Chapter 9

Energy in a Cell

What You'll Learn

- You will recognize why organisms need a constant supply of energy and where that energy comes from.
- You will identify how cells store and release energy as ATP.
- You will describe the pathways by which cells obtain energy.
- You will compare ATP production in mitochondria and in chloroplasts.

Why It's Important

Every cell in your body needs energy in order to function. The energy your cells store is the fuel for basic body functions such as walking and breathing.

Understanding the Photo

This squirrel is eating seeds produced by the conifer. The conifer traps light energy and stores it in the bonds of certain molecules for later use. How do the squirrel's cells, which cannot trap light energy, use the molecules in the seeds to supply energy for the squirrel?

Biology Online

Visit **bdol.glencoe.com** to
- study the entire chapter online
- access Web Links for more information and activities on cell energy
- review content with the Interactive Tutor and self-check quizzes

Johann Schumacher/Peter Arnold, Inc.

Section
9.1

SECTION PREVIEW

Objectives

Explain why organisms need a supply of energy.

Describe how energy is stored and released by ATP.

Review Vocabulary

active transport: movement of materials through a membrane against a concentration gradient; requires energy from the cell (p. 199)

New Vocabulary

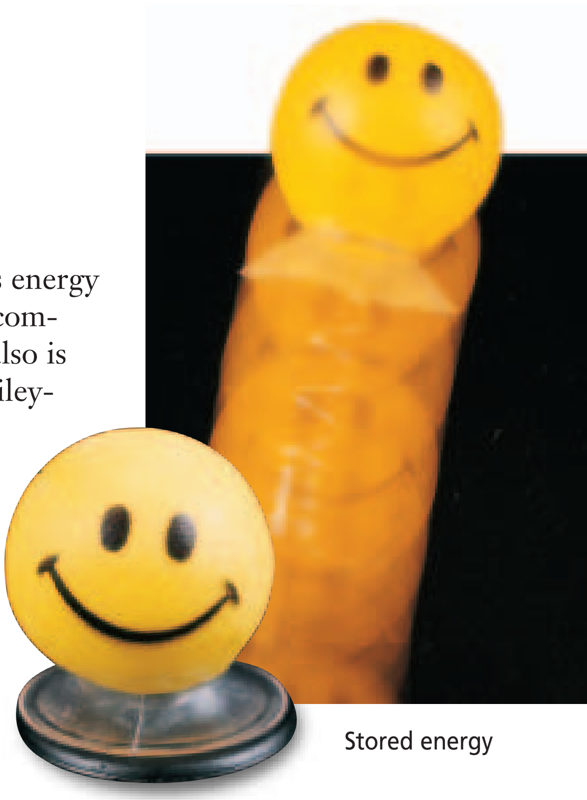
ATP (adenosine triphosphate)
ADP (adenosine diphosphate)

The Need for Energy

Why ATP?

Using an Analogy A spring stores energy when it is compressed. When the compressed spring is released, energy also is released, energy that sends this smiley-faced toy flying into the air. Like this coiled spring, chemical bonds store energy that can be released when the bond is broken. Just as some springs are tighter than others, some chemical bonds store more energy than others.

Summarize *Scan this section and make a list of general ways in which cells use energy.*



Stored energy

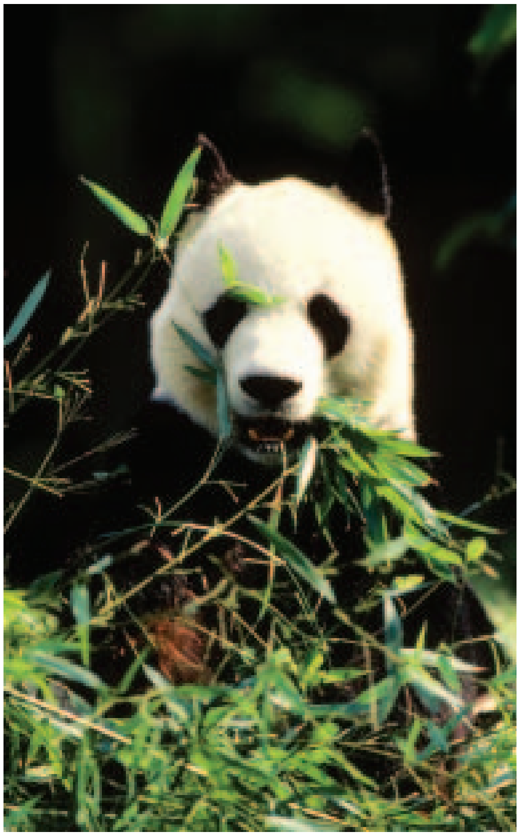


Figure 9.1
Because this panda cannot trap the sun's energy for use in its body, it eats bamboo. Molecules in bamboo leaves contain energy in their chemical bonds. Some of those molecules supply energy for the panda.

Cell Energy

Energy is essential to life. All living organisms must be able to obtain energy from the environment in which they live. Plants and other green organisms are able to trap the light energy in sunlight and store it in the bonds of certain molecules for later use. Other organisms, such as the panda shown in ***Figure 9.1***, cannot use sunlight directly. Instead, they eat green plants. In that way, they obtain the energy stored in plants.

Work and the need for energy

You've learned about several cell processes that require energy. Active transport, cell division, movement of flagella or cilia, and the production, transport, and storage of proteins are some examples. You can probably come up with other examples of biological work, such as muscles contracting during exercise, your

Problem-Solving Lab 9.1

Recognize Cause and Effect

Why is fat the choice? Humans store their excess energy as fat rather than as carbohydrates. Why is this? From an evolutionary and efficiency point of view, fats are better for storage than carbohydrates. Find out why.

Solve the Problem

The following facts compare certain characteristics of fats and carbohydrates:

A. When broken down by the body, each six-carbon molecule of fat yields 51 ATP molecules. Each six-carbon carbohydrate molecule yields 36 ATP molecules.

B. Carbohydrates bind and store water. The metabolism of water yields no ATP. Fat has no water bound to it.

C. An adult who weighs 70 kg can survive on the energy derived from stored fat for 30 days without eating. The same person would have to weigh nearly 140 kg to survive 30 days on stored carbohydrates.

Thinking Critically

1. **Analyze** From an ATP production viewpoint, use fact B to make a statement regarding the efficiency of fats vs. carbohydrates.
2. **Define Operationally** Explain why the average weight for humans is close to 70 kg and not 140 kg.

Word Origin

mono-, di-, tri- from the Latin words *mono, di,* and *tri,* meaning "one," "two," and "three," respectively; Adenosine triphosphate contains three phosphate groups.

heart pumping and your brain controlling your entire body. This work cannot be done without energy.

When you finish strenuous physical exercise, such as running cross country, your body needs a quick source of energy, so you may eat a granola bar. On a cellular level, there is a molecule in your cells that is a quick source of energy for any organelle in the cell that needs it. This energy is stored in the chemical bonds of the molecule and can be used quickly and easily by the cell.

The name of this energy molecule is **adenosine triphosphate** (uh DEH nuh seen • tri FAHS fayt), or **ATP** for short. ATP is composed of an adenosine molecule with three phosphate groups attached. Recall that phosphate groups are charged particles, and remember that particles with the same charge do not like being too close to each other.

Forming and Breaking Down ATP

The charged phosphate groups act like the positive poles of two magnets. If like poles of a magnet are placed next to each other, it is difficult to force the magnets together. Likewise, bonding three phosphate groups to form adenosine triphosphate requires considerable energy. When only one phosphate group bonds, a small amount of energy is required and the chemical bond does not store much energy. This molecule is called adenosine monophosphate (AMP). When a second phosphate group is added, more energy is required to force the two groups together. This molecule is called **adenosine diphosphate,** or **ADP.** An even greater amount of energy is required to force a third charged phosphate group close enough to the other two to form a bond. When this bond is broken, energy is released.

The energy of ATP becomes available to a cell when the molecule is broken down. In other words, when the chemical bond between the second and third phosphate groups in ATP is broken, energy is released and the resulting molecule is ADP. At this

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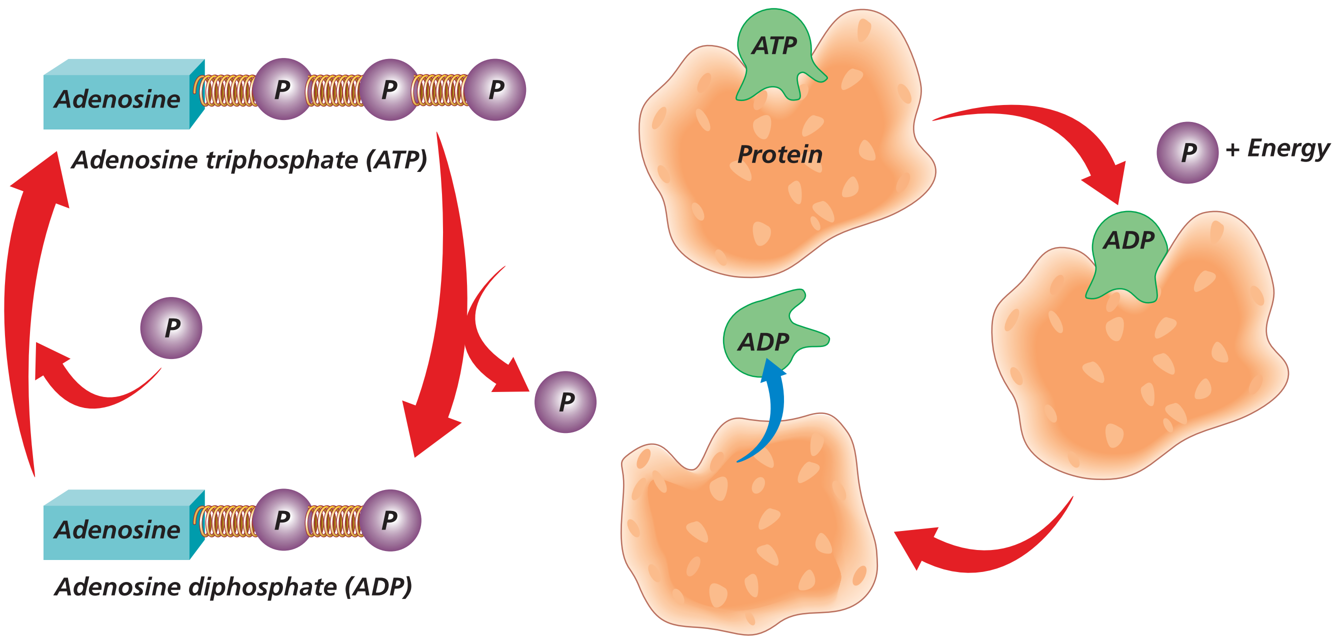
point, ADP can form ATP again by bonding with another phosphate group. This process creates a renewable cycle of ATP formation and breakdown. ***Figure 9.2A*** illustrates the chemical reactions that are involved in the cycle.

