervous system includes the brain and spinal cord (central nervous system) and nerves that run throughout the body (peripheral nervous system).

Neuron Structure

As shown in **Figure** 2.3, a neuron consists of three basic parts: the cell body, dendrites, and axon. You can watch an animation of the parts of a neuron at this link: http://www.garyfisk.com/anim/neuronparts.swf .

- The **cell body** contains the nucleus and other cell organelles.
- **Dendrites** extend from the cell body and receive nerve impulses from other neurons.
- The **axon** is a long extension of the cell body that transmits nerve impulses to other cells. The axon branches at the end, forming **axon terminals**. These are the points where the neuron communicates with other cells.

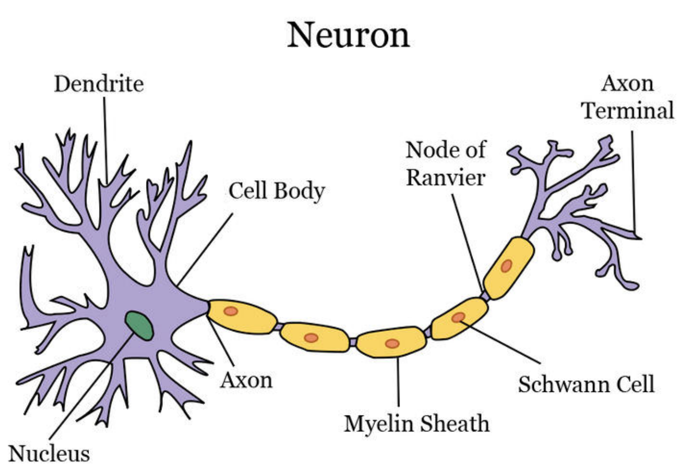
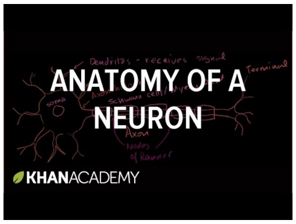


FIGURE 2.3
The structure of a neuron allows it to rapidly transmit nerve impulses to other cells.

The neuron is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/39/ob5U8zPbAX4 (6:13).



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Myelin Sheath

The axon of many neurons has an outer layer called a **myelin sheath** (see **Figure** 2.3). **Myelin** is a lipid produced by a type of a glial cell known as a **Schwann cell**. The myelin sheath acts like a layer of insulation, similar to the plastic that encases an electrical cord. Regularly spaced nodes, or gaps, in the myelin sheath allow nerve impulses to skip along the axon very rapidly.

Types of Neurons

Neurons are classified based on the direction in which they carry nerve impulses.

- **Sensory neurons** carry nerve impulses from tissues and organs to the spinal cord and brain.
- **Motor neurons** carry nerve impulses from the brain and spinal cord to muscles and glands (see **Figure** 2.4).
- **Interneurons** carry nerve impulses back and forth between sensory and motor neurons.

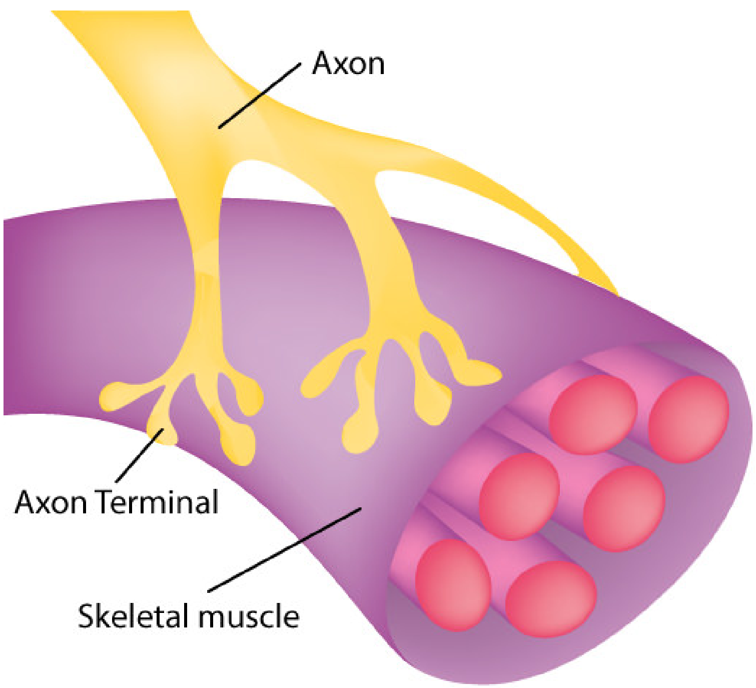


FIGURE 2.4

This axon is part of a motor neuron. It transmits nerve impulses to a skeletal muscle, causing the muscle to contract.

Summary

- Neurons are the structural and functional units of the nervous system. They consist of a cell body, dendrites, and axon.

- Neurons transmit nerve impulses to other cells.
- Types of neurons include sensory neurons, motor neurons, and interneurons.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Neuron Structure**

1. Describe the three parts of a neuron.
2. What are accessory cells?
3. What is myelin?
4. What is a synapse?
5. Define neurotransmitter.

Practice II

- **Quiz on Neuron** at http://www.neok12.com/quiz/NERSYS04 .
- **Label the Diagram of Neuron** at http://www.neok12.com/diagram/Nervous-System-01.htm .

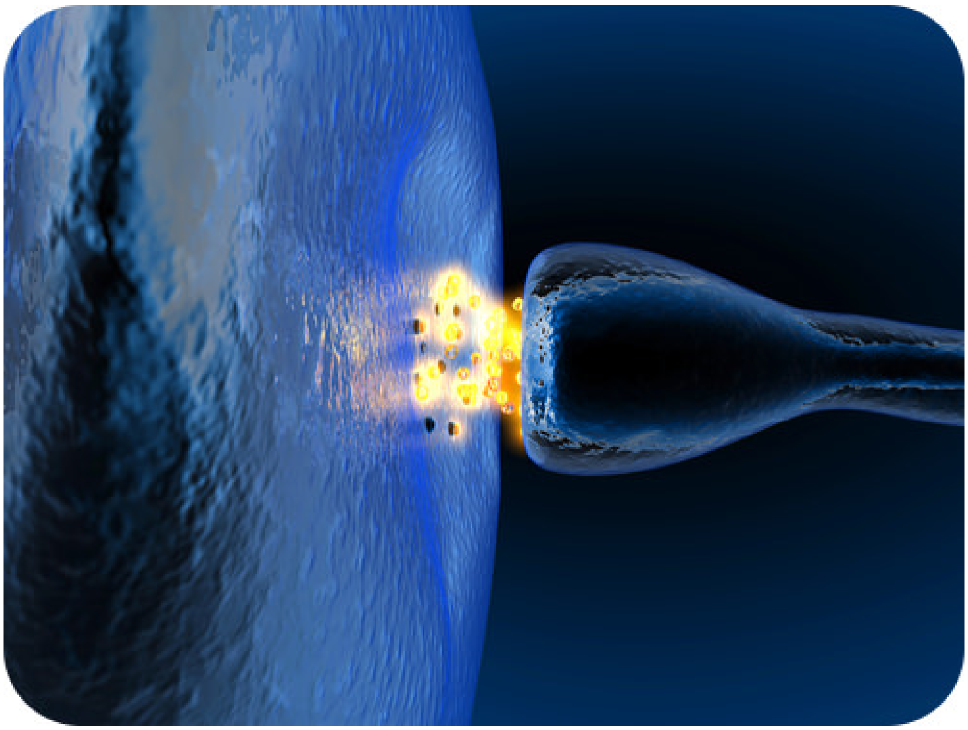
Review

1. List and describe the parts of a neuron.

2. What do motor neurons do?

2.3 Nerve Impulses

- Explain how nerve impulses are transmitted.



How does a nervous system signal move from one cell to the next?

It literally jumps by way of a chemical transmitter. Notice the two cells are not connected, but separated by a small gap. The synapse. The space between a neuron and the next cell.

Nerve Impulses

Nerve impulses are electrical in nature. They result from a difference in electrical charge across the plasma membrane of a neuron. How does this difference in electrical charge come about? The answer involves **ions**, which are electrically charged atoms or molecules.

Resting Potential

When a neuron is not actively transmitting a nerve impulse, it is in a resting state, ready to transmit a nerve impulse. During the resting state, the **sodium-potassium pump** maintains a difference in charge across the cell membrane (see **Figure** 2.5). It uses energy in ATP to pump positive sodium ions (Na^+) out of the cell and potassium ions (K^+) into the cell. As a result, the inside of the neuron is negatively charged, compared to the extracellular fluid surrounding the neuron. This is due to many more positivly charged ions outside the cell compared to inside the cell. This difference in electrical charge is called the **resting potential.**

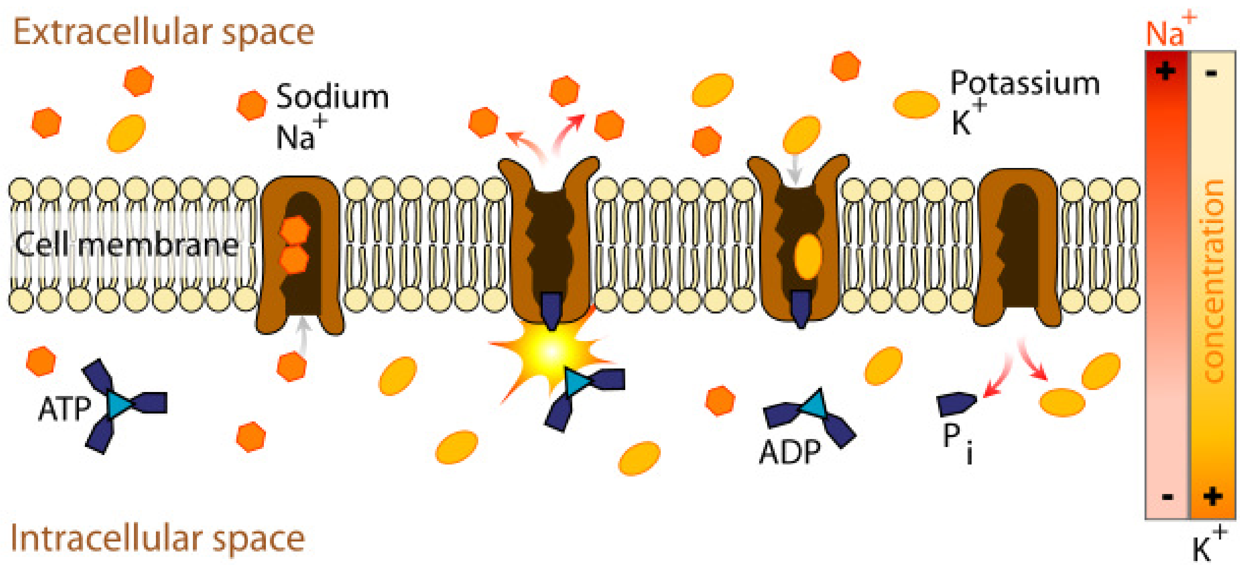


FIGURE 2.5
The sodium-potassium pump maintains the resting potential of a neuron.

Action Potential

A **nerve impulse** is a sudden reversal of the electrical charge across the membrane of a resting neuron. The reversal of charge is called an **action potential.** It begins when the neuron receives a chemical signal from another cell. The signal causes gates in sodium ion channels to open, allowing positive sodium ions to flow back into the cell. As a result, the inside of the cell becomes positively charged compared to the outside of the cell. This reversal of charge ripples down the axon very rapidly as an electric current (see **Figure** 2.6). You can watch a detailed animation of an action potential at this link: http://outreach.mcb.harvard.edu/animations/actionpotential_short.swf .

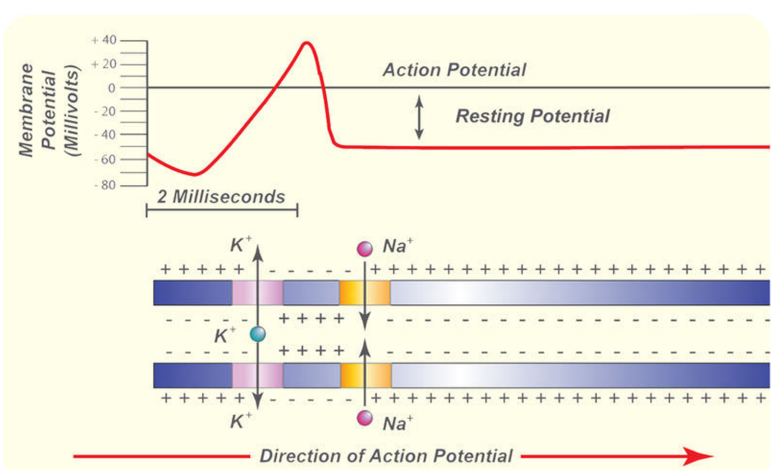
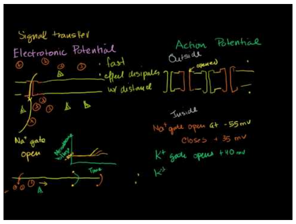


FIGURE 2.6
An action potential speeds along an axon in milliseconds.

In neurons with myelin sheaths, ions flow across the membrane only at the nodes between sections of myelin. As a result, the action potential jumps along the axon membrane from node to node, rather than spreading smoothly along the entire membrane. This increases the speed at which it travels.

The action potential is discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/42/gkQtRec2464 (18:53) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/43/7wgb7ggzFNs (12:04).



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You may choose to review the sodium-potassium pump (http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/40/C_H-ONQFjpQ) prior to watching the action potential videos.

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The Synapse

The place where an axon terminal meets another cell is called a **synapse**. The axon terminal and other cell are separated by a narrow space known as a **synaptic cleft** (see **Figure** 2.7). When an action potential reaches the axon terminal, the axon terminal releases molecules of a chemical called a **neurotransmitter**. The neurotransmitter molecules travel across the synaptic cleft and bind to receptors on the membrane of the other cell. If the other cell is a neuron, this starts an action potential in the other cell. You can view animations of neurotransmission at a synapse at the following links:

- http://outreach.mcb.harvard.edu/animations/synaptic.swf
- http://www.garyfisk.com/anim/neurotransmission.swf .

The synapse is further discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/44/Tbq-KZaXiL4 .

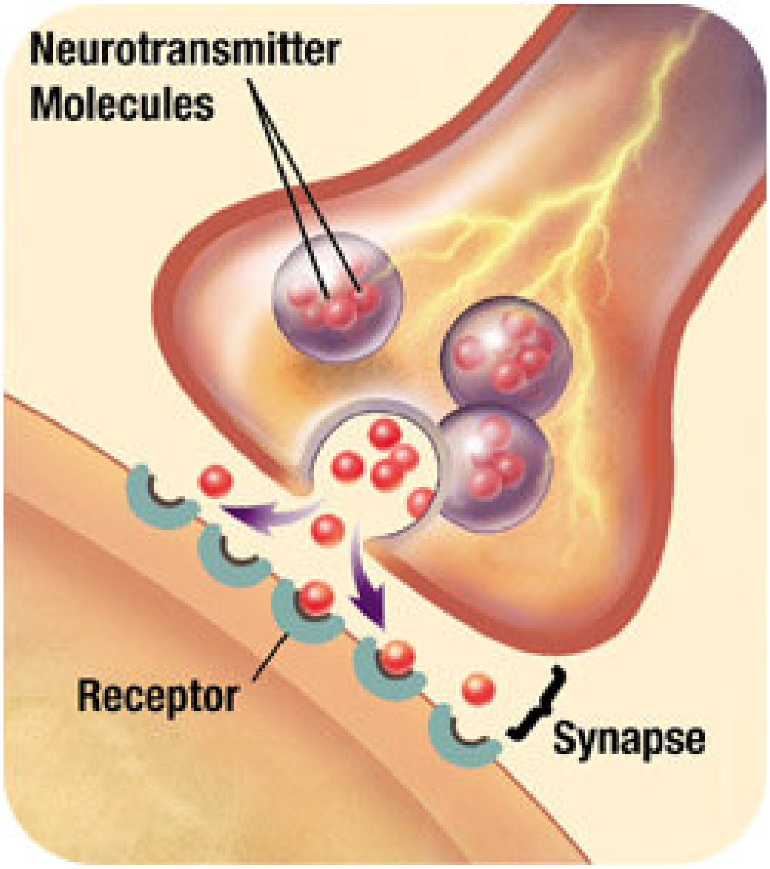
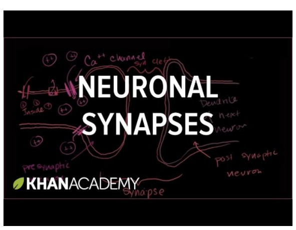


FIGURE 2.7
At a synapse, neurotransmitters are released by the axon terminal. They bind with receptors on the other cell.