The formation/breakdown recycling activity is important because it relieves the cell of having to store all of the ATP it needs. As long as phosphate groups are available, the cell can make more ATP. Another benefit of the formation/breakdown cycle is that ADP also can be used as an energy source. Although most cell functions require the amount of energy in ATP, some cell functions do not require as much energy and can use the energy stored in ADP. Read the *Problem-Solving Lab* on the opposite page and think about how the human body stores energy.

How cells tap into the energy stored in ATP

When ATP is broken down and the energy is released, as shown in ***Figure 9.2B,*** the energy must be captured and used efficiently by cells. Otherwise, it is wasted. ATP is a small molecule. Many proteins have a specific site where ATP can bind. Then, when the phosphate bond is broken and the energy released, the cell can use the energy for activities such as making a protein or transporting molecules through the plasma membrane. This cellular process is similar to the way energy in batteries is used by a radio. Batteries sitting on a table are of little use if the energy stored within the batteries cannot be accessed. When the batteries are snapped into the holder in the radio, the radio then has access to the stored energy and can use it. When the energy in the

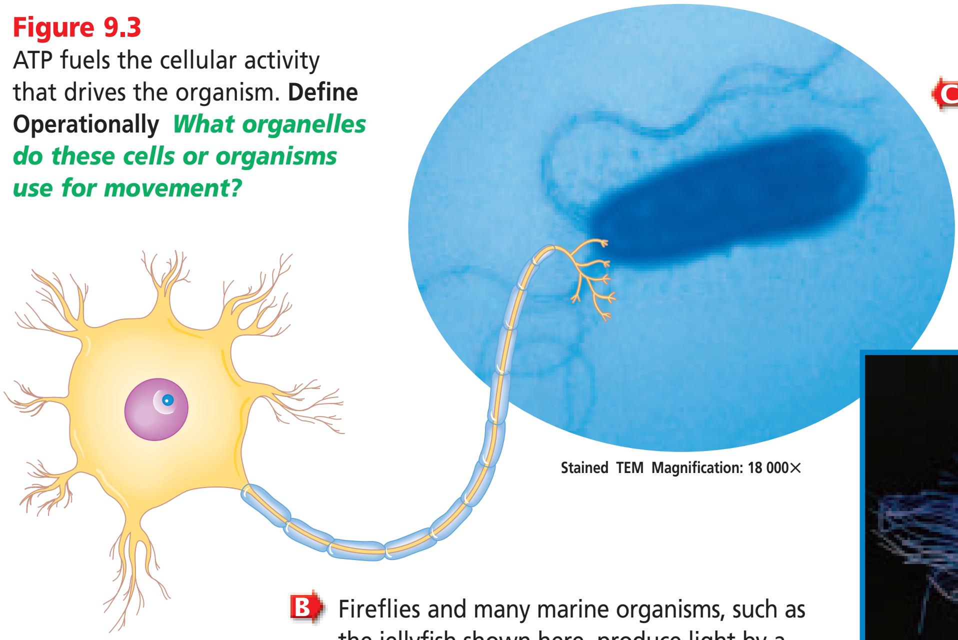
Figure 9.2
The formation and breakdown of ATP is cyclic.



A The addition and release of a phosphate group on adenosine diphosphate creates a cycle of ATP formation and breakdown.

B To access the energy stored in ATP, proteins bind ATP and uncouple the phosphate group. The ADP that is formed is released, and the protein binding site can once again bind ATP.

Figure 9.3
ATP fuels the cellular activity that drives the organism. **Define Operationally** ***What organelles do these cells or organisms use for movement?***



C Some organisms (left) use energy from ATP to move.

B Fireflies and many marine organisms, such as the jellyfish shown here, produce light by a process called bioluminescence. The light results from a chemical reaction that is powered by the breakdown of ATP.

A Nerve cells transmit impulses by using ATP to power the active transport of certain ions.

batteries has been used, the batteries can be taken out, recharged, and replaced in the holder. In a similar fashion in a cell, when ATP has been broken down to ADP, the ADP is released from the binding site in the protein and the binding site may then be filled by another ATP molecule.

Uses of Cell Energy

You can probably think of hundreds of physical activities that require energy, but energy is equally important at the cellular level.

Making new molecules is one way that cells use energy. Some of these molecules are enzymes. Other molecules build membranes and cell organelles. Cells use energy to maintain homeostasis. Kidneys use energy to move molecules and ions in order to eliminate waste substances while keeping needed substances in the bloodstream. *Figure 9.3* shows several ways that cells use energy.

Reading Check **List** three cellular activities that require energy.

Section Assessment

Understanding Main Ideas

1. Identify cellular processes that need energy from ATP.
2. How does ATP store energy?
3. How can ADP be "recycled" to form ATP again?
4. How do proteins in your cells access the energy stored in ATP?
5. List three biological activities that require energy.

Thinking Critically

6. Phosphate groups in ATP repel each other because they have negative charges. What charge might be present in the ATP binding site of a protein to attract ATP?

Skill Review

7. **Get the Big Picture** How does an animal access the energy in sunlight? For more help, refer to *Get the Big Picture* in the **Skill Handbook.**

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CONTENTS

Section

9.2

Photosynthesis: Trapping the Sun's Energy

SECTION PREVIEW

Objectives

Relate the structure of chloroplasts to the events in photosynthesis.

Describe light-dependent reactions.

Explain the reactions and products of the light-independent Calvin cycle.

Review Vocabulary

chloroplast: cell organelle that captures light energy and produces food to store for later use (p. 184)

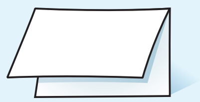
New Vocabulary

photosynthesis
light-dependent reactions
light-independent reactions
pigment
chlorophyll
electron transport chain
$NADP^+$
photolysis
Calvin cycle

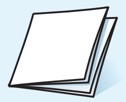
FOLDABLES Study Organizer

Photosynthesis Make the following Foldable to help you illustrate what happens during each phase of photosynthesis.

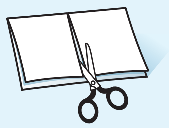
STEP 1 **Fold** a vertical sheet of paper in half from top to bottom.



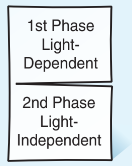
STEP 2 **Fold** in half from side to side with the fold at the top.



STEP 3 **Unfold** the paper once. **Cut** only the fold of the top flap to make two tabs.



STEP 4 **Turn** the paper vertically and **label** on the front tabs as shown.



Compare and Contrast As you read Section 9.2, compare and contrast the two phases of photosynthesis under the appropriate tab.

Trapping Energy from Sunlight

To use the energy in sunlight, the cells of green organisms must trap light energy and store it in a manner that is readily usable by cell organelles—in the chemical bonds of ATP. However, light energy is not available 24 hours a day, so the cell must also store some of the energy for use during the dark hours. The process that uses the sun's energy to make simple sugars is called **photosynthesis.** These simple sugars are then converted into complex carbohydrates, such as starches, which store energy.

Photosynthesis happens in two phases. The **light-dependent reactions** convert light energy into chemical energy. The molecules of ATP produced in the light-dependent reactions are then used to fuel the **light-independent reactions** that produce simple sugars. The general equation for photosynthesis is written as follows:

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

The *BioLab* at the end of this chapter can be performed to study what factors influence the rate of photosynthesis.

Word Origin

photosynthesis from the Greek words *photo,* meaning "light," and *syntithenai,* meaning "to put together"; Photosynthesis puts together sugar molecules using water, carbon dioxide, and energy from light.

MiniLab 9.1

Experiment

Separating Pigments

Chromatography is an important diagnostic tool. In this experiment, you will use paper chromatography to separate different pigments from plant leaves.

Procedure

1. Obtain a pre-made plant solution from your teacher.
2. Place a few drops 2 cm high on a 5-cm × 14-cm strip of filter paper. Let it dry. Make sure a small colored spot is visible.
3. Pour rubbing alcohol in a 100-mL beaker to a depth of 1 cm.
4. Place the filter paper into the beaker. The filter paper should touch the alcohol, but the dot should not. Hold it in place 15 minutes and observe what happens.

Analysis

1. **Explain** What did you observe as the solvent moved up the filter paper?
2. **Infer** Why did you see different colors at different locations on the filter paper?

Figure 9.4
The red, yellow, and purple pigments are visible in the autumn.
Recognize Cause and Effect ***Why can't you see these colors during the summer?***

The chloroplast and pigments

Recall that the chloroplast is the cell organelle where photosynthesis occurs. It is in the membranes of the thylakoid discs in chloroplasts that the light-dependent reactions take place.

To trap the energy in the sun's light, the thylakoid membranes contain **pigments,** molecules that absorb specific wavelengths of sunlight. Pigments are arranged within the thylakoid membranes in clusters known as photosystems. Although a photosystem contains several kinds of pigments, the most common is **chlorophyll.** Chlorophyll absorbs most wavelengths of light except green. Because chlorophyll cannot absorb this wavelength, it is reflected, giving leaves a green appearance. In the fall, trees stop producing chlorophyll in their leaves. Other pigments become visible, giving leaves like those in ***Figure 9.4*** a wide variety of colors. The *MiniLab* on this page will allow you to separate the pigments in a leaf. Read the *Connection to Chemistry* at the end of this chapter to find out more about biological pigments.

Light-Dependent Reactions

The first phase of photosynthesis requires sunlight. As sunlight strikes the chlorophyll molecules in a photosystem of the thylakoid membrane, the energy in the light is transferred to electrons. These highly energized, or excited, electrons are passed from chlorophyll to an **electron transport chain,** a series of proteins embedded in the thylakoid membrane. ***Figure 9.5*** summarizes this process.

Each protein in the chain passes energized electrons along to the next protein, similar to a bucket brigade in which a line of people pass a bucket of water from person to person to fight a fire. At each step along the transport chain, the electrons lose energy, just as some of the water might be spilled from buckets in the fire-fighting chain. This "lost" energy can be used to form ATP from ADP, or to pump hydrogen ions into the center of the thylakoid disc.