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Summary

- A nerve impulse begins when a neuron receives a chemical stimulus.
- The nerve impulse travels down the axon membrane as an electrical action potential to the axon terminal.
- The axon terminal releases neurotransmitters that carry the nerve impulse to the next cell.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Intracellular Signaling**

1. What is meant by an excitable cell?
2. What is an electrical potential?
3. What causes the difference in electrical charges across a cell membrane?

4. What is the resting potential? What determines this potential?
5. What changes the potential across a membrane?
6. What ion channels open first after a stimulus?
7. What is an action potential? What is meant by an "all or none" response?
8. Describe the change in charges during an action potential, and what causes these changes.

Practice II

- **Neuron** at http://phet.colorado.edu/en/simulation/neuron .

Multimedia

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Review

1. Define resting potential.

2. Explain how resting potential is maintained and how an action potential occurs.

2.4 Central Nervous System

- Identify parts of the central nervous system and their functions.

The human brain. The "control center." What does it control?

Practically everything. From breathing and heartbeat to reasoning, memory, and language. And it is the main part of the central nervous system.

Central Nervous System

The nervous system has two main divisions: the central nervous system and the peripheral nervous system (see **Figure** 2.8). The **central nervous system (CNS)** includes the brain and spinal cord (see **Figure** 2.9). You can see an overview of the central nervous system at this link: http://vimeo.com/2024719 .

The Brain

The **brain** is the most complex organ of the human body and the control center of the nervous system. It contains an astonishing 100 billion neurons! The brain controls such mental processes as reasoning, imagination, memory, and language. It also interprets information from the senses. In addition, it controls basic physical processes such as breathing and heartbeat.

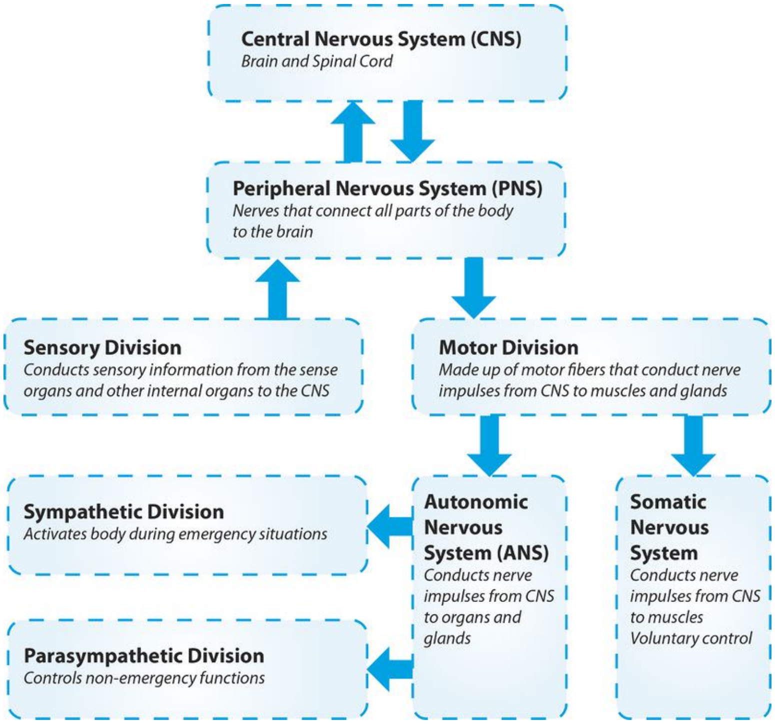

FIGURE 2.8
The two main divisions of the human nervous system are the central nervous system and the peripheral nervous system. The peripheral nervous system has additional divisions.

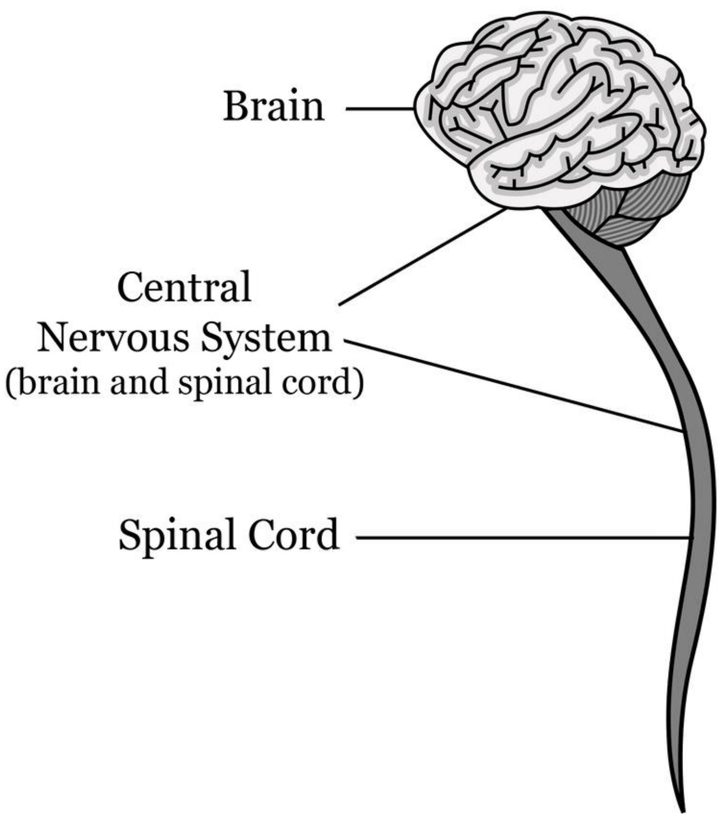

FIGURE 2.9
This diagram shows the components of the central nervous system.

The brain has three major parts: the cerebrum, cerebellum, and brain stem. These parts are shown in **Figure** 2.10 and described in this section. For a video of the parts of the brain and their functions, go to this link: http://www.teachers.tv/video/13838 .

You can also take interactive animated tours of the brain at these links:

- http://www.pbs.org/wnet/brain/3d/index.html
- http://www.garyfisk.com/anim/neuroanatomy.swf .

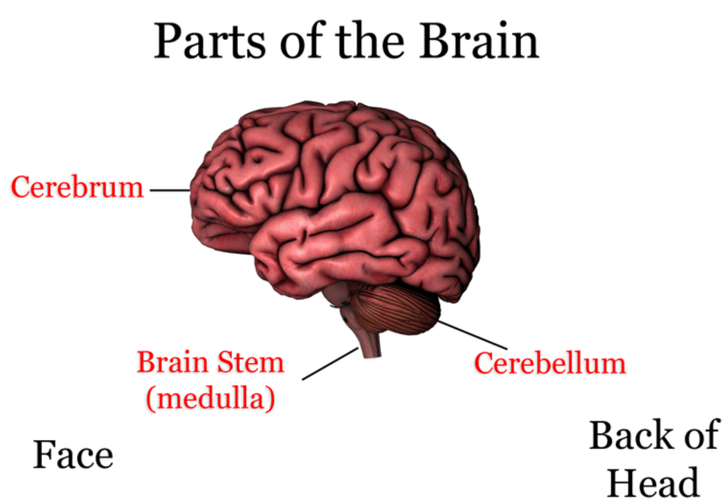

FIGURE 2.10
In this drawing, assume you are looking at the left side of the head. This is how the brain would appear if you could look underneath the skull.

- The **cerebrum** is the largest part of the brain. It controls conscious functions such as reasoning, language, sight, touch, and hearing. It is divided into two hemispheres, or halves. The hemispheres are very similar but not identical to one another. They are connected by a thick bundle of axons deep within the brain. Each hemisphere is further divided into the four lobes shown in **Figure** 2.11.
- The **cerebellum** is just below the cerebrum. It coordinates body movements. Many nerve pathways link the cerebellum with motor neurons throughout the body.
- The **brain stem** is the lowest part of the brain. It connects the rest of the brain with the spinal cord and passes nerve impulses between the brain and spinal cord. It also controls unconscious functions such as heart rate and breathing.

Spinal Cord

The **spinal cord** is a thin, tubular bundle of nervous tissue that extends from the brainstem and continues down the center of the back to the pelvis. It is protected by the **vertebrae**, which encase it. The spinal cord serves as an information superhighway, passing messages from the body to the brain and from the brain to the body.

Summary

- The central nervous includes the brain and spinal cord.
- The brain is the control center of the nervous system. It controls virtually all mental and physical processes.
- The spinal cord is a long, thin bundle of nervous tissue that passes messages from the body to the brain and from the brain to the body.

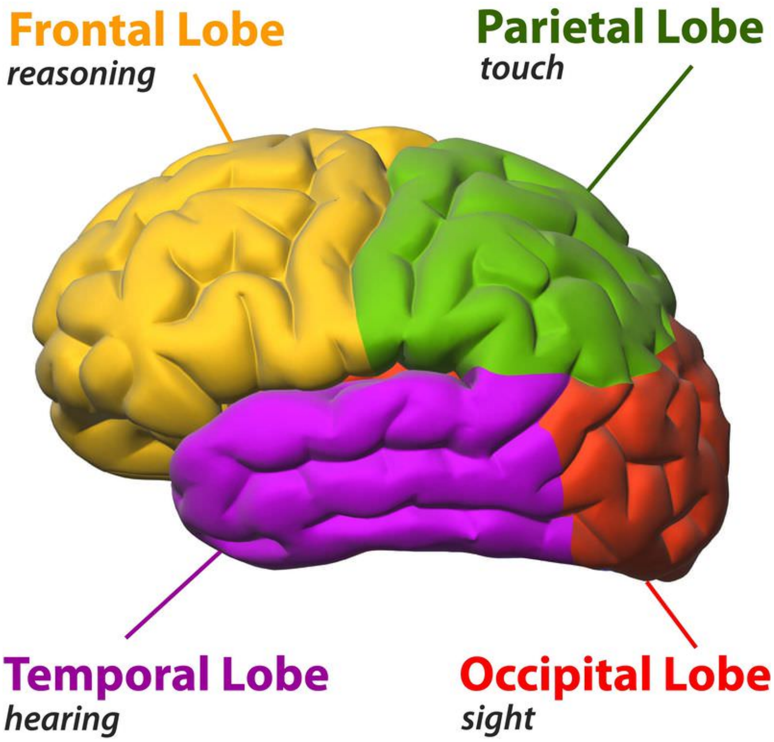

FIGURE 2.11
Each hemisphere of the cerebrum consists of four parts, called lobes. Each lobe is associated with particular brain functions. Just one function of each lobe is listed here.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Central Nervous Systems**

1. What is the central nervous system?
2. What is the role of the spinal cord?
3. Distinguish between white and grey matter.
4. Describe the main structures and functions of the mammalian brain.

Practice II

- **Human Brain** at http://www.neok12.com/diagram/Nervous-System-02.htm .
- **Quiz on Human Brain** at http://www.neok12.com/quiz/NERSYS05 .

Review

1. Name the organs of the central nervous system.

2. Which part of the brain controls conscious functions such as reasoning?

3. What are the roles of the brain stem?

4. Tony's dad was in a car accident in which his neck was broken. He survived the injury but is now paralyzed from the neck down. Explain why.

2.5 Glucose and ATP

- Compare and contrast glucose and ATP.

Needs lots of energy?

To run a marathon, probably. Where does this extra energy come from? Carbohydrate loading is a strategy used by endurance athletes to maximize the storage of energy, in the form of glycogen, in the muscles. Glycogen forms an energy reserve that can be quickly mobilized to meet a sudden need for glucose, which is then turned into ATP through the process of cellular respiration.

Glucose and ATP

Energy-Carrying Molecules

You know that the fish you had for lunch contained protein molecules. But do you know that the atoms in that protein could easily have formed the color in a dragonfly's eye, the heart of a water flea, and the whiplike tail of a *Euglena* before they hit your plate as sleek fish muscle? Food consists of organic (carbon-containing) molecules which store energy in the chemical bonds between their atoms. Organisms use the atoms of food molecules to build larger organic molecules including proteins, DNA, and fats (lipids) and use the energy in food to power life processes. By breaking the bonds in food molecules, cells release energy to build new compounds. Although some energy dissipates as heat at each energy transfer, much of it is stored in the newly made molecules. Chemical bonds in organic molecules are a reservoir of the energy used to make them. Fueled by the energy from food molecules, cells can combine and recombine the elements of life to form thousands of different molecules. Both the energy (despite some loss) and the materials (despite being reorganized) pass from producer to consumer –perhaps from algal tails, to water flea hearts, to dragonfly eye colors, to fish muscle, to you!

The process of photosynthesis, which usually begins the flow of energy through life, uses many different kinds of energy-carrying molecules to transform sunlight energy into chemical energy and build food. Some carrier molecules hold energy briefly, quickly shifting it like a hot potato to other molecules. This strategy allows energy to be released in small, controlled amounts. An example starts in **chlorophyll,** the green pigment present in most plants, which helps convert solar energy to chemical energy. When a chlorophyll molecule absorbs light energy, electrons are excited and "jump" to a higher energy level. The excited electrons then bounce to a series of carrier molecules, losing a little energy at each step. Most of the "lost" energy powers some small cellular task, such as moving ions across a membrane or building up another molecule. Another short-term energy carrier important to photosynthesis, **NADPH**, holds chemical energy a bit longer but soon "spends" it to help to build sugar.

Two of the most important energy-carrying molecules are **glucose** and **ATP**, adenosine triphosphate. These are nearly universal fuels throughout the living world and are both key players in photosynthesis, as shown below.

Glucose

A molecule of glucose, which has the chemical formula $C_6H_{12}O_6$, carries a packet of chemical energy just the right size for transport and uptake by cells. In your body, glucose is the "deliverable" form of energy, carried in your blood through capillaries to each of your 100 trillion cells. Glucose is also the carbohydrate produced by photosynthesis, and as such is the near-universal food for life.

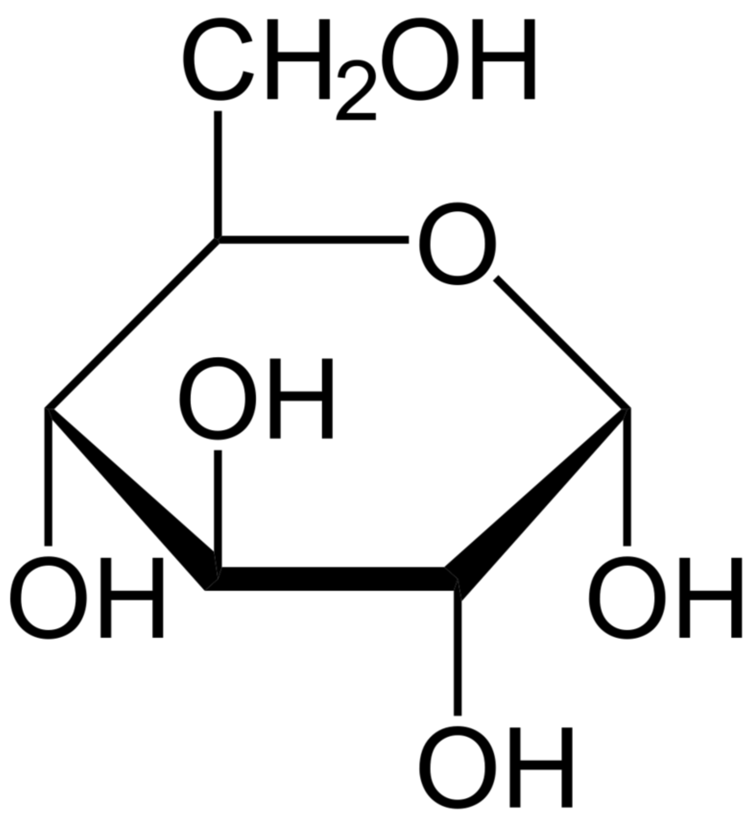

FIGURE 2.12
Glucose is the energy-rich product of photosynthesis, a universal food for life. It is also the primary form in which your bloodstream delivers energy to every cell in your body.