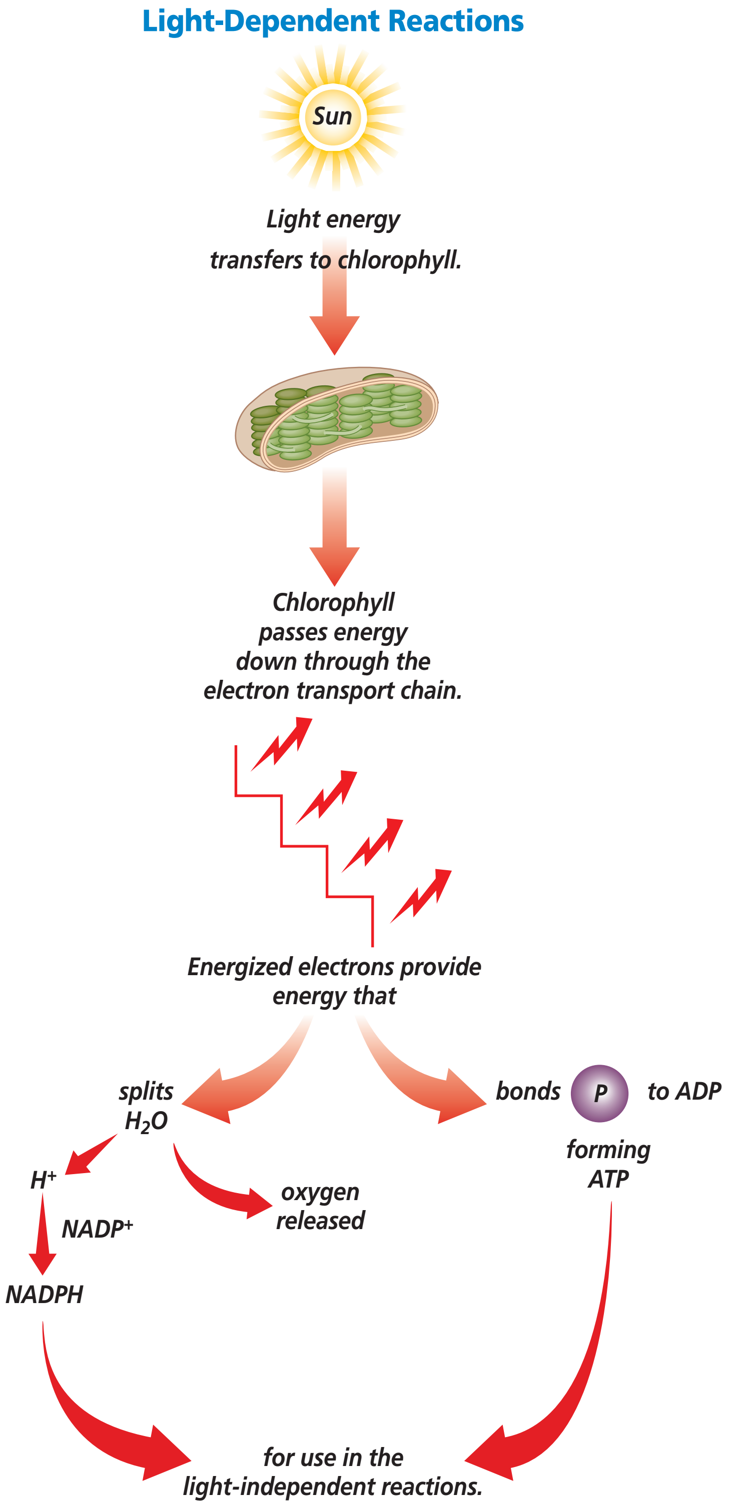
After the electrons have traveled down the electron transport chain, they are re-energized in a second photosystem and passed down a second electron transport chain. At the bottom of this chain, the electrons are still very energized. So that this energy is not wasted, the electrons are transferred to the stroma of the chloroplast. To do this, an electron carrier molecule called **$NADP^+$** (nicotinamide adenine dinucleotide phosphate) is used. $NADP^+$ can combine with two excited electrons and a hydrogen ion (H^+) to become NADPH. NADPH does not use the energy present in the energized electrons; it simply stores the energy until it can transfer it to the stroma. There, NADPH will play an important role in the light-independent reactions.

Reading Check **Explain** how energy from electrons is released.

Restoring electrons

Recall that at the beginning of photosynthesis, electrons are lost from chlorophyll molecules when light is absorbed. If these electrons are not replaced, the chlorophyll will be unable to absorb additional light and the light-dependent reactions will stop, as will the production of ATP. To replace the lost electrons, molecules of water are split in the first photosystem. This reaction is called **photolysis** (fo TAH luh sis). For every water molecule that is

Figure 9.5
Chlorophyll molecules absorb light energy and energize electrons for producing ATP and NADPH.



MiniLab 9.2

Formulate Models

van Niel

Use Isotopes to Understand Photosynthesis C. B. van Niel demonstrated that photosynthesis is a light-dependent reaction in which the O_2 comes from water. Other scientists confirmed his findings by using radioactive isotopes of oxygen as tracers. Radioactive tracers are used to follow a particular molecule through a chemical reaction.

Procedure

1. Study the following general equation that resulted from the van Niel experiment:

$$CO_2 + 2H_2O^* \rightarrow CH_2O + H_2O + O_2^*$$

2. Radioactive water, water tagged with an isotope of oxygen as a tracer (shown by the *), was used. Note where the tagged oxygen ends up on the right side of the equation.
3. Assume that the experiment was repeated, but this time a radioactive tag was put on the oxygen in CO_2.
4. Using materials provided by your teacher, model what you predict the appearance of the results would be. Your model must include a “tag” to indicate the oxygen isotope on the left side of the arrow as well as where it ends up on the right side of the arrow.
5. You also must use labels or different colors in your model to indicate what happens to the carbon and hydrogen.

Analysis

1. **Explain** How can an isotope be used as a tag?
2. **Use Models** Using your model, predict what happens to:
   - **a.** all oxygen molecules that originated from carbon dioxide.
   - **b.** all carbon molecules that originated from carbon dioxide.
   - **c.** all hydrogen molecules that originated from water.

split, one half molecule of oxygen, two electrons, and two hydrogen ions are formed, as shown in ***Figure 9.6.*** The oxygen produced by photolysis is released into the air and supplies the oxygen we breathe. The electrons are returned to chlorophyll. The hydrogen ions are pumped into the thylakoid, where they accumulate in high concentration. Because this difference in concentration forms a concentration gradient across the membrane, H^+ ions diffuse out of the thylakoid and provide energy for the production of ATP. This coupling of the movement of H^+ ions to ATP production is called chemiosmosis (keh mee oz MOH sis). The *MiniLab* on this page shows how the steps of photosynthesis were traced.

Light-Independent Reactions

The second phase of photosynthesis does not require light. It is called the **Calvin cycle,** which is a series of reactions that use carbon dioxide to form sugars. The Calvin cycle takes place in the stroma of the chloroplast, as shown in ***Figure 9.7.***

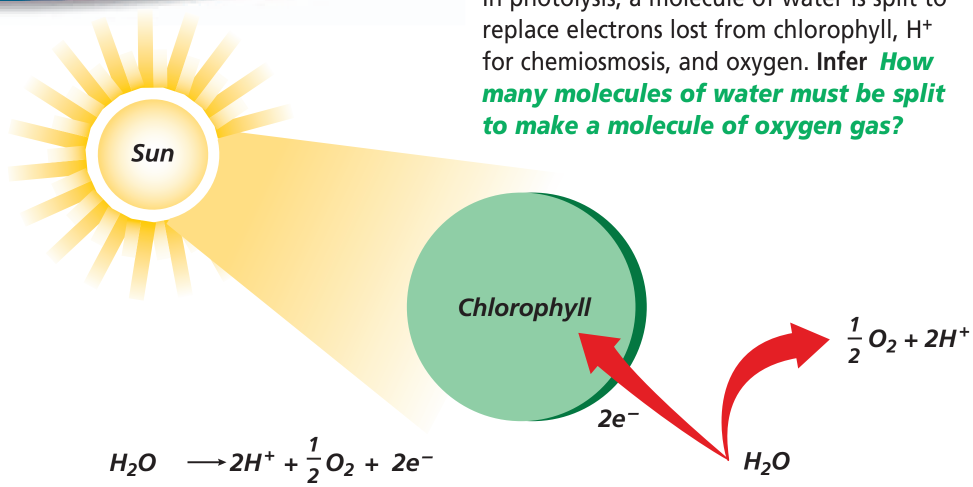


Figure 9.6
In photolysis, a molecule of water is split to replace electrons lost from chlorophyll, H^+ for chemiosmosis, and oxygen. **Infer** ***How many molecules of water must be split to make a molecule of oxygen gas?***

INSIDE STORY

The Calvin Cycle

Figure 9.7

The Calvin cycle takes the carbon in CO_2, adds it to one molecule of RuBP, and forms sugars through a series of reactions in the stroma of chloroplasts. The NADPH and ATP produced during the earlier light-dependent reactions are important molecules for this series of reactions. **Critical Thinking** ***Why is the Calvin cycle in plants directly and indirectly important to animals?***

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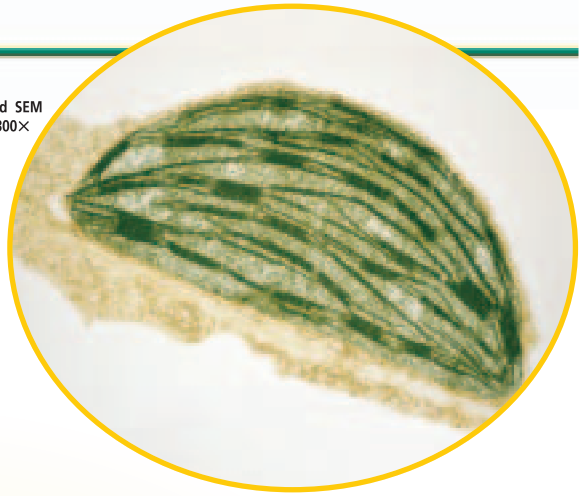
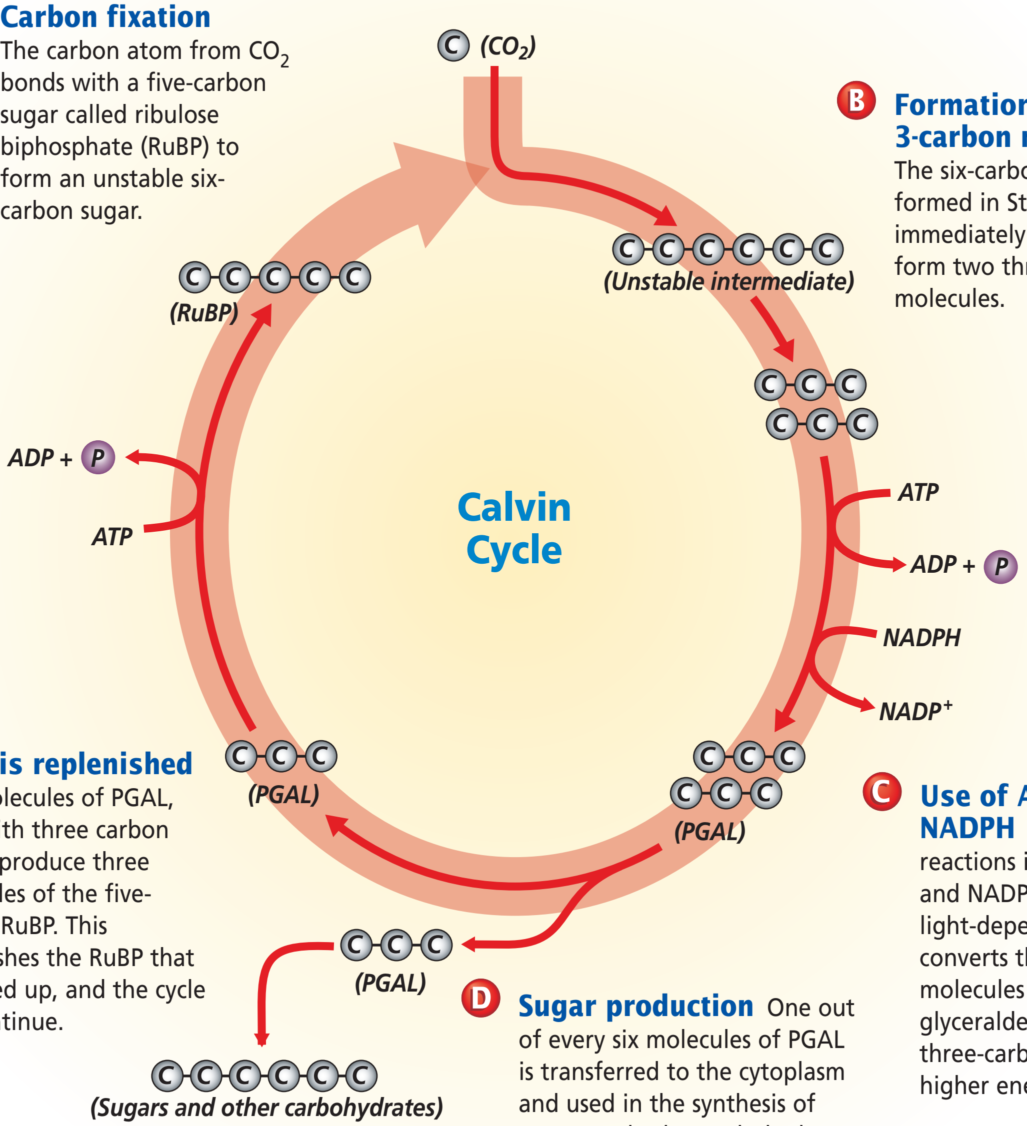