ATP

ATP molecules store smaller quantities of energy, but each releases just the right amount to actually do work within a cell. Muscle cell proteins, for example, pull each other with the energy released when bonds in ATP break open (discussed below). The process of photosynthesis also makes and uses ATP - for energy to build glucose! ATP, then, is the useable form of energy for your cells.

Why do we need both glucose and ATP?

Why don't plants just make ATP and be done with it? If energy were money, ATP would be a quarter. Enough money to operate a parking meter or washing machine. Glucose would be a ten dollar bill –much easier to carry around in your wallet, but too large to do the actual work of paying for parking or washing. Just as we find several denominations of money useful, organisms need several "denominations" of energy –a smaller quantity for work within cells, and a larger quantity for stable storage, transport, and delivery to cells.

Let's take a closer look at a molecule of ATP. Although it carries less energy than glucose, its structure is more complex. The "A" in ATP refers to the majority of the molecule, adenosine, a combination of a nitrogenous base and a five-carbon sugar. The "P" indicates the three phosphates, linked by bonds which hold the energy actually used by cells. Usually, only the outermost bond breaks to release or spend energy for cellular work.

An ATP molecule, shown below, is like a rechargeable battery: its energy can be used by the cell when it breaks apart into ADP (adenosine diphosphate) and phosphate, and then the "worn-out battery" ADP can be recharged using new energy to attach a new phosphate and rebuild ATP. The materials are recyclable, but recall that energy is not!

How much energy does it cost to do your body's work? A single cell uses about 10 million ATP molecules per second, and recycles all of its ATP molecules about every 20-30 seconds.

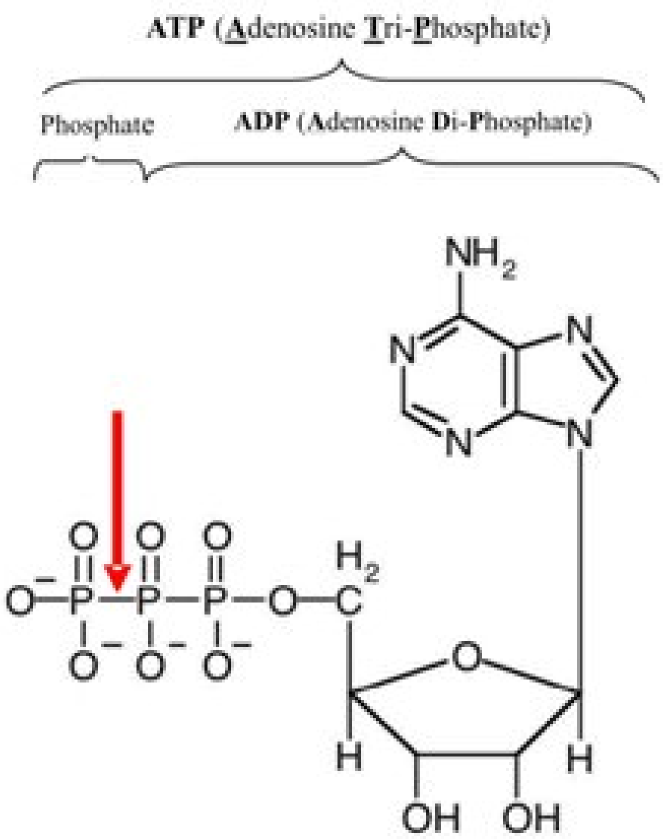

FIGURE 2.13

A red arrow shows the bond between two phosphate groups in an ATP molecule. When this bond breaks, its chemical energy can do cellular work. The resulting ADP molecule is recycled when new energy attaches another phosphate, rebuilding ATP.

A explanation of ATP as "biological energy" is found at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/18/YQfWiDlFEcA .

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Summary

- Glucose is the carbohydrate produced by photosynthesis. Energy-rich glucose is delivered through your blood to each of your cells.
- ATP is the usable form of energy for your cells.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Glycolysis: Overview**

1. Where does a cell's chemical energy come from?
2. How does a cell start breaking down glucose? Does this process need oxygen?
3. What is the purpose of glycolysis?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Glycolytic Pathway**

1. What is the chemical formula of glucose? Describe the structure of glucose molecules.
2. Where does our glucose come from? What happens to this glucose?
3. Glycolysis produces a net total of how many ATP molecules?

Review

1. The fact that all organisms use similar energy-carrying molecules shows one aspect of the grand "Unity of Life." Name two universal energy-carrying molecules, and explain why most organisms need both carriers rather than just one.

2. A single cell uses about 10 million ATP molecules per second. Explain how cells use the energy and recycle the materials in ATP.

3. ATP and glucose are both molecules that organisms use for energy. They are like the tank of a tanker truck that delivers gas to a gas station and the gas tank that holds the fuel for a car. Which molecule is like the tank of the delivery truck, and which is like the gas tank of the car? Explain your answer.

2.6 Smooth, Skeletal, and Cardiac Muscles

- Identify and describe the three types of human muscle tissue.

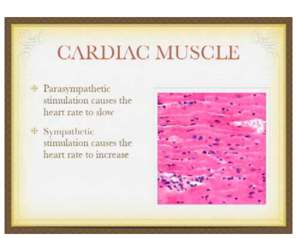
What exactly are muscles?

Does the word "muscle" make you think of the biceps of a weightlifter, like the man in pictured above? Muscles such as biceps that move the body are easy to feel and see, but they aren't the only muscles in the human body. Many muscles are deep within the body. They form the walls of internal organs such as the heart and stomach. You can flex your biceps like a body builder, but you cannot control the muscles inside you. It's a good thing that they work on their own without any conscious effort on your part, because movement of these muscles is essential for survival.

What Are Muscles?

The **muscular system** consists of all the muscles of the body. Muscles are organs composed mainly of muscle cells, which are also called **muscle fibers**. Each muscle fiber is a very long, thin cell that can do something no other cell can do. It can contract, or shorten. Muscle contractions are responsible for virtually all the movements of the body, both inside and out. There are three types of muscle tissues in the human body: cardiac, smooth, and skeletal muscle tissues. They are shown in **Figure** 2.14 and described below.

You can also watch an overview of the three types at this link: http://www.youtube.com/watch?v=TermIXEkavY .



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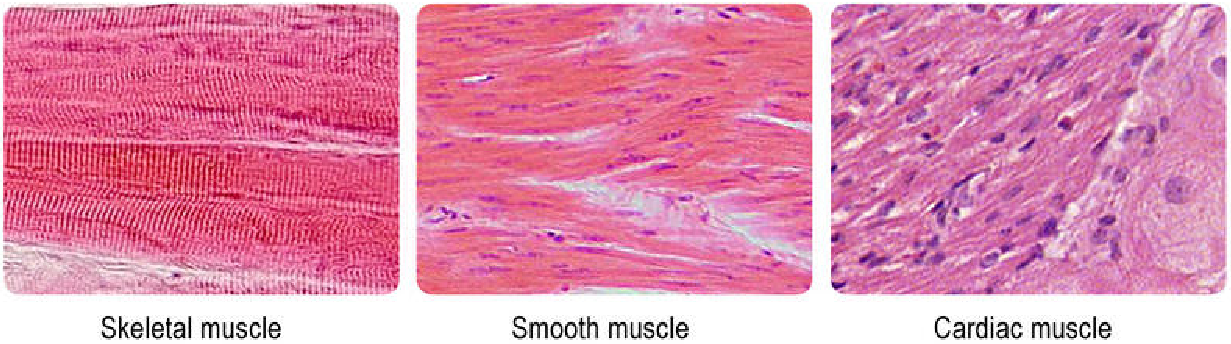


FIGURE 2.14

Types of Muscle Tissue. Both skeletal and cardiac muscles appear striated, or striped, because their cells are arranged in bundles. Smooth muscles are not striated because their cells are arranged in sheets instead of bundles.

Smooth Muscle

Muscle tissue in the walls of internal organs such as the stomach and intestines is **smooth muscle**. When smooth muscle contracts, it helps the organs carry out their functions. For example, when smooth muscle in the stomach contracts, it squeezes the food inside the stomach, which helps break the food into smaller pieces. Contractions of smooth muscle are involuntary. This means they are not under conscious control.

Skeletal Muscle

Muscle tissue that is attached to bone is **skeletal muscle**. Whether you are blinking your eyes or running a marathon, you are using skeletal muscle. Contractions of skeletal muscle are voluntary, or under conscious control. Skeletal muscle is the most common type of muscle in the human body.

Cardiac Muscle

Cardiac muscle is found only in the walls of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Cardiac muscle contains a great many mitochondria, which produce ATP for energy. This helps the heart resist fatigue. Contractions of cardiac muscle are involuntary, like those of smooth muscle. Cardiac muscle, like skeletal muscle, is arranged in bundles, so it appears **striated**, or striped.

Summary

- There are three types of human muscle tissue: smooth muscle (in internal organs), skeletal muscle, and cardiac muscle (only in the heart).

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Other Types of Muscle**

1. Describe cardiac muscle.
2. What is the main difference between cardiac muscle and skeletal muscle?
3. What is smooth muscle?
4. How are the filaments arranged in smooth muscle? What are the results of this structure?

Practice II

- **Muscles Game** at http://www.bbc.co.uk/science/humanbody/body/index_interactivebody.shtml .

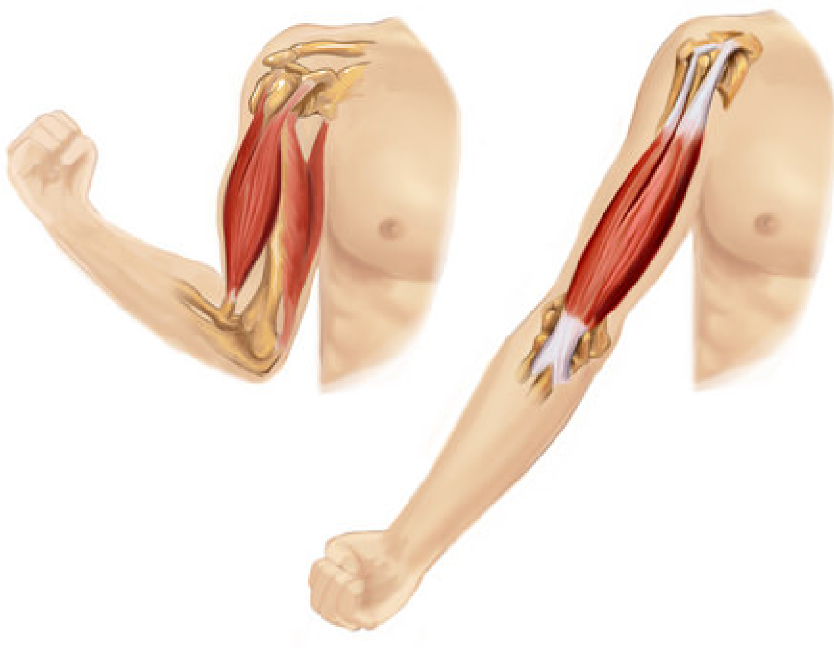
- **Muscular System Quiz #1** at http://www.neok12.com/quiz/SKESYS05 .

Review

1. Compare and contrast the three types of muscle tissue.
2. What can muscle cells do that other cells cannot?
3. Why are skeletal and cardiac muscles striated?
4. Where is smooth muscle tissue found?
5. What is the function of skeletal muscle?

2.7 Skeletal Muscles

- Describe the structure of skeletal muscles, and explain how they move bones.



How do your bones move?

By the contraction and extension of your skeletal muscles. Notice how the muscles are attached to the bones. The muscles pull on the bones, causing movement.

Skeletal Muscles

There are well over 600 skeletal muscles in the human body, some of which are identified in **Figure** 2.15. Skeletal muscles vary considerably in size, from tiny muscles inside the middle ear to very large muscles in the upper leg.

Structure of Skeletal Muscles

Each skeletal muscle consists of hundreds or even thousands of skeletal **muscle fibers**. The fibers are bundled together and wrapped in connective tissue, as shown **Figure** 2.16. The connective tissue supports and protects the delicate muscle cells and allows them to withstand the forces of contraction. It also provides pathways for nerves and blood vessels to reach the muscles. Skeletal muscles work hard to move body parts. They need a rich blood supply to provide them with nutrients and oxygen and to carry away their wastes.

You can watch a video about skeletal muscle structure and how skeletal muscles work at the link below. http://www.youtube.com/watch?v=XoP1diaXVCI

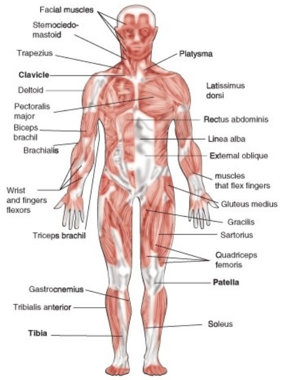
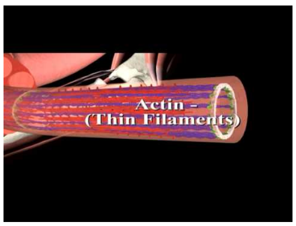


FIGURE 2.15
Skeletal Muscles. Skeletal muscles enable the body to move.



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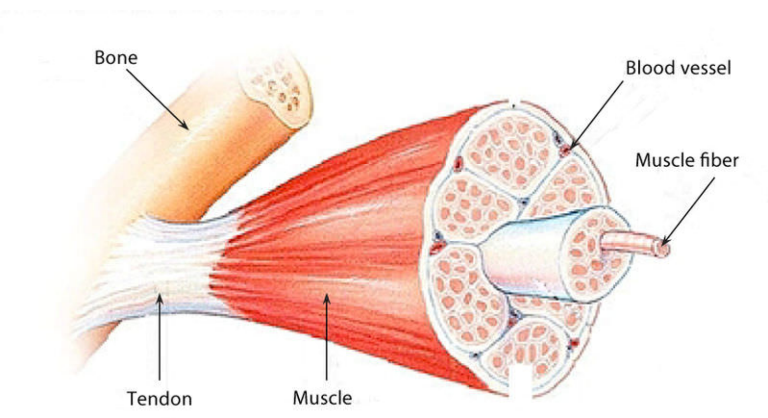
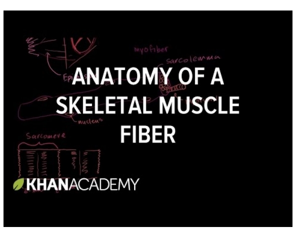


FIGURE 2.16
Skeletal Muscle Structure. A skeletal muscle contains bundles of muscle fibers inside a “coat” of connective tissue.

"The Anatomy of a Muscle Cell" is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/48/uY2ZOsCnXIA (16:32).



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Skeletal Muscles and Bones

Skeletal muscles are attached to the skeleton by tough connective tissues called **tendons** (see **Figure** 2.16). Many skeletal muscles are attached to the ends of bones that meet at a **joint**. The muscles span the joint and connect the bones. When the muscles contract, they pull on the bones, causing them to move.

You can watch a video showing how muscles and bones move together at this link: http://www.youtube.com/watch?v=7Rzi7zYlWno&feature=related .

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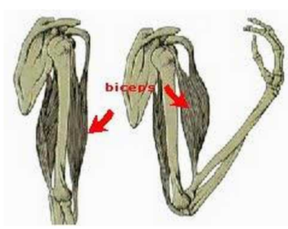
Muscles can only contract. They cannot actively extend, or lengthen. Therefore, to move bones in opposite directions, pairs of muscles must work in opposition. For example, the biceps and triceps muscles of the upper arm work in opposition to bend and extend the arm at the elbow (see **Figure** 2.17).

You can watch an animation of these two muscles working in opposition at the link below. What other body movements do you think require opposing muscle pairs? http://www.youtube.com/watch?v=T-ozRNVhGVg&feature=related



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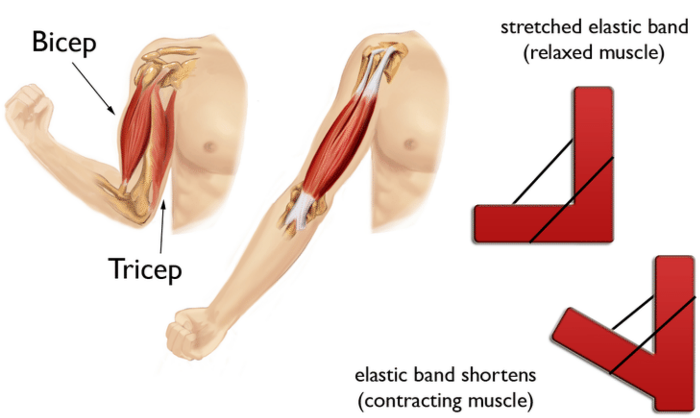


FIGURE 2.17

Triceps and biceps muscles in the upper arm are opposing muscles.

Use It or Lose It

In exercises such as weight lifting, skeletal muscle contracts against a resisting force (see **Figure** 2.18). Using skeletal muscle in this way increases its size and strength. In exercises such as running, the cardiac muscle contracts faster and the heart pumps more blood. Using cardiac muscle in this way increases its strength and efficiency. Continued exercise is necessary to maintain bigger, stronger muscles. If you don't use a muscle, it will get smaller and weaker—so use it or lose it.

FIGURE 2.18
This exercise pits human muscles against a force. What force is it?

Summary

- Skeletal muscles are attached to the skeleton and cause bones to move when they contract.

Practice I

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **The Structure of Skeletal Muscle**

1. Define skeletal muscle.

2. Describe skeletal muscle structure.
3. Define the sarcomere and Z-line.

Practice II

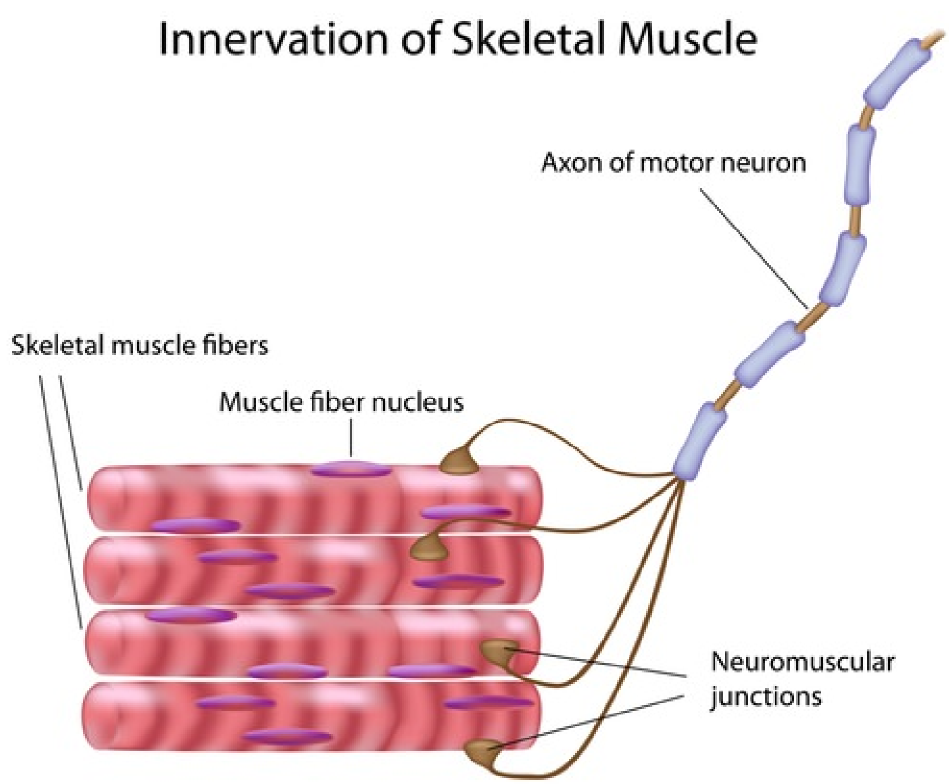
- **Skeletal System Quiz** at http://www.neok12.com/quiz/SKESYS01 .

Review

1. What is the function of skeletal muscle?
2. How are skeletal muscles attached to bones?
3. Explain why many skeletal muscles must work in opposing pairs.

2.8 Muscle Contraction

- Explain how muscles contract according to the sliding filament theory.



What makes a muscle contract?

It starts with a signal from the nervous system. So it starts with a signal from your brain. The signal goes through your nervous system to your muscle. Your muscle contracts, and your bones move. And all this happens incredibly fast.

Muscle Contraction

Muscle contraction occurs when muscle fibers get shorter. Literally, the muscle fibers get smaller in size. To understand how this happens, you need to know more about the structure of muscle fibers.

Structure of Muscle Fibers

Each muscle fiber contains hundreds of organelles called **myofibrils**. Each myofibril is made up of two types of protein filaments: **actin** filaments, which are thinner, and **myosin** filaments, which are thicker. Actin filaments are anchored to structures called **Z lines** (see **Figure** 2.19). The region between two Z lines is called a **sarcomere**. Within a sarcomere, myosin filaments overlap the actin filaments. The myosin filaments have tiny structures called **cross bridges** that can attach to actin filaments.

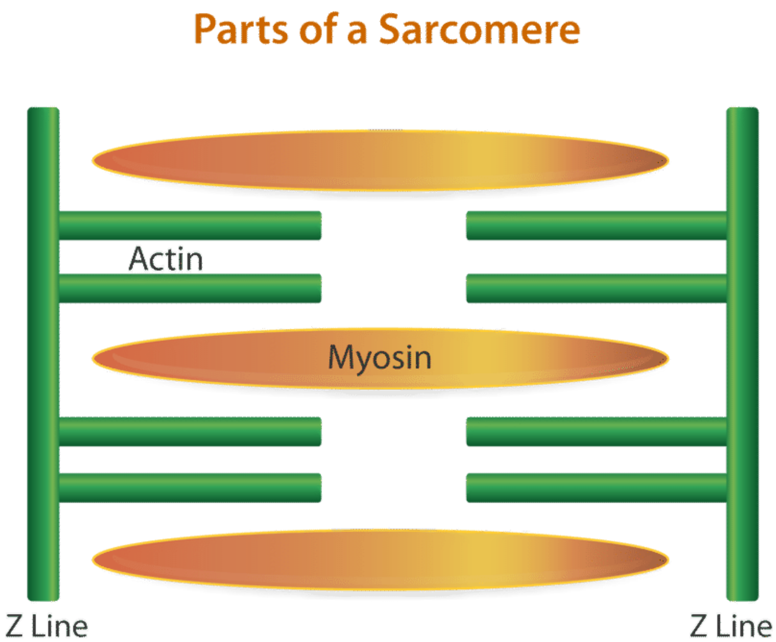
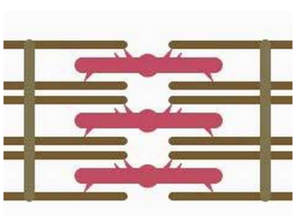


FIGURE 2.19
Sarcomere. A sarcomere contains actin and myosin filaments between two Z lines.

Sliding Filament Theory

The most widely accepted theory explaining how muscle fibers contract is called the **sliding filament theory**. According to this theory, myosin filaments use energy from ATP to "walk" along the actin filaments with their cross bridges. This pulls the actin filaments closer together. The movement of the actin filaments also pulls the Z lines closer together, thus shortening the sarcomere.

You can watch this occurring in a video animation at the link below. http://www.youtube.com/watch?v=7V-zFVnFkWg&feature=related



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When all of the sarcomeres in a muscle fiber shorten, the fiber contracts. A muscle fiber either contracts fully or it doesn't contract at all. The number of fibers that contract determines the strength of the muscular force. When more fibers contract at the same time, the force is greater.

Actin, myosin and muscle contraction are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/45/zopoN2i7ALQ (9:38).

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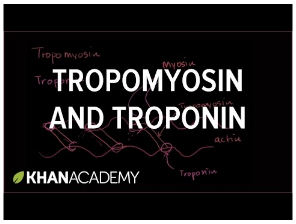
Additional information about muscle contraction is available at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/46/LiOfeSsjrB8 (9:22) and http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/47/SauhB2fYQkM (14:42).



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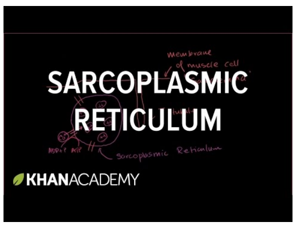

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Muscles and Nerves

Muscles cannot contract on their own. They need a stimulus from a nerve cell to "tell" them to contract. Let's say you decide to raise your hand in class. Your brain sends electrical messages to nerve cells, called **motor neurons**, in your arm and shoulder. The motor neurons, in turn, stimulate muscle fibers in your arm and shoulder to contract, causing your arm to rise. Involuntary contractions of cardiac and smooth muscles are also controlled by nerves.

Summary

- According to the sliding filament theory, a muscle fiber contracts when myosin filaments pull actin filaments closer together and thus shorten sarcomeres within a fiber.
- When all the sarcomeres in a muscle fiber shorten, the fiber contracts.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Skeletal Muscle Contraction**

1. Draw a sacromere.
2. What happens when a sarcomere contracts?
3. Describe the molecular events that occur during skeletal muscle contraction.
4. What is creatine phosphate?
5. Describe the role of tropomyosin.
6. What is the role of calcium ions?

Review

1. Explain how muscles contract according to the sliding filament theory.
2. A serious neck injury may leave a person paralyzed from the neck down. Explain why.

Summary

The human body. Made of numerous organ systems. Maybe one of the most complex structures ever. But all these systems and structures come together in an exquisite manner to make a fascinating organism. Currently, the end of the line of evolution. The most intelligent of all organisms. An organism that can protect itself from pathogens, has bones for support, muscles to help it move, systems that allow it to respond to the environment, systems to bring oxygen into and around the body, systems to extract nutrients from food and get rid of wastes, and systems to make the next generation. And all these systems and organs and tissues and cells work together to form one complete organism.

2.9 References

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CHAPTER 3 Photosynthesis and Cellular Respiration

Chapter Outline

This caterpillar is busily munching its way through leaf after leaf. In fact, caterpillars do little more than eat, day and night. Like all living things, they need food to provide their cells with energy. The caterpillar will soon go through an amazing transformation to become a beautiful butterfly. These changes require a lot of energy.

Like this caterpillar and all other living things, you need energy to power everything you do. Whether it's running a race or blinking an eye, it takes energy. In fact, every cell of your body constantly needs energy to carry out life processes. You probably know that you get energy from the food you eat, but where does food come from? How does it come to contain energy, and how do your cells get the energy from food? When you read this chapter, you will learn the answers to these questions.

3.1 Energy for Life

Lesson Objectives

- State why living things need energy.
- Describe how autotrophs and heterotrophs obtain energy.
- Compare and contrast glucose and ATP.
- Outline how living things make and use food.

Vocabulary

- autotroph
- cellular respiration
- consumer
- energy
- food
- glucose
- heterotroph
- photosynthesis
- producer

Introduction

All living things need **energy**, which is defined as the ability to do work. You can often see energy at work in living things—a bird flies through the air, a firefly glows in the dark, a dog wags its tail. These are obvious ways that living things use energy, but living things constantly use energy in less obvious ways as well.

Why Living Things Need Energy

Inside every cell of all living things, energy is needed to carry out life processes. Energy is required to break down and build up molecules and to transport molecules across plasma membranes. All life's work needs energy. A lot of energy is also simply lost to the environment as heat. The story of life is a story of energy flow—its capture, its change of form, its use for work, and its loss as heat. Energy, unlike matter, cannot be recycled, so organisms require a constant input of energy. Life runs on chemical energy. Where do living organisms get this chemical energy?

How Organisms Get Energy: Autotrophs and Heterotrophs

The chemical energy that organisms need comes from food. **Food** consists of organic molecules that store energy in their chemical bonds. In terms of obtaining food for energy, there are two types of organisms: autotrophs and heterotrophs.

Autotrophs

Autotrophs are organisms that make their own food. Most autotrophs use the energy in sunlight to make food in a process called **photosynthesis**. Only three types of organisms—plants, algae, and some bacteria—can make food through photosynthesis. Examples of each type of photosynthetic organism are shown in **Figure** 3.1.

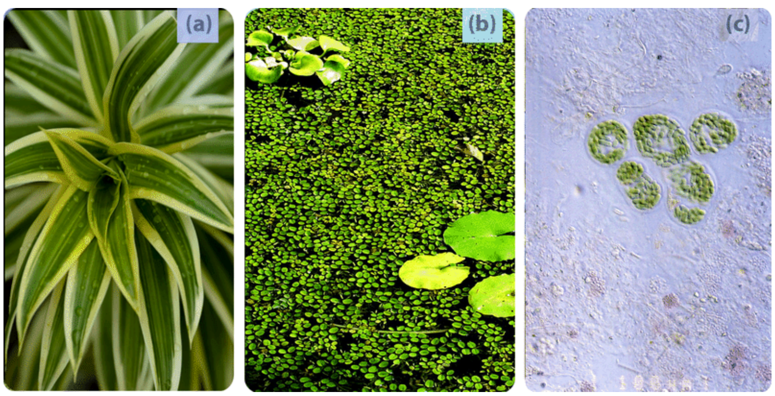

FIGURE 3.1
Photosynthetic autotrophs, which make food using the energy in sunlight, include (a) plants, (b) algae, and (c) certain bacteria.

Autotrophs are also called **producers**. They produce food not only for themselves but for all other living things as well (which are known as consumers). This is why autotrophs form the basis of food chains, such as the food chain shown in **Figure** 3.2.

Heterotrophs

Heterotrophs are living things that cannot make their own food. Instead, they get their food by consuming other organisms, which is why they are also called **consumers**. They may consume autotrophs or other heterotrophs. Heterotrophs include all animals and fungi and many single-celled organisms. In **Figure** 3.2, all of the organisms are consumers except for the grass. What do you think would happen to consumers if all producers were to vanish from Earth?

Energy Molecules: Glucose and ATP

Organisms mainly use two types of molecules for chemical energy: glucose and ATP. Both molecules are used as fuels throughout the living world. Both molecules are also key players in the process of photosynthesis.

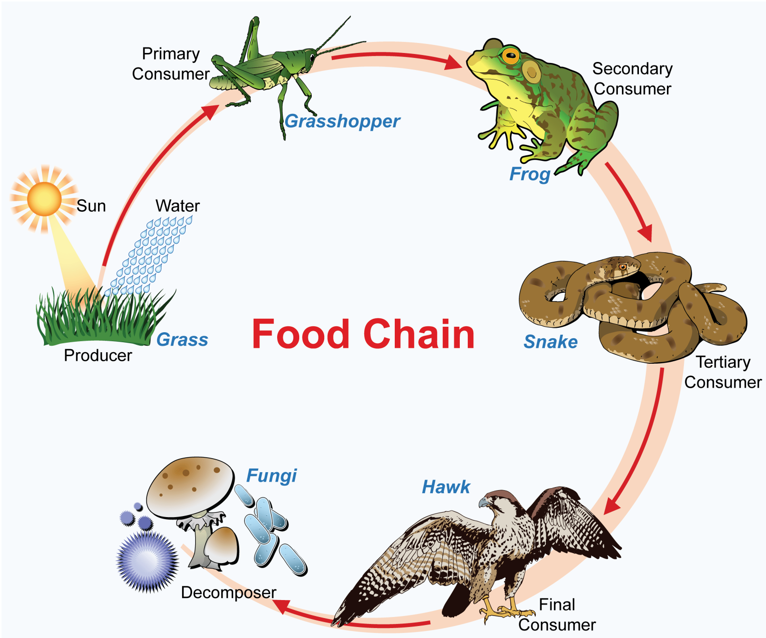

FIGURE 3.2
A food chain shows how energy and matter flow from producers to consumers. Matter is recycled, but energy must keep flowing into the system. Where does this energy come from? (Though the decomposers are shown as the final step in this food chain, these organisms decompose material from each step of the food chain. See the Ecology Concepts for additional information.)