The stroma in chloroplasts hosts the Calvin cycle.



A **Carbon fixation**
The carbon atom from CO_2 bonds with a five-carbon sugar called ribulose biphosphate (RuBP) to form an unstable six-carbon sugar.

B **Formation of 3-carbon molecules**
The six-carbon sugar formed in Step A immediately splits to form two three-carbon molecules.

C **Use of ATP and NADPH** A series of reactions involving ATP and NADPH from the light-dependent reactions converts the three-carbon molecules into phosphoglyceraldehyde (PGAL), three-carbon sugars with higher energy bonds.

D **Sugar production** One out of every six molecules of PGAL is transferred to the cytoplasm and used in the synthesis of sugars and other carbohydrates. After three rounds of the cycle, six molecules of PGAL are produced.

E **RuBP is replenished**
Five molecules of PGAL, each with three carbon atoms, produce three molecules of the five-carbon RuBP. This replenishes the RuBP that was used up, and the cycle can continue.

BIOTECHNOLOGY CAREERS

Biochemist

If you are curious about what makes plants and animals grow and develop, consider a career as a biochemist. The basic research of biochemists seeks to understand how processes in an organism work to ensure the organism's survival.

Skills for the Job

A bachelor's degree in chemistry or biochemistry will qualify you to be a lab assistant. For a more involved position, you will need a master's degree; advanced research requires a Ph.D. Some biochemists work with genes to create new plants and new chemicals from plants. Others research the causes and cures of diseases or the effects of poor nutrition. Still others investigate solutions for urgent problems, such as finding better ways of growing, storing, and caring for crops.

To find out more about careers in related fields, visit bdol.glencoe.com/careers

You have learned that in the electron transport chain, an energized electron is passed from protein to protein, and the energy is released slowly. You can imagine that making a complex carbohydrate from a molecule of CO_2 would be a large task for a cell, so the light-independent reactions in the stroma of the chloroplast break down the complicated process into small steps.

The Calvin cycle

The Calvin cycle, named after Melvin Calvin, who worked out the details of the reactions, is called a cycle because one of the last molecules formed in the series of chemical reactions is also one of the molecules needed for the first reaction of the cycle. Therefore, one of the products can be used again to continue the cycle.

At the beginning of the Calvin cycle, one molecule of carbon dioxide is added to one molecule of RuBP to form a six-carbon sugar. This step is called carbon fixation because carbon is "fixed" into a six-carbon sugar. In a series of reactions, the sugar breaks down and is eventually converted to two three-carbon sugars called phosphoglyceraldehyde, or PGAL. After three rounds of the cycle, with each round fixing one molecule of CO_2, six molecules of PGAL are produced. Five of these molecules are rearranged to form three molecules of RuBP, the starting material. The sixth molecule of PGAL is available to the organism for making sugars, complex carbohydrates, and other organic compounds. As you will see in the next section, PGAL is important to all organisms because it plays a role in cellular respiration.

Section Assessment

Understanding Main Ideas

1. Why do you see green when you look at a leaf on a tree? Why do you see other colors in the fall?

2. How do the light-dependent reactions of photosynthesis relate to the Calvin cycle?

3. What is the function of water in photosynthesis? Explain the reaction that achieves this function.

4. How does the electron transport chain transfer light energy in photosynthesis?

Thinking Critically

5. In photosynthesis, is chlorophyll considered a reactant, a product, or neither? How does the role of chlorophyll compare with the roles of CO_2 and H_2O?

SKILL REVIEW

6. Get the Big Picture Identify the parts of the chloroplast in which the various steps of photosynthesis take place. For more help, refer to *Get the Big Picture* in the **Skill Handbook.**

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Section

9.3

Getting Energy to Make ATP

SECTION PREVIEW

Objectives

Compare and contrast cellular respiration and fermentation.

Explain how cells obtain energy from cellular respiration.

Review Vocabulary

mitochondria: cell organelles that transform energy for the cell (p. 185)

New Vocabulary

cellular respiration
anaerobic
aerobic
glycolysis
citric acid cycle
lactic acid fermentation
alcoholic fermentation

What happens to sugars?

Using Prior Knowledge You know that the chlorophyll in green plants is the key to photosynthesis and that sugars are produced. You also know that your body needs energy to survive. Sugars can be broken down in cells to yield large amounts of energy. But, your cells can't convert light energy to sugars. What will you do? Fortunately, the cells of all organisms can use the sugars made by plants during the Calvin cycle. By eating plant material, animals, too, can access the sun's energy.

Identify *In which organelle are sugars converted to ATP?*

Cellular Respiration

The process by which mitochondria break down food molecules to produce ATP is called **cellular respiration.** There are three stages of cellular respiration: glycolysis, the citric acid cycle, and the electron transport chain. The first stage, glycolysis, is **anaerobic**—no oxygen is required. The last two stages are **aerobic** and require oxygen to be completed.

Word Origin

anaerobic from the Greek words *an,* meaning "without," and *aeros,* meaning "air"; Anaerobic organisms can live without oxygen.

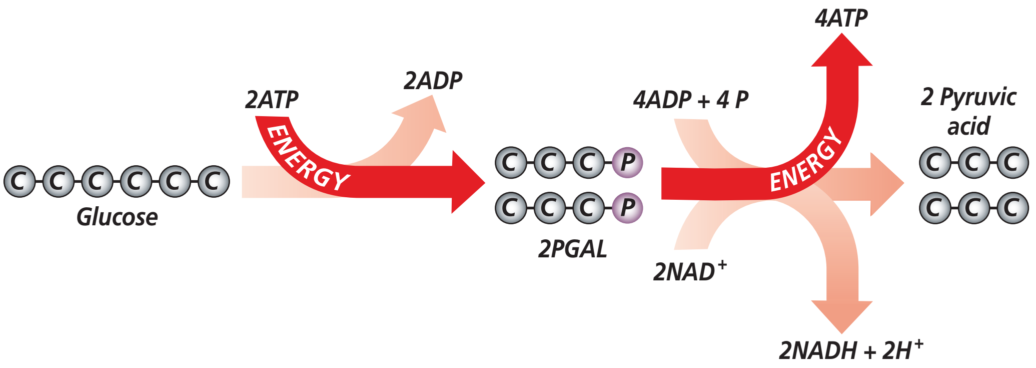
Glycolysis

Glycolysis (gli KAH lih sis) is a series of chemical reactions in the cytoplasm of a cell that break down glucose, a six-carbon compound, into two molecules of pyruvic (pie RUE vik) acid, a three-carbon compound. Because two molecules of ATP are used to start glycolysis, and only four ATP molecules are produced, glycolysis is not very effective, producing only two ATP molecules for each glucose molecule broken down.

In the electron transport chain of photosynthesis, an electron carrier called $NADP^+$ was described as carrying energized electrons to another location in the cell for further chemical reactions. Glycolysis also uses an electron carrier, called NAD^+ (nicotinamide adenine dinucleotide). NAD^+ forms NADH when it accepts two electrons.

Michael Keller/CORBIS

Figure 9.8
Glycolysis breaks down a molecule of glucose into two molecules of pyruvic acid. In the process, it forms a net of two molecules of ATP, two molecules of NADH , and two hydrogen ions.



Notice in ***Figure 9.8*** that two molecules of PGAL are formed during glycolysis. Recall that PGAL also forms in the Calvin cycle. The PGAL made during photosynthesis can enter the glycolysis pathway and lead to the formation of ATP and organic molecules.

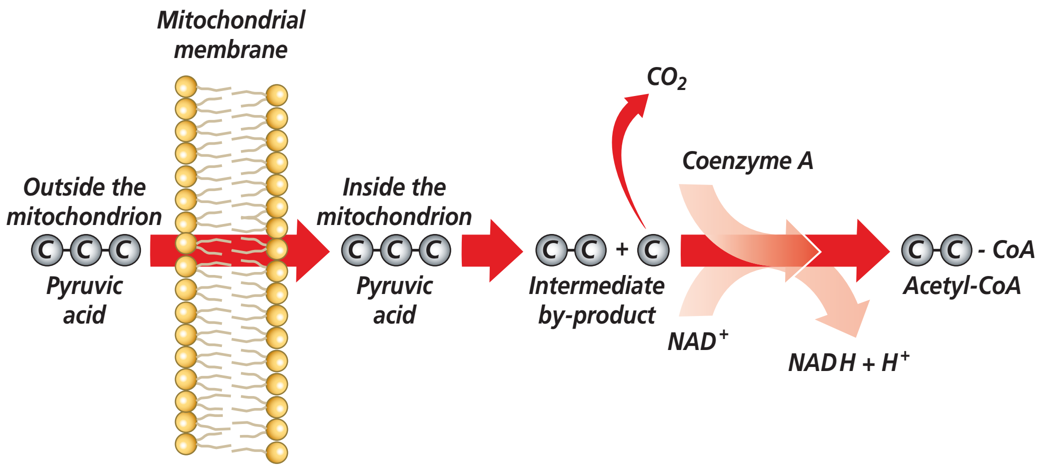
Following glycolysis, the pyruvic acid molecules move into the mitochondria, the organelles that transform energy for the cell. In the presence of oxygen, two more stages complete cellular respiration: the citric acid cycle and the electron transport chain of the mitochondrion. Before these two stages can begin, however, pyruvic acid undergoes a series of reactions in which it gives off a molecule of CO_2 and combines with a molecule called coenzyme A to form acetyl-CoA. The reaction with coenzyme A produces a molecule of NADH and H^+. These reactions are shown in ***Figure 9.9.***

The citric acid cycle

The **citric acid cycle,** also called the Krebs cycle, is a series of chemical reactions similar to the Calvin cycle in that the molecule used in the first reaction is also one of the end products. Read ***Figure 9.10*** to study the citric acid cycle.