Glucose

Glucose is a simple carbohydrate with the chemical formula $C_6H_{12}O_6$. It stores chemical energy in a concentrated, stable form. In your body, glucose is the form of energy that is carried in your blood and taken up by each of your trillions of cells. Glucose is the end product of photosynthesis, and it is the nearly universal food for life.

ATP

ATP (adenosine triphosphate) is the energy-carrying molecule that cells use for energy. ATP is made during the first half of photosynthesis and then used for energy during the second half of photosynthesis, when glucose is made. It is also used for energy by cells for most other cellular processes. ATP releases energy when it gives up one of its three phosphate groups and changes to ADP (adenosine diphosphate [*two phosphates*]).

Why Organisms Need Both Glucose and ATP

Why do living things need glucose if ATP is the molecule that cells use for energy? Why don't autotrophs just make ATP and be done with it? The answer is in the "packaging." A molecule of glucose contains more chemical energy in a smaller "package" than a molecule of ATP. Glucose is also more stable than ATP. Therefore, glucose is better for storing and transporting energy. However, glucose is too powerful for cells to use. ATP, on the other hand, contains just the right amount of energy to power life processes within cells. For these reasons, both glucose and ATP are needed by living things.

A explanation of ATP as *biological energy* is found at http://www.youtube.com/watch?v=YQfWiDlFEcA .

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Making and Using Food

The flow of energy through living organisms begins with photosynthesis. This process stores energy from sunlight in the chemical bonds of glucose. By breaking the chemical bonds in glucose, cells release the stored energy and make the ATP they need. The process in which glucose is broken down and ATP is made is called **cellular respiration**.

Photosynthesis and cellular respiration are like two sides of the same coin. This is apparent from **Figure** 3.3. The products of one process are the reactants of the other. Together, the two processes store and release energy in living organisms. The two processes also work together to recycle oxygen in Earth's atmosphere.

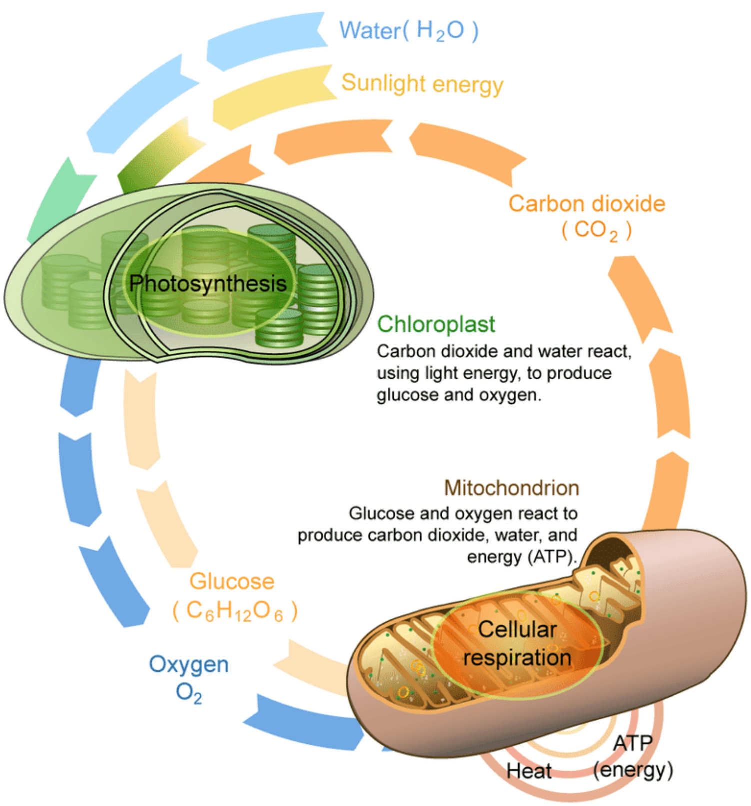


FIGURE 3.3

This diagram compares and contrasts photosynthesis and cellular respiration. It also shows how the two processes are related.

Photosynthesis

Photosynthesis is often considered to be the single most important life process on Earth. It changes light energy into chemical energy and also releases oxygen. Without photosynthesis, there would be no oxygen in the atmosphere. Photosynthesis involves many chemical reactions, but they can be summed up in a single chemical equation:

$6CO_2 + 6H_2O$ + Light Energy $\rightarrow C_6H_{12}O_6 + 6O_2$.

Photosynthetic autotrophs capture light energy from the sun and absorb carbon dioxide and water from their environment. Using the light energy, they combine the reactants to produce glucose and oxygen, which is a waste product. They store the glucose, usually as starch, and they release the oxygen into the atmosphere.

Cellular Respiration

Cellular respiration actually "burns" glucose for energy. However, it doesn't produce light or intense heat as some other types of burning do. This is because it releases the energy in glucose slowly, in many small steps. It uses the energy that is released to form molecules of ATP. Cellular respiration involves many chemical reactions, which can be summed up with this chemical equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Chemical Energy (in ATP)

Cellular respiration occurs in the cells of all living things. It takes place in the cells of both autotrophs and heterotrophs. All of them burn glucose to form ATP.

Lesson Summary

- Living things need energy to carry out all life processes. They get energy from food.
- Autotrophs make their own food. Heterotrophs get food by eating other living things.
- Glucose and ATP are used for energy by nearly all living things. Glucose is used to store and transport energy, and ATP is used to power life processes inside cells.
- Many autotrophs make food through the process of photosynthesis, in which light energy from the sun is changed to chemical energy that is stored in glucose. All organisms use cellular respiration to break down glucose, release its energy, and make ATP.

Lesson Review Questions

Recall

1. Define energy, and state where living things get the energy they need.

2. What is an autotroph? Give an example.

3. How does photosynthesis change energy?

4. How do heterotrophs obtain food?

Apply Concepts

5. ATP and glucose are both molecules that organisms use for energy. They are like the tank of a tanker truck that delivers gas to a gas station and the gas tank that holds the fuel for a car. Which molecule is like the tank of the delivery truck, and which is like the gas tank of the car? Explain your answer.

Think Critically

6. Compare and contrast photosynthesis and cellular respiration. Why are the processes like two sides of the same coin?

7. Explain why living things need both glucose and ATP.

8. Explain how living things recycle oxygen in Earth's atmosphere.

Points to Consider

Living things must have chemical energy from food to power life processes. Most of the chemical energy in food comes ultimately from the energy in sunlight.

- Do you know how the energy in sunlight is captured by plants and other photosynthetic autotrophs?
- How do you think light energy changes to chemical energy during the process of photosynthesis?
- Some producers live in places that do not receive sunlight. How do you think they make food?

3.2 Photosynthesis: Sugar as Food

Lesson Objectives

- Outline the stages of photosynthesis.
- Describe the chloroplast and its role in photosynthesis.
- List the steps of the light reactions.
- Describe the Calvin cycle.
- Define chemosynthesis.

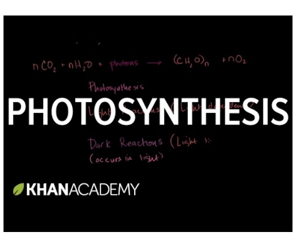
Vocabulary

- Calvin cycle
- chemosynthesis
- chlorophyll
- electron transport chain
- grana
- light reactions
- photosystem
- stroma
- thylakoid membrane

Introduction

Plants and other autotrophs make food out of "thin air"—at least, they use carbon dioxide from the air to make food. Most food is made in the process of photosynthesis. This process provides more than 99% of the energy used by living things on Earth. Photosynthesis also supplies Earth's atmosphere with oxygen.

An overview of photosynthesis is available at http://www.youtube.com/watch?v=-rsYk4eCKnA (13:37).



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Stages of Photosynthesis

Photosynthesis occurs in two stages, which are shown in **Figure** 3.4.

1. Stage I is called the **light reactions**. This stage uses water and changes light energy from the sun into chemical energy stored in ATP and NADPH (another energy-carrying molecule). This stage also releases oxygen as a waste product.
2. Stage II is called the **Calvin cycle**. This stage combines carbon from carbon dioxide in the air and uses the chemical energy in ATP and NADPH to make glucose.

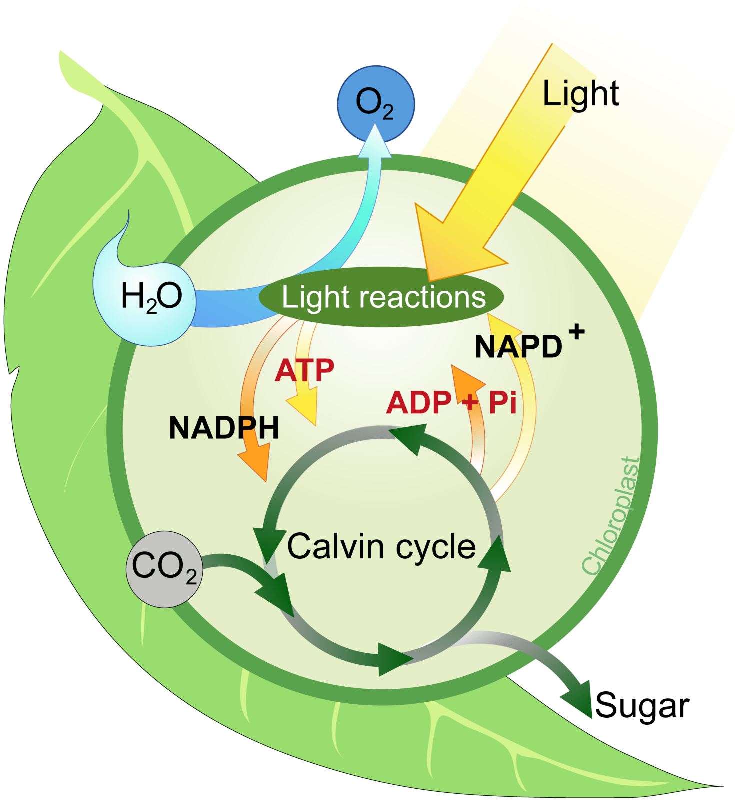


FIGURE 3.4
The two stages of photosynthesis are the light reactions and the Calvin cycle. Do you see how the two stages are related?

Before you read about these two stages of photosynthesis in greater detail, you need to know more about the chloroplast, where the two stages take place.

The Chloroplast: Theater for Photosynthesis

The "theater" where both stages of photosynthesis take place is the chloroplast. Chloroplasts are organelles that are found in the cells of plants and algae. (Photosynthetic bacteria do not have chloroplasts, but they contain structures similar to chloroplasts and produce food in the same way.) Look at the **Figure** 3.5. The figure is a high power microscopic photo of the upper part of a Winter Jasmine leaf. If you could look at a single leaf of this plant under a microscope, you would see small green ovals, like those shown. These small green ovals are chloroplasts.

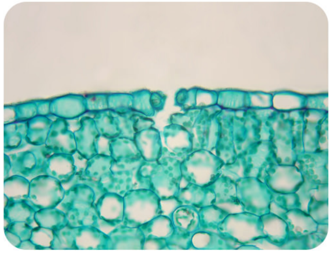


FIGURE 3.5

High power microscopic photo of the upper part of a Winter Jasmine leaf. Viewed under a microscope many green chloroplasts are visible.

Figure 3.6 shows the components of a chloroplast. Each chloroplast contains neat stacks called **grana** (singular, granum). The grana consist of sac-like membranes, known as **thylakoid membranes**. These membranes contain **photosystems**, which are groups of molecules that include **chlorophyll**, a green pigment. The light reactions of photosynthesis occur in the thylakoid membranes. The **stroma** is the space outside the thylakoid membranes. This is where the reactions of the Calvin cycle take place.

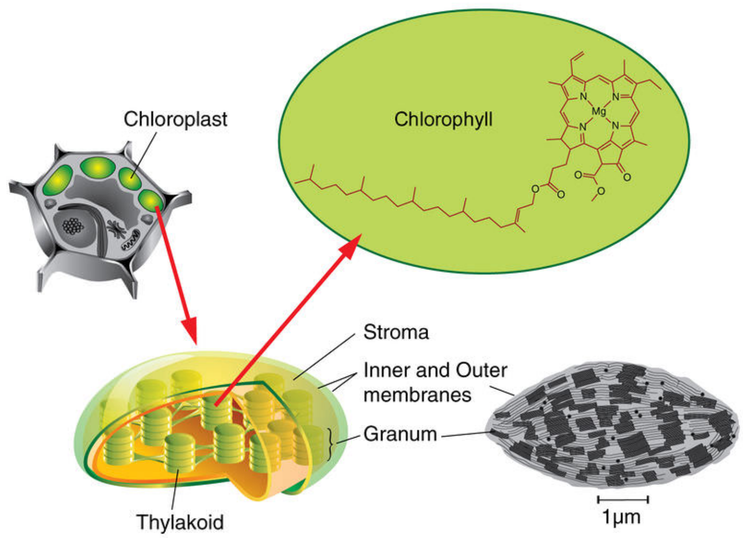


FIGURE 3.6

A chloroplast consists of thylakoid membranes surrounded by stroma. The thylakoid membranes contain molecules of the green pigment chlorophyll.

Photosynthesis Stage I: The Light Reactions

The first stage of photosynthesis is called the light reactions. During this stage, light is absorbed and transformed to chemical energy in the bonds of NADPH and ATP. You can follow the process in the **Figure** 3.7 as you read about it below.

Steps of the Light Reactions

The light reactions occur in several steps, all of which take place in the thylakoid membrane, as shown in **Figure** 3.7.

- Step 1: Units of sunlight, called photons, strike a molecule of chlorophyll in photosystem II of the thylakoid membrane. The light energy is absorbed by two electrons (2 e^-) in the chlorophyll molecule, giving them enough energy to leave the molecule.

- Step 2: At the same time, enzymes in the thylakoid membrane use light energy to split apart a water molecule. This produces:

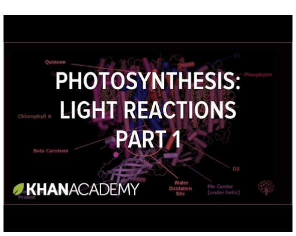
1. two electrons (2 e^-). These electrons replace the two electrons that were lost from the chlorophyll molecule in Step 1.
2. an atom of oxygen (O). This atom combines with another oxygen atom to produce a molecule of oxygen gas (O_2), which is released as a waste product.
3. two hydrogen ions (2 H^+). The hydrogen ions, which are positively charged, are released inside the membrane in the thylakoid interior space.

- Step 3: The two excited electrons from Step 1 contain a great deal of energy, so, like hot potatoes, they need something to carry them. They are carried by a series of electron-transport molecules, which make up an **electron transport chain**. The two electrons are passed from molecule to molecule down the chain. As this happens, their energy is captured and used to pump more hydrogen ions into the thylakoid interior space.
- Step 4: When the two electrons reach photosystem I, they are no longer excited. Their energy has been captured and used, and they need more energy. They get energy from light, which is absorbed by chlorophyll in photosystem I. Then, the two re-energized electrons pass down another electron transport chain.
- Step 5: Enzymes in the thylakoid membrane transfer the newly re-energized electrons to a compound called $NADP^+$. Along with a hydrogen ion, this produces the energy-carrying molecule NADPH. This molecule is needed to make glucose in the Calvin cycle.
- Step 6: By now, there is a greater concentration of hydrogen ions—and positive charge—in the thylakoid interior space. This difference in concentration and charge creates what is called a chemiosmotic gradient. It causes hydrogen ions to flow back across the thylakoid membrane to the stroma, where their concentration is lower. Like water flowing through a hole in a dam, the hydrogen ions have energy as they flow down the chemiosmotic gradient. The enzyme ATP synthase acts as a channel protein and helps the ions cross the membrane. ATP synthase also uses their energy to add a phosphate group (Pi) to a molecule of ADP, producing a molecule of ATP. The energy in ATP is needed for the Calvin cycle.

Summary of Stage I

By the time Step 6 is finished, energy from sunlight has been stored in chemical bonds of NADPH and ATP. Thus, light energy has been changed to chemical energy, and the first stage of photosynthesis is now complete.