For every turn of the cycle, one molecule of ATP and two molecules of carbon dioxide are produced. Two electron carriers are used, NAD^+ and FAD (flavin adenine dinucleotide). A total of three NADH, three H^+ ions, and one $FADH_2$ are formed. The electron carriers each pass two energized electrons along to the electron transport chain in the inner membrane of the mitochondrion.

Figure 9.9
Before the citric acid cycle and electron transport chain begin, pyruvic acid undergoes a series of reactions. **Infer** ***What products are formed as a result of the reactions within the mitochondrion?***



INSIDE STORY

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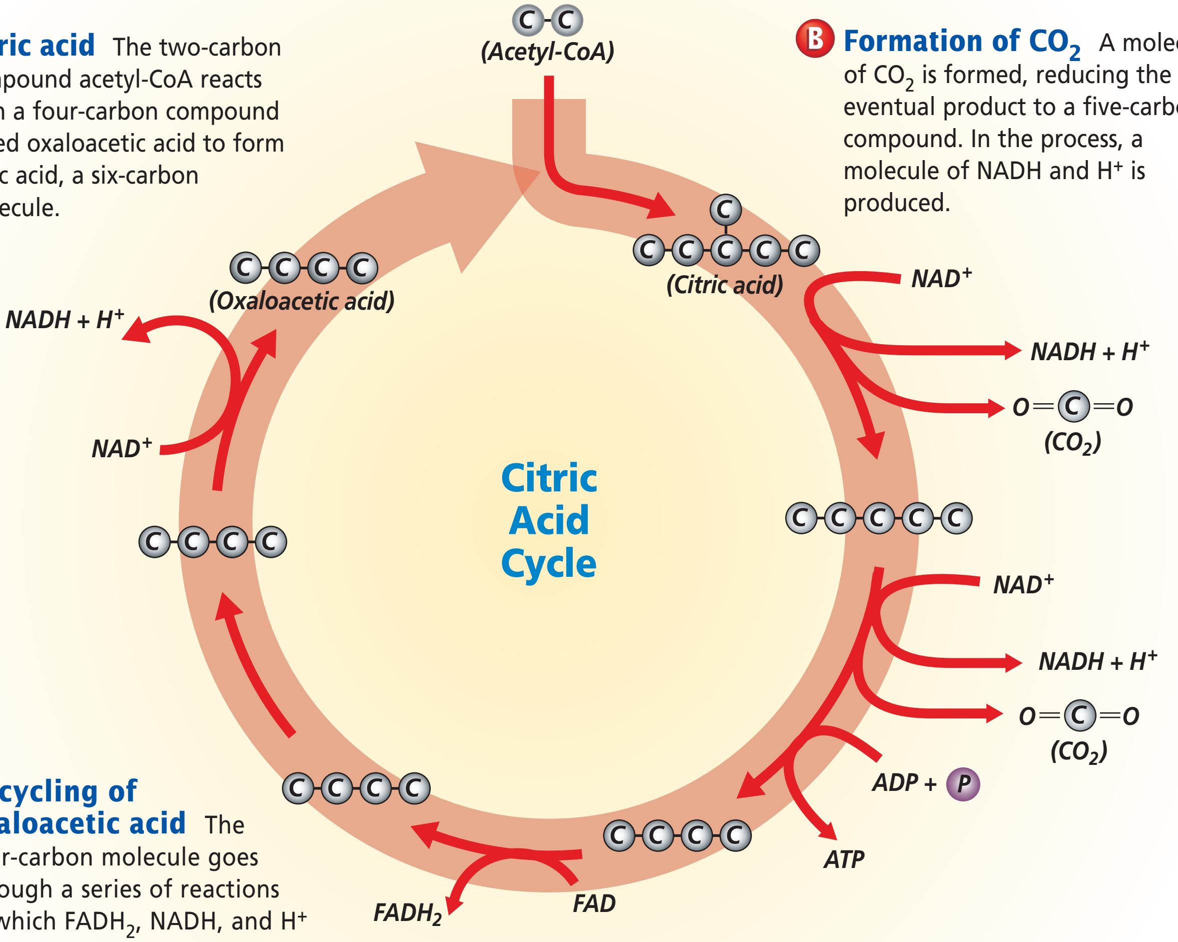
The Citric Acid Cycle

Figure 9.10
The citric acid cycle breaks down a molecule of acetyl-CoA and forms ATP and CO_2. The electron carriers NAD^+ and FAD pick up energized electrons and pass them to the electron transport chain in the inner mitochondrial membrane. **Critical Thinking** ***How many CO_2 molecules are produced for every glucose molecule that entered the cellular respiration pathways?***

The mitochondria host the citric acid cycle.

A Citric acid The two-carbon compound acetyl-CoA reacts with a four-carbon compound called oxaloacetic acid to form citric acid, a six-carbon molecule.

B Formation of CO_2 A molecule of CO_2 is formed, reducing the eventual product to a five-carbon compound. In the process, a molecule of NADH and H^+ is produced.



D Recycling of oxaloacetic acid The four-carbon molecule goes through a series of reactions in which $FADH_2$, NADH, and H^+ are formed. The carbon chain is rearranged, and oxaloacetic acid is again made available for the cycle.

C Formation of the second CO_2 Another molecule of CO_2 is released, forming a four-carbon compound. One molecule of ATP and a molecule of NADH are also produced.

Profs. P. Motta & T. Naguro/Science Photo Library/Custom Medical Stock Photo

CONTENTS

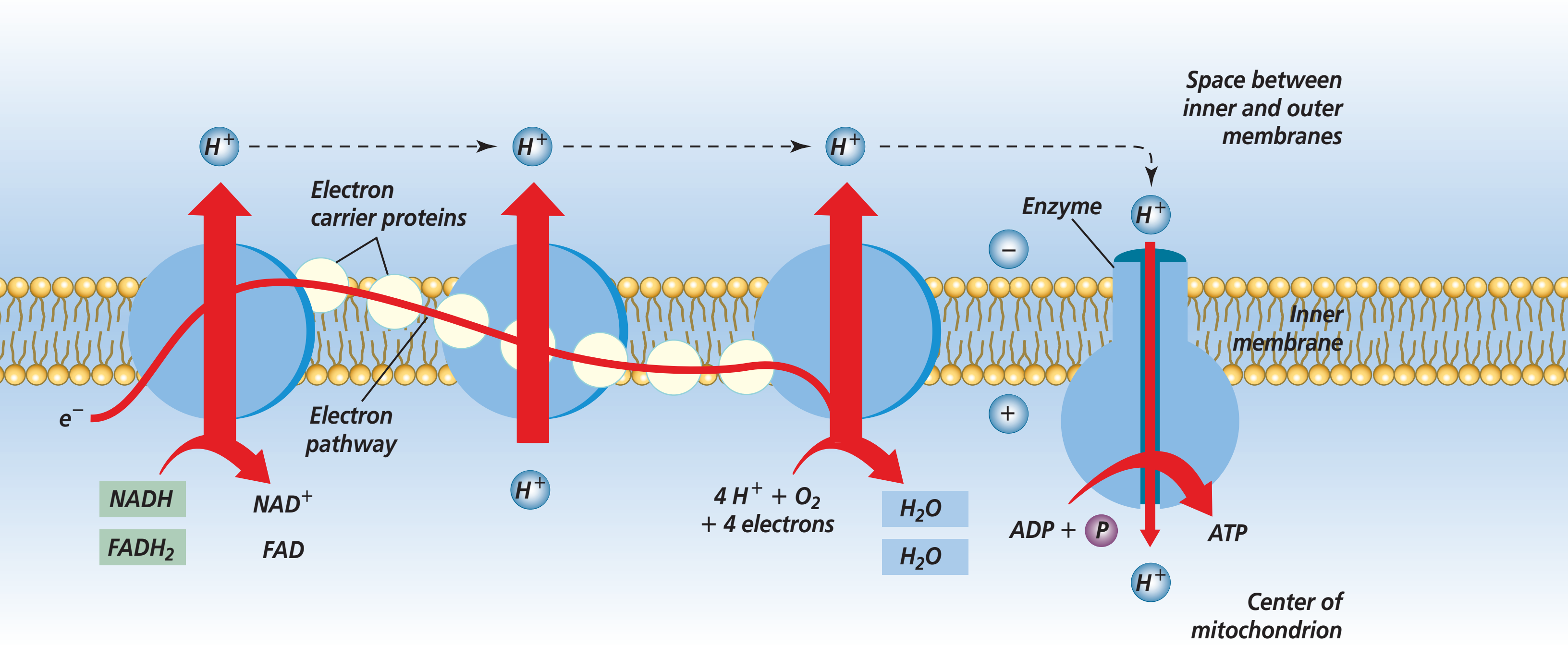


Figure 9.11
In the electron transport chain, the carrier molecules NADH and $FADH_2$ give up electrons that pass through a series of reactions. Oxygen is the final electron acceptor.

The electron transport chain

The electron transport chain in the inner membrane of the mitochondrion is very similar to the electron transport chains of the thylakoid membrane in the chloroplasts of plant cells during photosynthesis. NADH and $FADH_2$ deliver energized electrons at the top of the chain. The electrons are passed from protein to protein within the membrane, slowly releasing their energy in steps. Some of that energy is used directly to form ATP; some is used by an enzyme to pump H^+ ions into the center of the mitochondrion. Consequently, the mitochondrion inner membrane becomes positively charged because of the high concentration of positively charged hydrogen ions. At the same time, the exterior of the membrane is negatively charged, which further attracts hydrogen ions. The gradient of H^+ ions that results across the inner membrane of the mitochondrion provides the energy for ATP production, just as it does in the chemiosmotic process that takes place at the thylakoid membranes in the chloroplasts. ***Figure 9.11*** summarizes the electron transport chain and the formation of ATP.

The final electron acceptor at the bottom of the chain is oxygen, which reacts with four hydrogen ions ($4H^+$) and four electrons to form two molecules of water (H_2O). This is why oxygen is so important to our bodies. Without oxygen, the proteins in the electron transport chain cannot pass along the electrons. If a protein cannot pass along an electron to oxygen, it cannot accept another electron. Very quickly, the entire chain becomes blocked and ATP production stops.

Overall, the electron transport chain adds 32 ATP molecules to the four already produced. Obviously, the aerobic process of ATP production is very effective. In the absence of oxygen, however, an anaerobic process can produce small amounts of ATP to keep the cell from dying.

Fermentation

There are times, such as during heavy exercise, when your cells are without oxygen for a short period of time. When this happens, an anaerobic process called fermentation follows glycolysis and provides a means to continue producing ATP until oxygen is available again. There are two major types of fermentation: lactic acid fermentation and alcoholic fermentation. The table in ***Figure 9.12*** compares the two processes with respiration. Perform the *Problem-Solving Lab* shown here to further compare and contrast cellular respiration and fermentation.

✓Reading Check **Infer** when your body might perform fermentation reactions.

Lactic acid fermentation

You know that under anaerobic conditions, the electron transport chain backs up because oxygen is not present

Problem-Solving Lab 9.2

Acquire Information

Cellular respiration or fermentation? The methods by which organisms derive ATP may differ; however, the result, the production of ATP molecules, is similar.

Solve the Problem

Study the table in ***Figure 9.12*** and evaluate cellular respiration, lactic acid fermentation, and alcoholic fermentation.

Thinking Critically

1. **Describe** Why does cellular respiration produce so much more ATP than does fermentation?
2. **Use Scientific Explanations** Describe a situation when a human would need to use more than one of the processes listed above.
3. **Analyze** Think of an organism that might generate ATP only by fermentation and consider why fermentation is the best process for the organism.

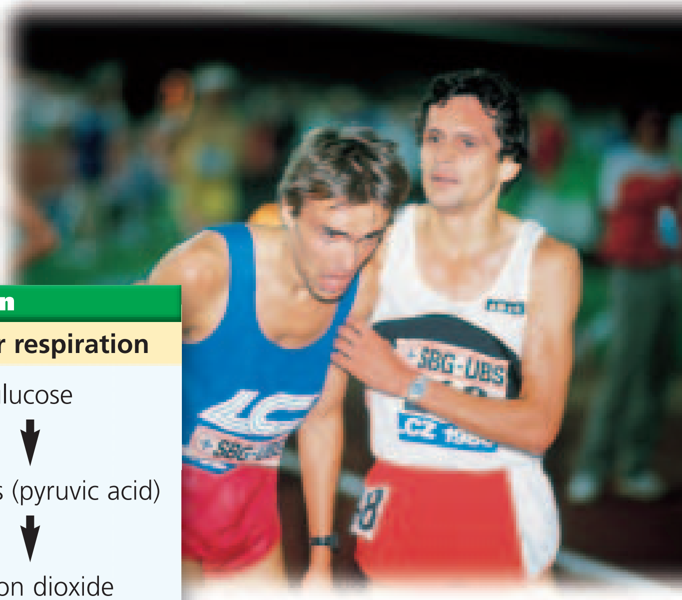


Figure 9.12
Lactic acid and alcoholic fermentations are comparable in the production of ATP, but compared to cellular respiration, it is obvious that fermentation is far less efficient in ATP production. This runner's muscles have been depleted of oxygen and fermentation is taking place.

Comparison of Fermentation to Cellular Respiration

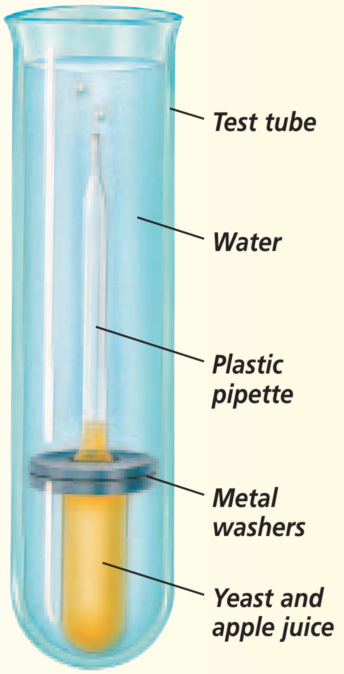
Lactic Acid	Alcoholic	Cellular respiration
glucose	glucose	glucose
↓	↓	↓
glycolysis (pyruvic acid)	glycolysis (pyruvic acid)	glycolysis (pyruvic acid)
↓	↓	↓
	carbon dioxide	carbon dioxide
	+	+
lactic acid	alcohol	water
+	+	+
2 ATP	2 ATP	36 ATP

Gerard Vandystadt/Vandystadt Agency/Photo Researchers

MiniLab 9.3

Predict

Determine if Apple Juice Ferments Some organisms, such as yeast, can break down food molecules and synthesize ATP when no oxygen is available. When food is available, yeast carry out alcoholic fermentation, producing CO_2. Thus, the production of CO_2 in the absence of oxygen can be used to judge whether alcoholic fermentation is taking place.



Procedure

1. Carefully study the diagram and set up the experiment as shown.
2. Hold the test tube in a beaker of warm (not hot) water and observe.

Analysis

1. **Interpret Data** What were the gas bubbles that came from the plastic pipette?
2. **Hypothesize** What would happen to the rate of bubbles given off if more yeast were present in the mixture?
3. **Analyze** Why was the test tube placed in warm water?
4. **Draw Conclusions** Was the process you demonstrated aerobic or anaerobic? Explain.

as the final electron acceptor. As NADH and $FADH_2$ arrive at the chain from the citric acid cycle and glycolysis, they cannot release their energized electrons. The citric acid cycle and glycolysis cannot continue without a steady supply of NAD^+ and FAD.

The cell does not have a method to replace FAD during anaerobic conditions; however, NAD^+ can be replaced through lactic acid fermentation. **Lactic acid fermentation** is one of the processes that supplies energy when oxygen is scarce. In this process, the reactions that produced pyruvic acid are reversed. Two molecules of pyruvic acid use NADH to form two molecules of lactic acid. This releases NAD^+ to be used in glycolysis, allowing two ATP molecules to be formed for each glucose molecule. The lactic acid is transferred from muscle cells, where it is produced during strenuous exercise, to the liver that converts it back to pyruvic acid. The lactic acid that builds up in muscle cells results in muscle fatigue.

Alcoholic fermentation

Another type of fermentation, **alcoholic fermentation,** is used by yeast cells and some bacteria to produce CO_2 and ethyl alcohol. When making bread, like that shown in ***Figure 9.13,*** yeast cells produce CO_2 that forms bubbles in the dough. Eventually the heat of the oven kills the yeast and the bubble pockets are left to lighten the bread. You can do the *MiniLab* on this page to study alcoholic fermentation in apple juice.

Figure 9.13
Alcoholic fermentation by the yeast in bread dough produces CO_2 bubbles that raise the dough. **Think Critically** ***What happens to the CO_2?***

Matt Meadows

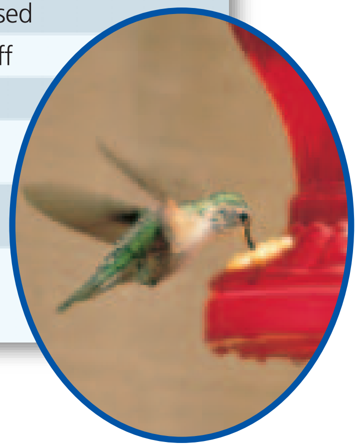
Comparing Photosynthesis and Cellular Respiration

The production and breakdown of food molecules are accomplished by distinct processes that bear certain similarities. Both photosynthesis and cellular respiration use electron carriers and a cycle of chemical reactions to form ATP. Both use electron transport chains to form ATP and to create a chemical and a concentration gradient of H^+ within a cell. This hydrogen ion gradient can be used to form ATP by chemiosmosis.

However, despite using such similar tools, the two cellular processes accomplish quite different tasks. Photosynthesis produces high-energy carbohydrates and oxygen from the sun's energy, whereas cellular respiration uses oxygen to break down carbohydrates to form ATP and compounds that provide less energy. Also, one of the end products of cellular respiration is CO_2, which is one of the beginning products for photosynthesis. The oxygen produced during photosynthesis is a critical molecule necessary for cellular respiration. ***Table 9.1*** compares these complementary processes.

Table 9.1 Comparison of Photosynthesis and Cellular Respiration

Photosynthesis	Cellular Respiration
Food synthesized	Food broken down
Energy from sun stored in glucose	Energy of glucose released
Carbon dioxide taken in	Carbon dioxide given off
Oxygen given off	Oxygen taken in
Produces sugars from PGAL	Produces CO_2 and H_2O
Requires light	Does not require light
Occurs only in presence of chlorophyll	Occurs in all living cells



Section Assessment

Understanding Main Ideas

1. Compare the ATP yields of glycolysis, the citric acid cycle, and the electron transport chain.
2. How do alcoholic fermentation and lactic acid fermentation differ?
3. How is most of the ATP from aerobic respiration produced?
4. Why is lactic acid fermentation important to the cell when oxygen is scarce?
5. How many ATP molecules are produced after the electrons go down the electron transport chain?

Thinking Critically

6. Compare the energy-producing processes in a jogger's leg muscles with those of a sprinter's leg muscles. Which is likely to build up more lactic acid? Explain.

SKILL REVIEW

7. **Get the Big Picture** How are the chemical reactions of photosynthesis and cellular respiration connected? What is the significance of this connection? For more help, refer to *Get the Big Picture* in the **Skill Handbook.**

(l)file photo, (r)George Robbins

INTERNET

BioLab

Before You Begin

Oxygen is one of the products of photosynthesis. Because oxygen is only slightly soluble in water, aquatic plants such as *Elodea* give off visible bubbles of oxygen as they carry out photosynthesis. By measuring the rate at which bubbles form, you can measure the rate of photosynthesis.

What factors influence photosynthesis?

PREPARATION

Problem

How do different wavelengths of light that a plant receives affect its rate of photosynthesis?

Objectives

In this BioLab, you will:

- **Observe** photosynthesis in an aquatic organism.
- **Measure** the rate of photosynthesis.
- **Research** the wavelengths of various colors of light.
- **Observe** how various wavelengths of light influence the rate of photosynthesis.
- **Use the Internet** to collect and compare data from other students.