For a more detailed discussion see http://www.youtube.com/watch?v=GR2GA7chA_c (20:16) and http://www.youtube.com/watch?v=yfR36PMWegg (18:51).



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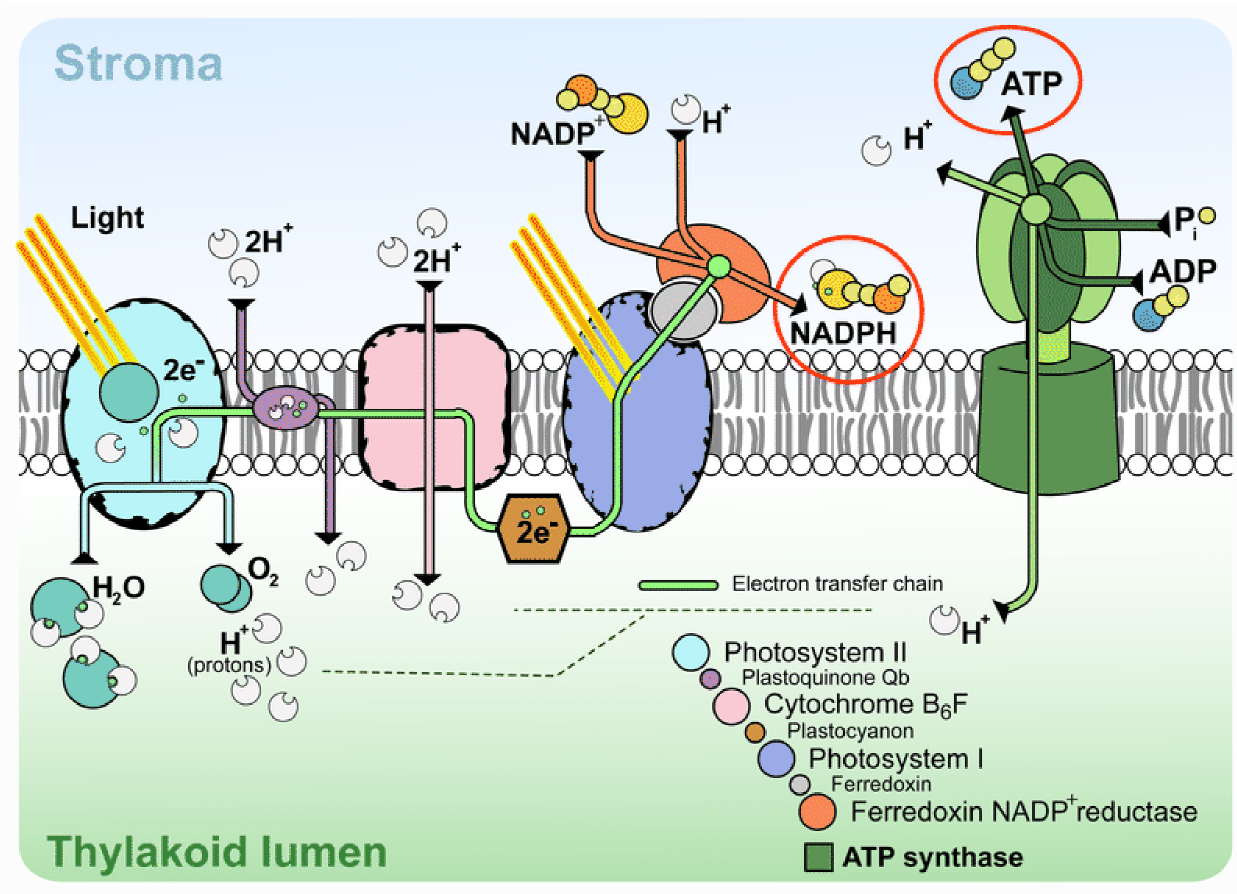
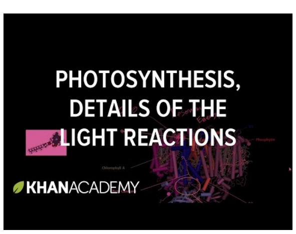


FIGURE 3.7

This figure shows the light reactions of photosynthesis. This stage of photosynthesis begins with photosystem II (so named because it was discovered after photosystem I). Find the two electrons (2 e^-) in photosystem II, and then follow them through the electron transport chain to the formation of NADPH in Step 5. In Step 6, where do the hydrogen ions (H^+) come from that help make ATP?



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Photosynthesis Stage II: The Calvin Cycle

The second stage of photosynthesis takes place in the stroma surrounding the thylakoid membranes of the chloroplast. The reactions of this stage can occur without light, so they are sometimes called light-independent or dark reactions. This stage of photosynthesis is also known as the Calvin cycle because its reactions were discovered by a scientist named Melvin Calvin. He won a Nobel Prize in 1961 for this important discovery.

In the Calvin cycle, chemical energy in NADPH and ATP from the light reactions is used to make glucose. You can follow the Calvin cycle in **Figure** 3.8 as you read about it in this section. You can also watch an animation of the Calvin cycle at this link: http://www.science.smith.edu/departments/Biology/Bio231/calvin.html .

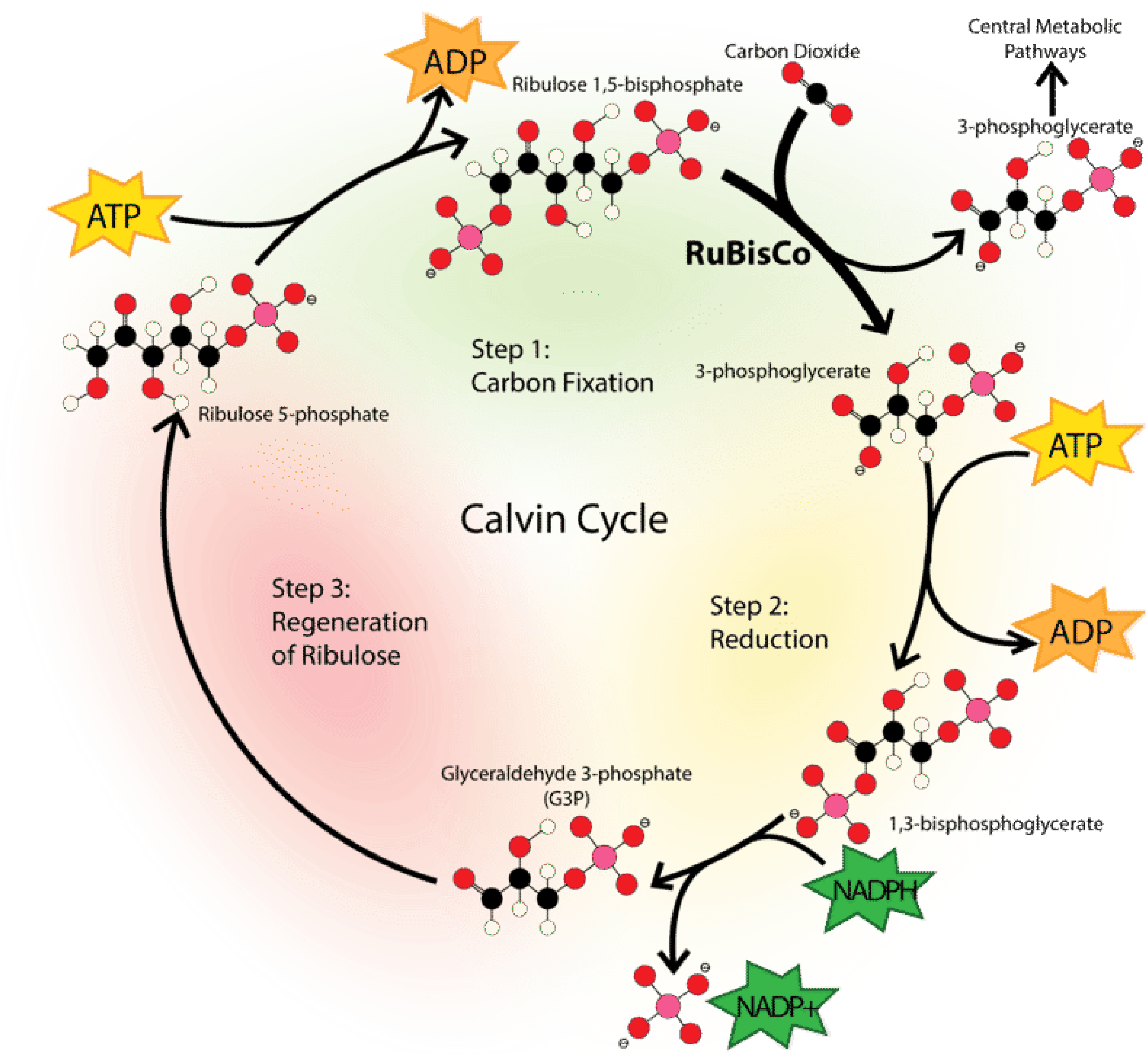


FIGURE 3.8

The Calvin cycle begins with a molecule named RuBP (a five-carbon sugar, Ribulose-1,5-bisphosphate) and uses the energy in ATP and NADPH from the light reactions. Follow the cycle to see what happens to all three of these molecules. Two turns of the cycle produce one molecule of glucose (called sucrose in the figure). In this diagram, each black dot represents a carbon atom. Keep track of what happens to the carbon atoms as the cycle proceeds.

Steps of the Calvin Cycle

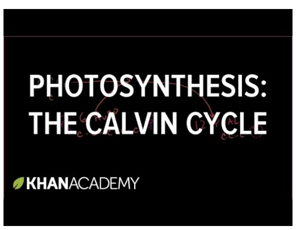
The Calvin cycle has three major steps: carbon fixation, reduction, and regeneration. All three steps take place in the stroma of a chloroplast.

- Step 1: Carbon Fixation. Carbon dioxide from the atmosphere combines with a simple, five-carbon compound called RuBP. This reaction occurs with the help of an enzyme named RuBisCo and produces molecules known as 3PG (a three-carbon compound, 3-Phosphoglyceric acid).
- Step 2: Reduction. Molecules of 3PG (from Step 1) gain energy from ATP and NADPH (from the light reactions) and re-arrange themselves to form G3P (glycerate 3-phosphate). This molecule also has three carbon atoms, but it has more energy than 3PG. One of the G3P molecules goes on to form glucose, while the rest of the G3P molecules go on to Step 3.
- Step 3: Regeneration. The remaining G3P molecules use energy from ATP to form RuBP, the five-carbon molecule that started the Calvin cycle. This allows the cycle to repeat.

Summary of Stage II

The Calvin cycle takes over where the light reactions end. It uses chemical energy stored in ATP and NADPH (from the light reactions) and carbon dioxide from the air to produce glucose, the molecule that virtually all organisms use for food.

The Calvin Cycle is discussed at http://www.youtube.com/watch?v=slm6D2VEXYs (13:28).



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Chemosynthesis

Most autotrophs make food by photosynthesis, but this isn't the only way that autotrophs produce food. Some bacteria make food by another process, which uses chemical energy instead of light energy. This process is called **chemosynthesis**.

Some chemosynthetic bacteria live around deep-ocean vents known as "black smokers." Compounds such as hydrogen sulfide, which flow out of the vents from Earth's interior, are used by the bacteria for energy to make food. Consumers that depend on these bacteria to produce food for them include giant tube worms, like these pictured in **Figure** 3.9. Why do bacteria that live deep below the ocean's surface rely on chemical compounds instead of sunlight for energy to make food?

Lesson Summary

- Most autotrophs make food using photosynthesis. This process occurs in two stages: the light reactions and the Calvin cycle.

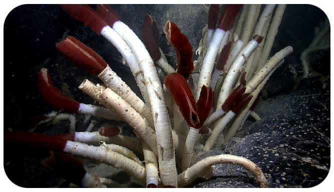

FIGURE 3.9
Tube worms deep in the Galapagos Rift get their energy from chemosynthetic bacteria. The bacteria actually live inside the worms.

- Both stages of photosynthesis take place in chloroplasts. The light reactions take place in the thylakoid membranes, and the Calvin cycle takes place in the stroma.
- The light reactions capture energy from sunlight, which they change to chemical energy that is stored in molecules of NADPH and ATP. The light reactions also release oxygen gas as a waste product.
- The reactions of the Calvin cycle add carbon (from carbon dioxide in the atmosphere) to a simple five-carbon molecule called RuBP. These reactions use chemical energy from NADPH and ATP that were produced in the light reactions. The final product of the Calvin cycle is glucose.
- Some bacterial autotrophs make food using chemosynthesis. This process uses chemical energy instead of light energy to produce food.

Lesson Review Questions

Recall

1. What are the stages of photosynthesis? Which stage occurs first?

2. Describe the chloroplast and its role in photosynthesis.

3. Summarize what happens during the light reactions of photosynthesis.

4. What happens during the carbon fixation step of the Calvin cycle?

5. During which stage of photosynthesis is glucose made?

Apply Concepts

6. The first living things appeared on Earth at least a billion years before photosynthetic organisms appeared. How might the earliest organisms have obtained energy before photosynthesis evolved? What process could they have used to make food?

Think Critically

7. Explain the role of the first electron transport chain in the formation of ATP during the light reactions of photosynthesis.

8. Explain what might happen if the third step of the Calvin cycle did not occur.

9. Plants release oxygen during the day but not during the night. Explain why.

Points to Consider

All living things need to break down glucose to make ATP for energy. Cellular respiration is the process in which this occurs.

- How do you think cellular respiration occurs? What steps do you think might be involved?
- How many molecules of ATP do you think cells get from a single molecule of glucose?

3.3 Powering the Cell: Cellular Respiration

Lesson Objectives

- Name the three stages of cellular respiration.
- Give an overview of glycolysis.
- Explain why glycolysis probably evolved before the other stages of aerobic respiration.
- Describe the mitochondrion and its role in aerobic respiration.
- List the steps of the Krebs cycle, and identify its products.
- Explain how electron transport results in many molecules of ATP.
- State the possible number of ATP molecules that can result from aerobic respiration.

Vocabulary

- aerobic respiration
- anaerobic respiration
- glycolysis
- Krebs cycle

Introduction

You have just read how photosynthesis stores energy in glucose. How do living things make use of this stored energy? The answer is cellular respiration. This process releases the energy in glucose to make ATP, the molecule that powers all the work of cells.

An introduction to cellular respiration can be viewed at http://www.youtube.com/watch?v=2f7YwCtHcgk (14:19).

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Stages of Cellular Respiration

Cellular respiration involves many chemical reactions. As you saw earlier, the reactions can be summed up in this equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Chemical Energy (in ATP)

The reactions of cellular respiration can be grouped into three stages: glycolysis, the Krebs cycle (also called the citric acid cycle), and electron transport. **Figure** 3.10 gives an overview of these three stages, which are also described below.

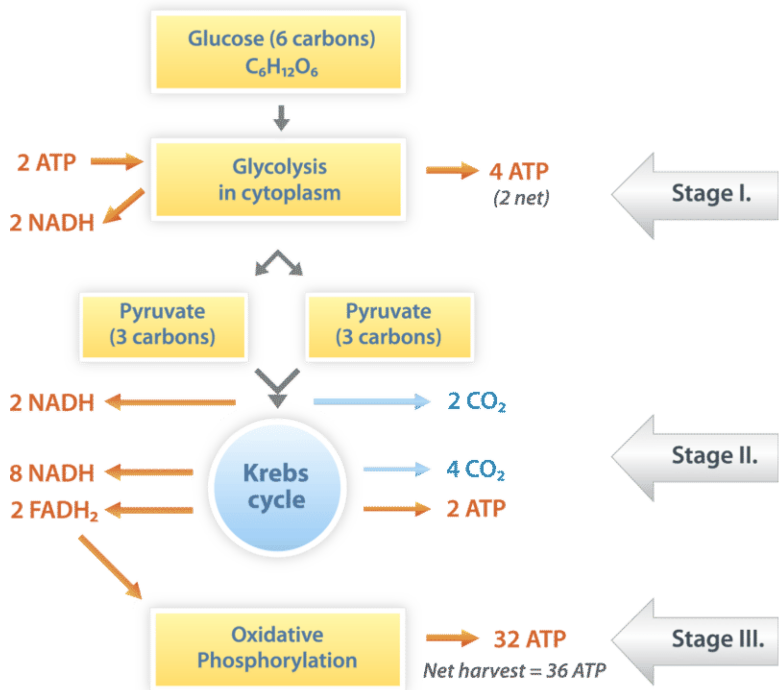


FIGURE 3.10
Cellular respiration takes place in the stages shown here. The process begins with a molecule of glucose, which has six carbon atoms. What happens to each of these atoms of carbon?