Materials

1000-mL beaker
three *Elodea* plants
string
washers
colored cellophane, assorted colors
lamp with reflector and 150-watt bulb
0.25% sodium hydrogen carbonate (baking soda) solution
watch with second hand

Safety Precautions

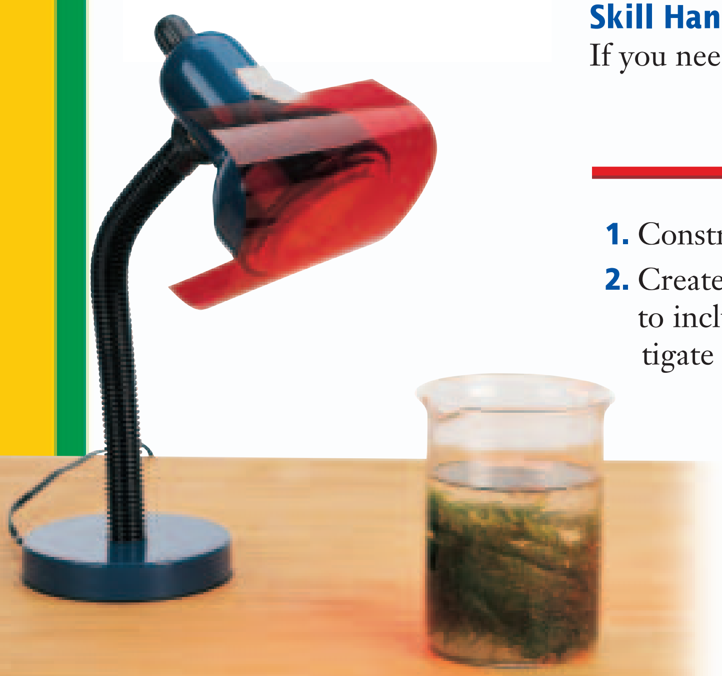
CAUTION: ***Always wear goggles in the lab.***

Skill Handbook

If you need help with this lab, refer to the **Skill Handbook.**

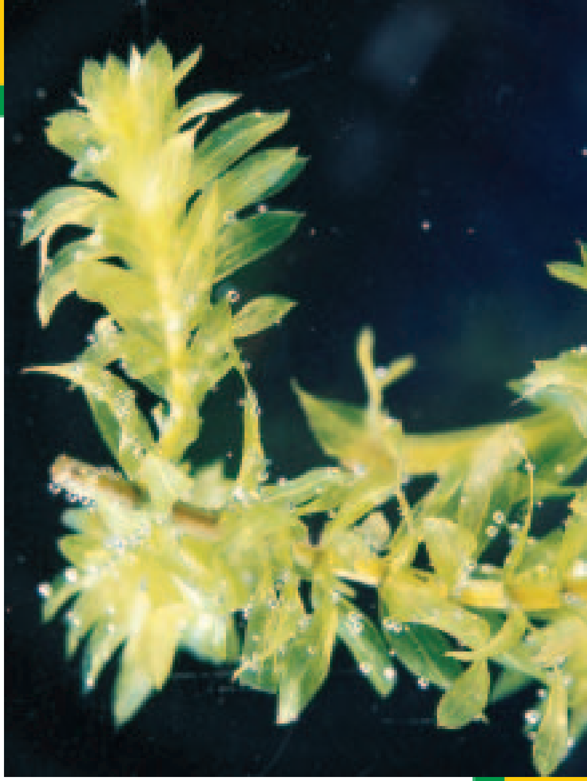
PROCEDURE

1. Construct a basic setup like the one shown here.
2. Create a data table to record your measurements. Be sure to include a column for each color of light you will investigate and a column for the control.
3. Place the *Elodea* plants in the beaker, then completely cover them with water. Add some of the baking soda solution. The solution provides CO_2 for the aquarium plants. **Be sure to use the same amount of water and solution for each trial.**



Matt Meadows

4. Conduct a control by directing the lamp (without colored cellophane) on the plant and noticing when you see the bubbles.
5. Observe and record the number of oxygen bubbles that *Elodea* generates in five minutes.
6. Cover the lamp with a piece of colored cellophane and repeat steps 4 and 5.
7. Repeat steps 4 and 5 with a different color of cellophane.
8. Go to bdol.glencoe.com/internet_lab to **post your data.**
9. **CLEANUP AND DISPOSAL** Return plant material to an aquarium to prevent it from drying out.



Data Table

	Control	Color 1	Color 2
Bubbles observed in five minutes			

ANALYZE AND CONCLUDE

1. **Interpret Observations** From where did the bubbles of oxygen emerge?
2. **Make Inferences** Explain how counting bubbles measures the rate of photosynthesis.
3. **Use the Internet** Look up the wavelengths of the colors of light you used. Make a graph of your data and data posted by other students with the rate of photosynthesis per minute plotted against the wavelengths of light you tested for both the control and experimental setups. Write a sentence or two explaining the graph.
4. **ERROR ANALYSIS** Why was it important to use the same amount of sodium hydrogen carbonate in each trial?

Share Your Data

Find this BioLab using the link below and post your data in the data table provided for this activity. Using the additional data from other students on the Internet, analyze the combined data and expand your graph.

bdol.glencoe.com/internet_lab

connection to Chemistry

Plant Pigments

In photosynthesis, light energy is converted into chemical energy. To begin the process, light is absorbed by colorful pigment molecules contained in chloroplasts.

A pigment is a substance that can absorb specific wavelengths of visible light. You can observe the colors of the various wavelengths of light by letting sunlight pass through a prism to create a "rainbow," or spectrum, that has red light on one end, violet on the other, and orange, yellow, green, blue, and indigo light in between.

Every photosynthetic pigment is distinctive in that it absorbs specific wavelengths in the visible light spectrum.

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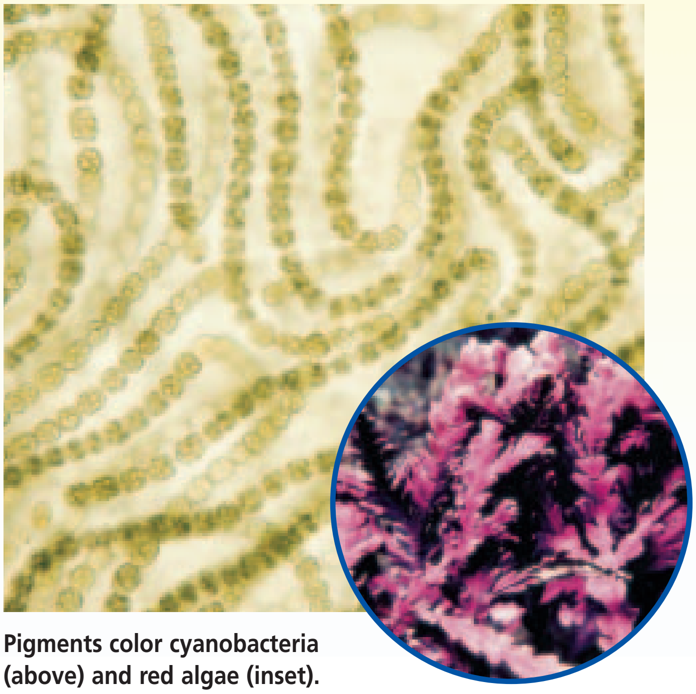


Pigments color cyanobacteria (above) and red algae (inset).

Chlorophylls *a* and *b* The principal pigment of photosynthesis is chlorophyll. Chlorophyll exists in two forms, designated as *a* and *b*. Chlorophyll *a* and *b* both absorb light in the violet to blue and the red to red-orange parts of the spectrum, although at somewhat different wavelengths. These pigments also reflect green light, which is why plant leaves appear green.

When chlorophyll *b* absorbs light, it transfers the energy it acquires to chlorophyll *a*, which then feeds that energy into the chemical reactions that lead to the production of ATP and NADPH. In this way, chlorophyll *b* acts as an "accessory" pigment by making it possible for photosynthesis to occur over a broader spectrum of light than would be possible with chlorophyll *a* alone.

Carotenoids and phycobilins Carotenoids and phycobilins are other kinds of accessory pigments that absorb wavelengths of light different from those absorbed by chlorophyll *a* and *b*, and so extend the range of light that can be used for photosynthesis.

Carotenoids are yellow-orange pigments. They are found in all green plants, but their color is usually masked by chlorophyll. Carotenoids are also found in cyanobacteria and in brown algae. A particular carotenoid called fucoxanthin gives brown algae their characteristic dark brown or olive green color.

Phycobilins are blue and red. Red algae get their distinctive blood-red coloration from phycobilins. Some phycobilins can absorb wavelengths of green, violet, and blue light, which penetrate deep water. One species of red algae that contains these pigments is able to live at ocean depths of 269 meters (884 feet). The algae's pigments absorb enough of the incredibly faint light that penetrates to this depth—only a tiny percent of what is available at the water's surface—to power photosynthesis.

Writing About Biology

Think Critically How do you think accessory pigments may have influenced the spread of photosynthetic organisms into diverse habitats such as the deep sea?

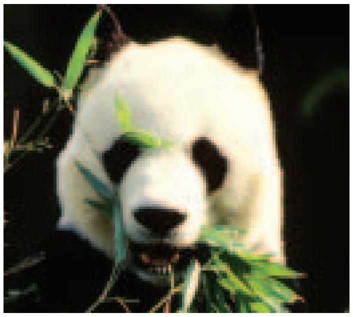
To find out more about pigments, visit **bdol.glencoe.com/chemistry**

Chapter 9 Assessment

Study Guide

Section 9.1

The Need for Energy



Key Concepts

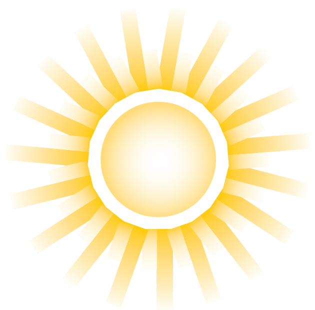
- ATP is the molecule that stores energy for easy use within the cell.
- ATP is formed when a phosphate group is added to ADP. When ATP is broken down, ADP and phosphate are formed and energy is released.
- Green organisms trap the energy in sunlight and store it in the bonds of certain molecules for later use.
- Organisms that cannot use sunlight directly obtain energy by consuming plants or other organisms that have consumed plants.

Vocabulary

(ADP) adenosine diphosphate (p. 222)
(ATP) adenosine triphosphate (p. 222)

Section 9.2

Photosynthesis: Trapping the Sun's Energy



Key Concepts

- Photosynthesis is the process by which cells use light energy to make simple sugars.
- Chlorophyll in the chloroplasts of plant cells traps light energy needed for photosynthesis.
- The light reactions of photosynthesis produce ATP and result in the splitting of water molecules.
- The reactions of the Calvin cycle make carbohydrates using CO_2 along with ATP and NADPH from the light reactions.

Vocabulary

Calvin cycle (p. 228)
chlorophyll (p. 226)
electron transport chain (p. 226)
light-dependent reactions (p. 225)
light-independent reactions (p. 225)
$NADP^+$ (p. 227)
photolysis (p. 227)
photosynthesis (p. 225)
pigment (p. 226)

Section 9.3

Getting Energy to Make ATP

Key Concepts

- In cellular respiration, cells break down carbohydrates to release energy.
- The first stage of cellular respiration, glycolysis, takes place in the cytoplasm and does not require oxygen.
- The citric acid cycle takes place in mitochondria and requires oxygen.

Vocabulary

aerobic (p. 231)
alcoholic fermentation (p. 236)
anaerobic (p. 231)
cellular respiration (p. 231)
citric acid cycle (p. 232)
glycolysis (p. 231)
lactic acid fermentation (p. 236)

FOLDABLES Study Organizer — To help you review photosynthesis and cellular respiration, use the Organizational Study Fold on page 225.