Cellular Respiration Stage I: Glycolysis

The first stage of cellular respiration is **glycolysis**. It takes place in the cytosol of the cytoplasm.

Splitting Glucose

The word *glycolysis* means "glucose splitting," which is exactly what happens in this stage. Enzymes split a molecule of glucose into two molecules of pyruvate (also known as pyruvic acid). This occurs in several steps, as shown in **Figure** 3.11. You can watch an animation of the steps of glycolysis at the following link: http://www.youtube.com/watch?v=6JGXayUyNVw .

Results of Glycolysis

Energy is needed at the start of glycolysis to split the glucose molecule into two pyruvate molecules. These two molecules go on to stage II of cellular respiration. The energy to split glucose is provided by two molecules of ATP. As glycolysis proceeds, energy is released, and the energy is used to make four molecules of ATP. As a result, there is a net gain of two ATP molecules during glycolysis. During this stage, high-energy electrons are also transferred to molecules of NAD^+ to produce two molecules of NADH, another energy-carrying molecule. NADH is used in stage III of cellular respiration to make more ATP.

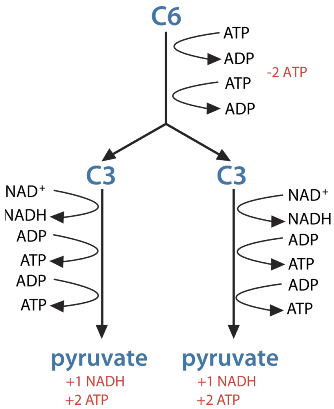
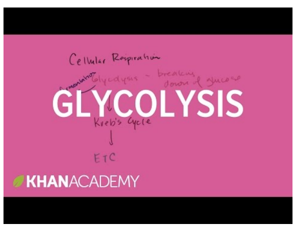


FIGURE 3.11

In glycolysis, glucose (C6) is split into two 3-carbon (C3) pyruvate molecules. This releases energy, which is transferred to ATP. How many ATP molecules are made during this stage of cellular respiration?

A summary of glycolysis can be viewed at http://www.youtube.com/watch?v=FE2jfTXAJHg .



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Anaerobic and Aerobic Respiration

Scientists think that glycolysis evolved before the other stages of cellular respiration. This is because the other stages need oxygen, whereas glycolysis does not, and there was no oxygen in Earth's atmosphere when life first evolved about 3.5 to 4 billion years ago. Cellular respiration that proceeds without oxygen is called **anaerobic respiration**.

Then, about 2 or 3 billion years ago, oxygen was gradually added to the atmosphere by early photosynthetic bacteria. After that, living things could use oxygen to break down glucose and make ATP. Today, most organisms make ATP with oxygen. They follow glycolysis with the Krebs cycle and electron transport to make more ATP than by glycolysis alone. Cellular respiration that proceeds in the presence of oxygen is called **aerobic respiration**.

Structure of the Mitochondrion: Key to Aerobic Respiration

Before you read about the last two stages of aerobic respiration, you need to know more about the mitochondrion, where these two stages take place. A diagram of a mitochondrion is shown in **Figure** 3.12.

As you can see from **Figure** 3.12, a mitochondrion has an inner and outer membrane. The space between the inner and outer membrane is called the intermembrane space. The space enclosed by the inner membrane is called the matrix. The second stage of cellular respiration, the Krebs cycle, takes place in the matrix. The third stage, electron transport, takes place on the inner membrane.

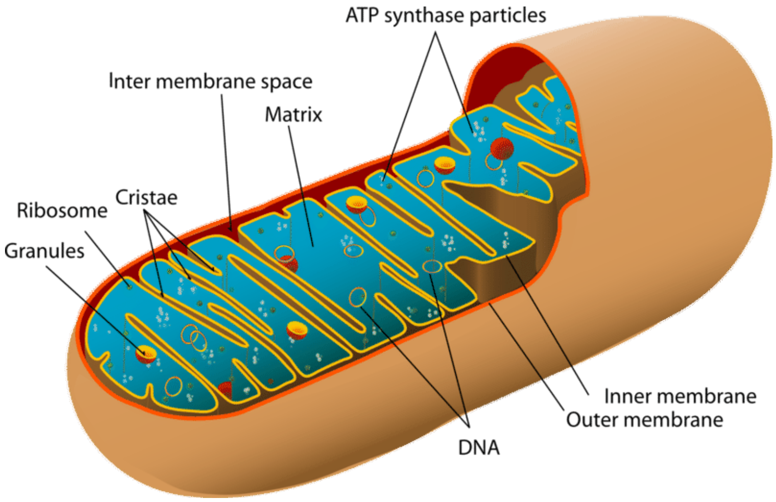


FIGURE 3.12
The structure of a mitochondrion is defined by an inner and outer membrane. This structure plays an important role in aerobic respiration.

Cellular Respiration Stage II: The Krebs Cycle

Recall that glycolysis produces two molecules of pyruvate (pyruvic acid). These molecules enter the matrix of a mitochondrion, where they start the **Krebs cycle**. The reactions that occur next are shown in **Figure** 3.13. You can watch an animated version at this link: http://www.youtube.com/watch?v=p-k0biO1DT8 .

Before the Krebs cycle begins, pyruvic acid, which has three carbon atoms, is split apart and combined with an enzyme known as CoA, which stands for coenzyme A. The product of this reaction is a two-carbon molecule called acetyl-CoA. The third carbon from pyruvic acid combines with oxygen to form carbon dioxide, which is released as a waste product. High-energy electrons are also released and captured in NADH.

Steps of the Krebs Cycle

The Krebs cycle itself actually begins when acetyl-CoA combines with a four-carbon molecule called OAA (oxaloacetate) (see **Figure** 3.13). This produces citric acid, which has six carbon atoms. This is why the Krebs cycle is also called the citric acid cycle.

After citric acid forms, it goes through a series of reactions that release energy. The energy is captured in molecules of NADH, ATP, and $FADH_2$, another energy-carrying compound. Carbon dioxide is also released as a waste product of these reactions.

The final step of the Krebs cycle regenerates OAA, the molecule that began the Krebs cycle. This molecule is needed for the next turn through the cycle. Two turns are needed because glycolysis produces two pyruvic acid molecules when it splits glucose. Watch the OSU band present the Krebs cycle: http://www.youtube.com/watch?v=FgXnH087JIk .

Results of the Krebs Cycle

After the second turn through the Krebs cycle, the original glucose molecule has been broken down completely. All six of its carbon atoms have combined with oxygen to form carbon dioxide. The energy from its chemical bonds has been stored in a total of 16 energy-carrier molecules. These molecules are:

- 4 ATP (including 2 from glycolysis)

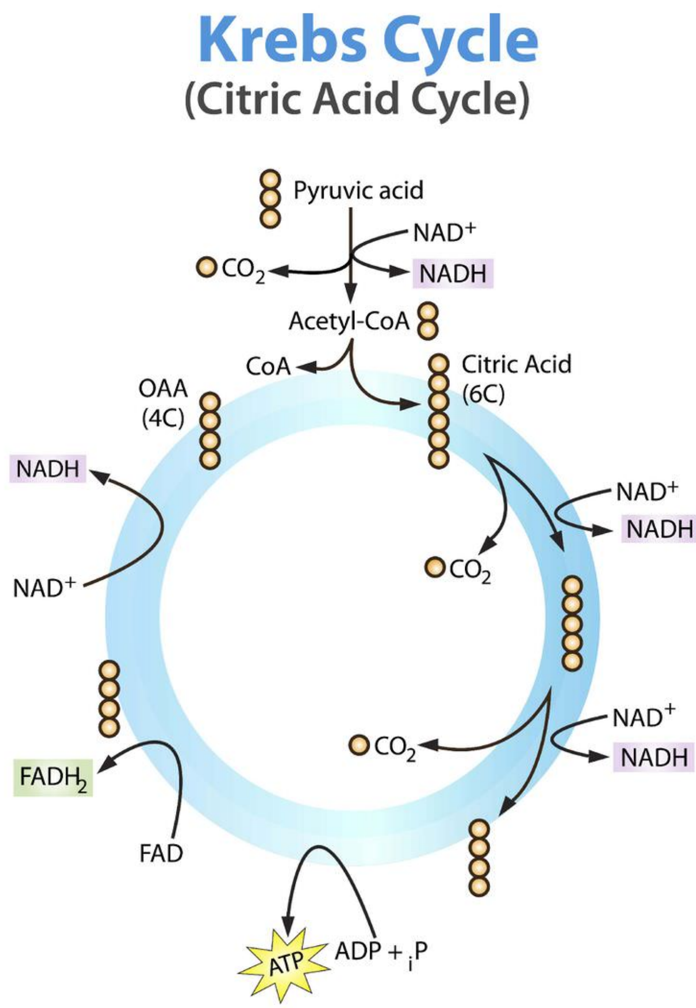
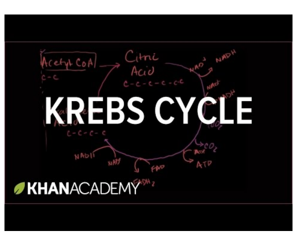


FIGURE 3.13

The Krebs cycle starts with pyruvic acid from glycolysis. Each small circle in the diagram represents one carbon atom. For example, citric acid is a six carbon molecule, and OAA (oxaloacetate) is a four carbon molecule. Follow what happens to the carbon atoms as the cycle proceeds. In one turn through the cycle, how many molecules are produced of ATP? How many molecules of NADH and $FADH_2$ are produced?

- 10 NADH (including 2 from glycolysis)
- 2 $FADH_2$

The Krebs cycle is reviewed at http://www.youtube.com/watch?v=juM2ROSLWfw .



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Cellular Respiration Stage III: Electron Transport

Electron transport is the final stage of aerobic respiration. In this stage, energy from NADH and $FADH_2$, which result from the Krebs cycle, is transferred to ATP. Can you predict how this happens? (*Hint:* How does electron transport occur in photosynthesis?)

See http://www.youtube.com/watch?v=1engJR_XWVU for an overview of the electron transport chain.

Transporting Electrons

High-energy electrons are released from NADH and $FADH_2$, and they move along electron transport chains, like those used in photosynthesis. The electron transport chains are on the inner membrane of the mitochondrion. As the high-energy electrons are transported along the chains, some of their energy is captured. This energy is used to pump hydrogen ions (from NADH and $FADH_2$) across the inner membrane, from the matrix into the intermembrane space. Electron transport in a mitochondrion is shown in **Figure** 3.14.

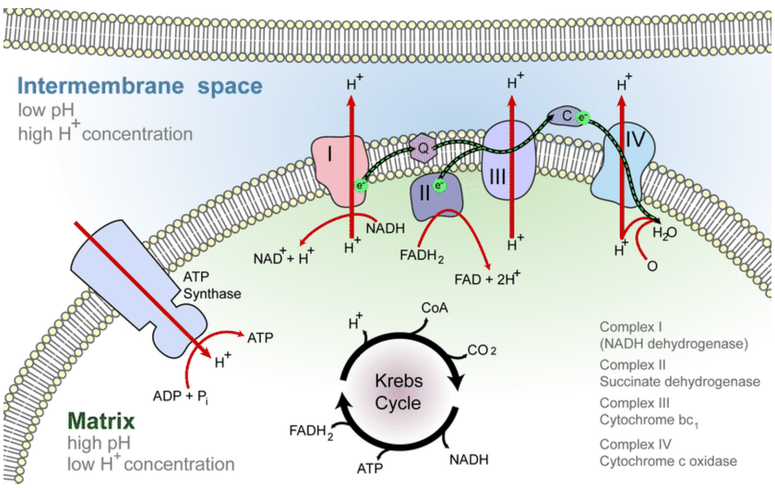

FIGURE 3.14

Electron-transport chains on the inner membrane of the mitochondrion carry out the last stage of cellular respiration.

Making ATP

The pumping of hydrogen ions across the inner membrane creates a greater concentration of the ions in the intermembrane space than in the matrix. This chemiosmotic gradient causes the ions to flow back across the membrane into the matrix, where their concentration is lower. ATP synthase acts as a channel protein, helping the hydrogen ions cross the membrane. It also acts as an enzyme, forming ATP from ADP and inorganic phosphate. After passing through the electron-transport chain, the "spent" electrons combine with oxygen to form water. This is why oxygen is needed; in the absence of oxygen, this process cannot occur. You can see how all these events occur at the following link: http://www.sp.uconn.edu/~terry/images/anim/ATPmito.html .

A summary of this process can be seen at the following sites: http://www.youtube.com/watch?v=mfgCcFXUZRk (17:16) and http://www.youtube.com/watch?v=W_Q17tqw_7A (4:59).

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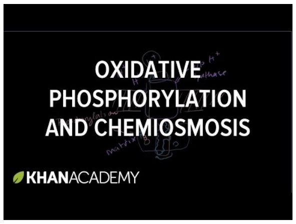

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How Much ATP?

You have seen how the three stages of aerobic respiration use the energy in glucose to make ATP. How much ATP is produced in all three stages? Glycolysis produces 2 ATP molecules, and the Krebs cycle produces 2 more. Electron transport begins with several molecules of NADH and $FADH_2$ from the Krebs cycle and transfers their energy into as many as 34 more ATP molecules. All told, then, up to 38 molecules of ATP can be produced from just one molecule of glucose in the process of aerobic respiration.

Lesson Summary

- Cellular respiration uses energy in glucose to make ATP. Aerobic ("oxygen-using") respiration occurs in three stages: glycolysis, the Krebs cycle, and electron transport.
- In glycolysis, glucose is split into two molecules of pyruvate. This results in a net gain of two ATP molecules.
- Life first evolved in the absence of oxygen, and glycolysis does not require oxygen. Therefore, glycolysis was probably the earliest way of making ATP from glucose.
- The Krebs cycle and electron transport occur in the mitochondria. The Krebs cycle takes place in the matrix, and electron transport takes place on the inner membrane.
- During the Krebs cycle, pyruvate undergoes a series of reactions to produce two more molecules of ATP and also several molecules of NADH and $FADH_2$.
- During electron transport, energy from NADH and $FADH_2$ is used to make many more molecules of ATP.
- In all three stages of aerobic respiration, up to 38 molecules of ATP may be produced from a single molecule of glucose.

Lesson Review Questions

Recall

1. List the stages of aerobic respiration in the order in which they occur.

2. Describe what happens during glycolysis. How many ATP molecules are gained during this stage?

3. Define aerobic and anaerobic respiration.

4. What role do mitochondria play in cellular respiration?

5. What are the products of the Krebs cycle?

6. What is the maximum number of ATP molecules that can be produced during the electron transport stage of aerobic respiration?

Apply Concepts

7. When you exhale onto a cold window pane, water vapor in your breath condenses on the glass. Where does the water vapor come from?

8. Assume that a new species of organism has been discovered. Scientists have observed its cells under a microscope and determined that they lack mitochondria. What type of cellular respiration would you predict that the new species uses? Explain your prediction.

Think Critically

9. Why do scientists think that glycolysis evolved before the other stages of cellular respiration?

10. Explain why two turns of the Krebs cycle are needed for each molecule of glucose.

Points to Consider

The last two stages of aerobic respiration require oxygen. However, not all organisms live in places where there is a plentiful supply of oxygen.

- How do you think organisms get energy from glucose to make ATP if they cannot use oxygen?
- Do they just use glycolysis, which produces only two ATP molecules? Or do you think there might be other steps involved?

3.4 Anaerobic Respiration

Lesson Objectives

- Define fermentation.
- Describe lactic acid fermentation and alcoholic fermentation.
- Compare the advantages of aerobic and anaerobic respiration.

Vocabulary

- alcoholic fermentation
- fermentation
- lactic acid fermentation

Introduction

Today, most living things use oxygen to make ATP from glucose. However, many living things can also make ATP without oxygen. This is true of some plants and fungi and also of many bacteria. These organisms use aerobic respiration when oxygen is present, but when oxygen is in short supply, they use anaerobic respiration instead. Certain bacteria can only use anaerobic respiration. In fact, they may not be able to survive at all in the presence of oxygen.

Fermentation

An important way of making ATP without oxygen is called **fermentation**. It involves glycolysis but not the other two stages of aerobic respiration. Many bacteria and yeasts carry out fermentation. People use these organisms to make yogurt, bread, wine, and biofuels. Human muscle cells also use fermentation. This occurs when muscle cells cannot get oxygen fast enough to meet their energy needs through aerobic respiration.

There are two types of fermentation: lactic acid fermentation and alcoholic fermentation. Both types of fermentation are described below. You can also watch animations of both types at this link: http://www.cst.cmich.edu/users/schul1te/animations/fermentation.swf .

Lactic Acid Fermentation

In **lactic acid fermentation**, pyruvic acid from glycolysis changes to lactic acid. This is shown in **Figure** 3.15. In the process, NAD^+ forms from NADH. NAD^+, in turn, lets glycolysis continue. This results in additional molecules of ATP. This type of fermentation is carried out by the bacteria in yogurt. It is also used by your own muscle cells when you work them hard and fast.

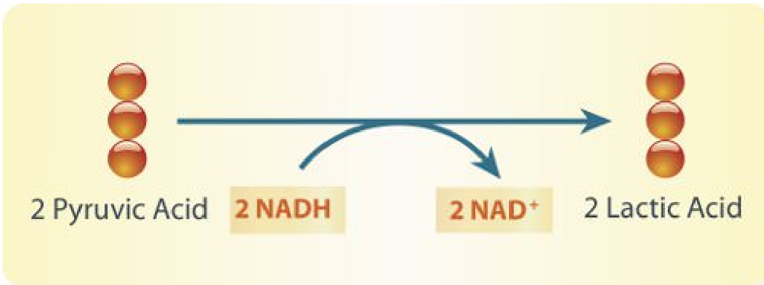

FIGURE 3.15
Lactic acid fermentation produces lactic acid and NAD^+. The NAD^+ cycles back to allow glycolysis to continue so more ATP is made. Each circle represents a carbon atom.

Did you ever run a race and notice that your muscles feel tired and sore afterward? This is because your muscle cells used lactic acid fermentation for energy. This causes lactic acid to build up in the muscles. It is the buildup of lactic acid that makes the muscles feel tired and sore.

Alcoholic Fermentation

In **alcoholic fermentation**, pyruvic acid changes to alcohol and carbon dioxide. This is shown in **Figure** 3.16. NAD^+ also forms from NADH, allowing glycolysis to continue making ATP. This type of fermentation is carried out by yeasts and some bacteria. It is used to make bread, wine, and biofuels.

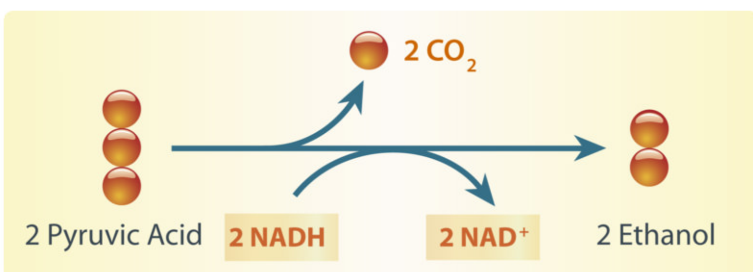

FIGURE 3.16
Alcoholic fermentation produces ethanol and NAD^+. The NAD^+ allows glycolysis to continue making ATP.

Have your parents ever put corn in the gas tank of their car? They did if they used gas containing ethanol. Ethanol is produced by alcoholic fermentation of the glucose in corn or other plants. This type of fermentation also explains why bread dough rises. Yeasts in bread dough use alcoholic fermentation and produce carbon dioxide gas. The gas forms bubbles in the dough, which cause the dough to expand. The bubbles also leave small holes in the bread after it bakes, making the bread light and fluffy. Do you see the small holes in the slice of bread in **Figure** 3.17?

FIGURE 3.17
The small holes in bread are formed by bubbles of carbon dioxide gas. The gas was produced by alcoholic fermentation carried out by yeast.

Aerobic vs. Anaerobic Respiration: A Comparison

Aerobic respiration evolved after oxygen was added to Earth's atmosphere. This type of respiration is useful today because the atmosphere is now 21% oxygen. However, some anaerobic organisms that evolved before the atmosphere contained oxygen have survived to the present. Therefore, anaerobic respiration must also have advantages.

Advantages of Aerobic Respiration

A major advantage of aerobic respiration is the amount of energy it releases. Without oxygen, organisms can just split glucose into two molecules of pyruvate. This releases only enough energy to make two ATP molecules. With oxygen, organisms can break down glucose all the way to carbon dioxide. This releases enough energy to produce up to 38 ATP molecules. Thus, aerobic respiration releases much more energy than anaerobic respiration.

The amount of energy produced by aerobic respiration may explain why aerobic organisms came to dominate life on Earth. It may also explain how organisms were able to become multicellular and increase in size.

Advantages of Anaerobic Respiration

One advantage of anaerobic respiration is obvious. It lets organisms live in places where there is little or no oxygen. Such places include deep water, soil, and the digestive tracts of animals such as humans (see **Figure** 3.18).

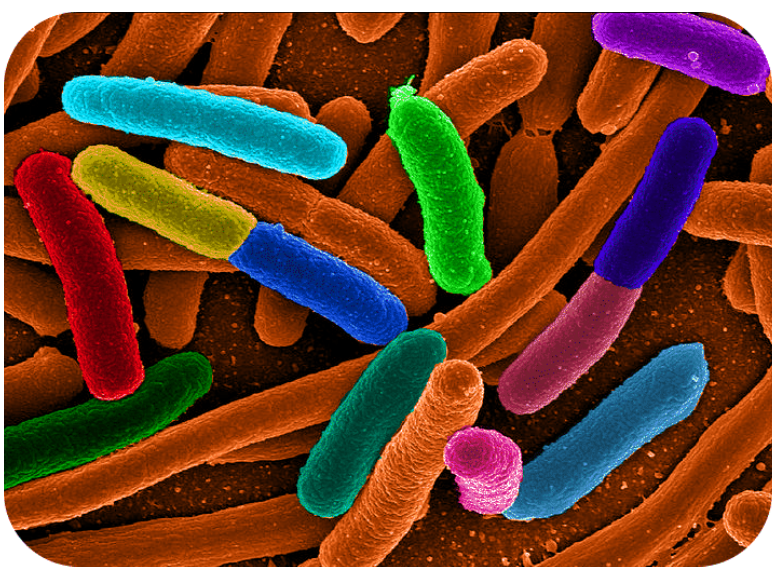

FIGURE 3.18
E. coli bacteria are anaerobic bacteria that live in the human digestive tract.

Another advantage of anaerobic respiration is its speed. It produces ATP very quickly. For example, it lets your muscles get the energy they need for short bursts of intense activity (see **Figure** 3.19). Aerobic respiration, on the other hand, produces ATP more slowly.

FIGURE 3.19
The muscles of these hurdlers need to use anaerobic respiration for energy. It gives them the energy they need for the short-term, intense activity of this sport.

Lesson Summary

- Fermentation is a way of making ATP from glucose without oxygen. There are two types of fermentation: lactic acid fermentation and alcoholic fermentation.
- Lactic acid fermentation changes pyruvic acid to lactic acid and forms NAD^+. The NAD^+ allows glycolysis to continue so it can make more ATP.
- Alcohol fermentation changes pyruvic acid to ethanol and carbon dioxide and forms NAD^+. Again, the NAD^+ allows glycolysis to keep making ATP.
- Aerobic respiration produces much more ATP than anaerobic respiration. However, anaerobic respiration occurs more quickly.

Lesson Review Questions

Recall

1. What is fermentation?

2. Name two types of fermentation.

3. What is the main advantage of aerobic respiration? Of anaerobic respiration?

4. What process produces fuel for motor vehicles from living plant products? What is the waste product of this process?

Apply Concepts

5. Tanya is on the high school track team and runs the 100-meter sprint. Marissa is on the cross-country team and runs 5-kilometer races. Explain which type of respiration the muscle cells in each runner's legs use.

Think Critically

6. Compare and contrast lactic acid fermentation and alcoholic fermentation. Include examples of organisms that use each type of fermentation.

7. Explain why bread dough rises when it is set aside in a warm place.

Points to Consider

Two important functions of cells are making food and using it for energy. Photosynthesis and cellular respiration are the processes that carry out these functions. Other important functions of cells are growing and dividing.

- Do you know how cells grow? What do you think controls the growth of cells?
- How do you think cells divide? Do all cells divide in the same way?

3.5 References

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Concept 4 Cell Transport and Homeostasis Worksheets

Lesson 3.3: True or False

Name___________________ **Class**______________ **Date**________

Write true if the statement is true or false if the statement is false.

_____ 1. Passive transport needs energy.

_____ 2. Active transport needs energy.

_____ 3. Carrier proteins change shape when they transport substances.

_____ 4. Diffusion does not require any help from other molecules.

_____ 5. Facilitated diffusion does not require any help from other molecules.

_____ 6. Endocytosis removes large molecules from the cell.

_____ 7. In diffusion, substances move from an area of lower concentration to an area of higher concentration.

_____ 8. The sodium-potassium pump is a type of channel protein.

_____ 9. Ions can easily flow through a carrier protein.

_____ 10. Diffusion is the osmosis of water.

_____ 11. Endocytosis and exocytosis are types of vesicle transport.

_____ 12. Channel proteins form small "holes" in the plasma membrane.

_____ 13. Transport of substances across the cell membrane helps maintain homeostasis by keeping the cell's conditions within normal ranges.

_____ 14. Channel proteins and carrier proteins are both transport proteins.

_____ 15. The plasma membrane controls what enters and leaves the cell.

Lesson 3.3: Critical Reading

Name___________________ **Class**______________ **Date**________

Read these passages from the text and answer the questions that follow.

Passive Transport

Passive transport occurs when substances cross the plasma membrane without any input of energy from the cell. No energy is needed because the substances are moving from an area where they have a higher concentration to an area where they have a lower concentration. Concentration refers to the number of particles of a substance per unit of volume. The more particles of a substance in a given volume, the higher the concentration. A substance always moves from an area where it is more concentrated to an area where it is less concentrated. It's a little like a ball rolling down a hill. It goes by itself without any input of extra energy.

Simple Diffusion

Diffusion is the movement of a substance across a membrane, due to a difference in concentration, without any help from other molecules. The substance simply moves from the side of the membrane where it is more concentrated to the side where it is less concentrated. Substances that can squeeze between the lipid molecules in the plasma membrane by simple diffusion are generally very small, hydrophobic molecules, such as molecules of oxygen and carbon dioxide.

Osmosis

Osmosis is a special type of diffusion — the diffusion of water molecules across a membrane. Like other molecules, water moves from an area of higher concentration to an area of lower concentration. Water moves in or out of a cell until its concentration is the same on both sides of the plasma membrane.

Facilitated Diffusion

Water and many other substances cannot simply diffuse across a membrane. Hydrophilic molecules, charged ions, and relatively large molecules, such as glucose, all need help with diffusion. The help comes from special proteins in the membrane known as **transport proteins**. Diffusion with the help of transport proteins is called **facilitated diffusion**. There are several types of transport proteins, including channel proteins and carrier proteins.

- Channel proteins form pores, or tiny holes, in the membrane. This allows water molecules and small ions to pass through the membrane without coming into contact with the hydrophobic tails of the lipid molecules in the interior of the membrane.
- Carrier proteins bind with specific ions or molecules, and in doing so, they change shape. As carrier proteins change shape, they carry the ions or molecules across the membrane.

Questions

1. Explain why passive transport does not require energy.

2. What is a main difference between diffusion and facilitated diffusion?

3. Describe how simple diffusion proceeds. What kind of molecules can move across the membrane by simple diffusion?

4. How is water transported across the membrane?

5. What are the two types of transport proteins? Describe how they function.

Lesson 3.3: Multiple Choice

Name___________________ Class______________ Date________

Circle the letter of the correct choice.

a. Controlling what enters and leaves the cell in an important function of the
    a. nucleus.
    b. vesicle.
    c. plasma membrane.
    d. Golgi apparatus.
b. During diffusion, substances move from an area of ____________ concentration to an area of ___________-_ concentration.
    a. higher, lower
    b. lower, higher
    c. higher, equal
    d. lower, equal

c. A channel protein does which of the following?
   a. Carries ions or molecules across the membrane.
   b. Forms tiny holes in the membrane.
   c. Changes shape as it transports molecules.
   d. all of the above
d. The sodium-potassium pump
   a. uses energy to move sodium ions out of the cell and potassium ions into the cell.
   b. uses energy to move potassium ions out of the cell and sodium ions into the cell.
   c. moves sodium ions out of the cell and potassium ions into the cell without using energy.
   d. moves potassium ions out of the cell and sodium ions into the cell without using energy.
e. Osmosis
   a. is the diffusion of water.
   b. is the diffusion of water and other small molecules.
   c. is the diffusion of water and small ions.
   d. is the diffusion of small molecules and ions.
f. Types of passive transport include which of the following? (1) simple diffusion, (2) osmosis, (3) facilitated diffusion, (4) active transport, and (5) vesicle transport.
   a. 1 and 2
   b. 1, 2, and 3
   c. 4 and 5
   d. 1, 2, 3, 4, and 5
g. Endocytosis and exocytosis
   a. are both a type of vesicle transport.
   b. move very large molecules either in or out of the cell.
   c. are both a form of active transport.
   d. all of the above
h. Which of the following needs energy? (1) passive transport, (2) active transport, (3) exocytosis, and (4) osmosis.
   a. 1 only
   b. 2 only
   c. 2 and 3
   d. 2, 3, and 4

Lesson 3.3: Vocabulary I

Name___________________ Class______________ Date________

Match the vocabulary word with the proper definition.

Definitions

_____ 1. transport across a membrane without any additional energy requirement

_____ 2. the diffusion of water

_____ 3. type of vesicle transport that moves a substance into the cell

_____ 4. type of vesicle transport that moves a substance out of the cell

_____ 5. special proteins in the membrane that aid diffusion

_____ 6. membrane protein that forms a small hole that allows ions to pass through

_____ 7. an active transport protein

_____ 8. diffusion with the help of transport proteins

_____ 9. the movement of a substance across a membrane without any help from other molecules

_____ 10. the transport of very large molecules, such as proteins

_____ 11. transport across a membrane in which energy is required

Terms

a. active transport

b. channel protein

c. diffusion

d. endocytosis

e. exocytosis

f. facilitated diffusion

g. osmosis

h. passive transport

i. sodium-potassium pump

j. transport protein

k. vesicle transport

Lesson 3.3: Vocabulary II

Name___________________ **Class**______________ **Date**________

Fill in the blank with the appropriate term.

1. By moving substances into and out of cells, ____________ , the process of keeping stable conditions inside a cell, is maintained.

2. A ____________ protein changes shape as it carries ions or molecules across the membrane.

3. Exocytosis is the type of ____________ transport that moves a substance out of the cell.

4. ____________ transport is movement across the plasma membrane that does not require an input of energy.

5. The sodium-potassium ____________ is involved in the active-transport of ions.

6. Facilitated diffusion needs the help of ____________ proteins

7. ____________ refers to the number of particles of a substance per unit of volume.

8. ____________ is the type of vesicle transport that moves a substance into the cell.

9. Energy for active transport is supplied by molecules of ____________.

10. ____________ is the diffusion of water.

11. During active transport, a substance is moving from an area of ____________ concentration to an area of ____________ concentration.

12. Moving molecules in and out of the cell is an important role of the ____________.

Lesson 3.3: Critical Writing

Name___________________ Class______________ Date________

Thoroughly answer the question below. Use appropriate academic vocabulary and clear and complete sentences.

Discuss passive and active transport. Describe the main differences between these two types of transport, and provide examples of each type.