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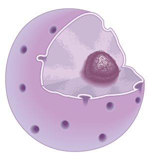
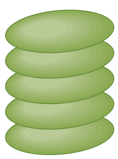
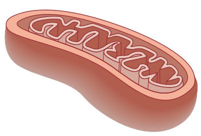
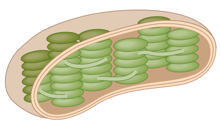
Chapter 9 Assessment

Vocabulary Review

Review the Chapter 9 vocabulary words listed in the Study Guide on page 241. For each set of vocabulary words, choose the one that does not belong. Explain why it does not belong.

1. light-dependent reactions—Calvin cycle—chlorophyll
2. glycolysis—alcoholic fermentation—aerobic
3. $NADP^+$—chlorophyll—pigment
4. photolysis—Calvin cycle—light-dependent reactions
5. cellular respiration—citric acid cycle—photosynthesis

Understanding Key Concepts

6. Which of the following is a product of the Calvin cycle?
   A. carbon dioxide
   B. $NADP^+$
   C. oxygen
   D. $FADH_2$
7. ________ processes require oxygen, whereas ________ processes do not.
   A. Anaerobic—aerobic
   B. Aerobic—anaerobic
   C. Photolysis—aerobic
   D. Aerobic—respiration
8. Four molecules of glucose would give a net yield of ________ ATP following glycolysis.
   A. 8 **C.** 4
   B. 16 **D.** 12
9. In which of the following structures do the light-independent reactions of photosynthesis take place?
   A. 
   C. 
   B. 
   D. 
10. What is the first process in an animal cell to be affected by anaerobic conditions?
    A. citric acid cycle
    B. fermentation
    C. glycolysis
    D. electron transport chain
11. In which stage of cellular respiration is glucose broken down into two molecules of pyruvic acid?
    A. Calvin cycle
    B. glycolysis
    C. citric acid cycle
    D. electron transport chain
12. Which of the following is a similarity between the citric acid cycle and the Calvin cycle?
    A. Both cycles utilize oxygen.
    B. Both cycles produce carbon dioxide.
    C. Both cycles utilize ATP to break down carbon bonds.
    D. Both cycles recycle the molecule needed for the first reaction.
13. When yeast ferments the sugar in a bread mixture, what is produced that causes the bread dough to rise?
    A. carbon dioxide **C.** ethyl alcohol
    B. water **D.** oxygen

Constructed Response

14. **Open Ended** Why would human muscle cells contain many more mitochondria than skin cells?
15. **Open Ended** How are cellular respiration and photosynthesis complementary processes?
16. **Open Ended** What happens to sunlight that strikes a leaf but is not trapped by chlorophyll?

Thinking Critically

17. **Sequence** Describe the pathway of electrons from the time they enter the intermembrane space of the mitochondrion to the time they are returned to the inside of the mitochondrion.

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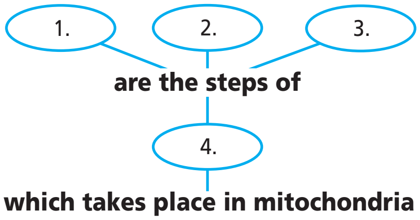
Chapter 9 Assessment

18. **Concept Map** Make a concept map using the following vocabulary terms: cellular respiration, glycolysis, citric acid cycle, electron transport chain.



19. **REAL WORLD BIOCHALLENGE** Muscle tissue is made of different types of fibers—fast-twitch and slow-twitch. These fibers vary in metabolic activities. Visit **bdol.glencoe.com** to find out about the various types of muscle fibers. How do the metabolic activities of these fibers vary? What types of fibers are used for different movements and why?

Standardized Test Practice

All questions aligned and verified by The Princeton Review

Part 1 Multiple Choice

Study the table and answer questions 20–23.

The following experimental data was collected by placing equal amounts of various plant parts in sealed containers and exposing them to various light colors. After eight hours in the container, the increase in oxygen was measured in the container.

Rate of Photosynthesis

Container	Plant	Plant Part	Light Color	Temperature (°C)	Increase in O_2 (mL)
1	Geranium	Leaf	Red	22	120
2	Geranium	Leaf	Green	22	15
3	Geranium	Root	Red	22	0
4	Violet	Leaf	Red	22	80
5	Violet	Leaf	Green	22	10

20. One could compare the amount of oxygen produced in eight hours at two different light colors by comparing ________.
A. 1 and 3 **C.** 1 and 5
B. 2 and 4 **D.** 1 and 2

21. In which container was photosynthesis taking place at the fastest rate?
A. 1 **C.** 3
B. 2 **D.** 4

22. In which container was photosynthesis not occurring?
A. 1 **C.** 3
B. 2 **D.** 4

23. According to the data, which variable determined whether or not photosynthesis occurred?
A. plant **C.** temperature
B. light color **D.** plant part

Part 2 Constructed Response/Grid In

Record your answers on your answer document.

24. **Open Ended** Compare the energy storage in photosynthesis to the energy storage in cellular respiration.

25. **Open Ended** Compare alcoholic fermentation and lactic acid fermentation in terms of starting and ending material and ATP production.

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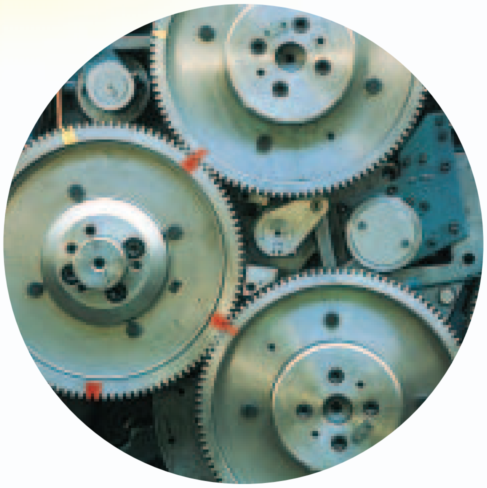
CONTENTS

BioDigest

UNIT 3 REVIEW

The Life of a Cell

All organisms are made of cells, and each cell is like a complex, self-contained machine that can perform life functions. Yet as small as they are, all of the mechanisms and processes of these little machines are not fully known, and scientists continue to unravel the marvelous mysteries of the living cell.



Cells are microscopic machines.

The Chemistry of Life

Although you are studying biology, chemistry is fundamental to all biological functions. Understanding some of the basic concepts of chemistry will enhance your understanding of the biological world.

Elements and Atoms

Every substance in and on Earth is composed of one or more kinds of elements. An atom, the smallest component of an element, is made of even smaller particles called electrons, protons, and neutrons. Atoms react to form compounds.

VITAL STATISTICS

Carbon Isotopes

Isotopes of carbon contain different numbers of neutrons.

Carbon-12: six protons and six neutrons
Carbon-13: six protons and seven neutrons
Carbon-14: six protons and eight neutrons

FOCUS ON HISTORY

The Cell Theory

LM Magnification: 100×

Van Leeuwenhoek might have viewed microorganisms like these found in a droplet of pond water.

In the 1600s, Anton van Leeuwenhoek was the first person to view living organisms through a microscope. Another scientist, Robert Hooke, named the structures *cells.* Two hundred years later, several scientists, including Matthias Schleiden, Theodor Schwann, and Rudolf Virchow continued to study animal and plant tissues under the microscope. Conclusions from many scientists were combined to form the cell theory:

1. All organisms are composed of one or more cells.
2. The cell is the basic unit of organization of organisms.
3. All cells come from preexisting cells.

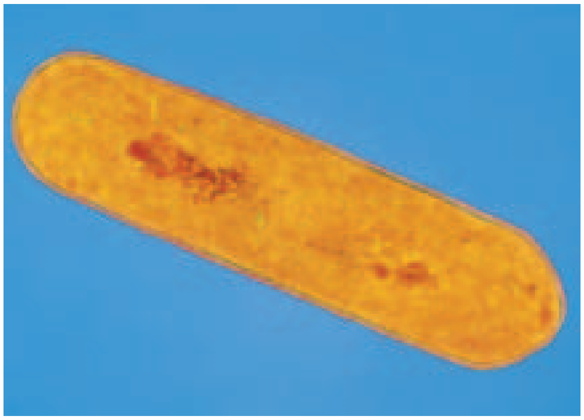
Organic Compounds

Carbohydrates are chemical compounds made of carbon, hydrogen, and oxygen. Common carbohydrates include sugars, starches, and cellulose. Lipids, known as fats and oils, contain a glycerol backbone and three fatty acid chains. Proteins are large molecules made of amino acids connected by peptide bonds. Enzymes are proteins that change the rates of chemical reactions. Nucleic acids such as DNA and RNA are complex biomolecules that store cellular information in the form of a code.

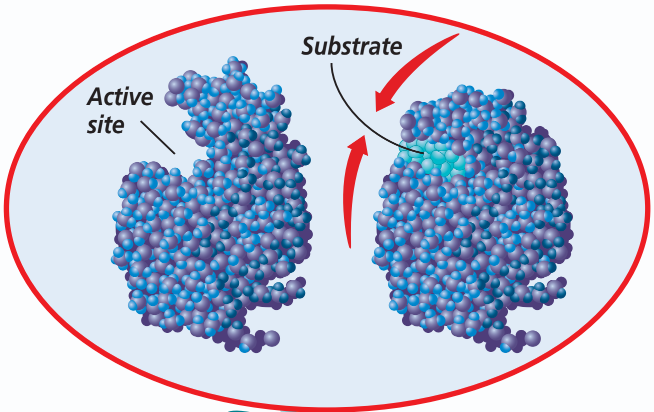
Eukaryotes and Prokaryotes

All cells are surrounded by a plasma membrane. Eukaryotic cells contain membrane-bound organelles within the cell. Cells without internal membrane-bound organelles are called prokaryotic cells.

Color-enhanced TEM Magnification: 41 150×

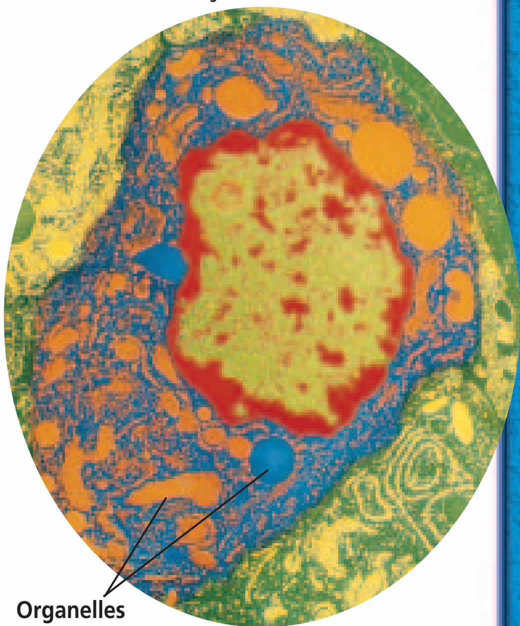


A prokaryotic cell does not contain membrane-bound organelles.

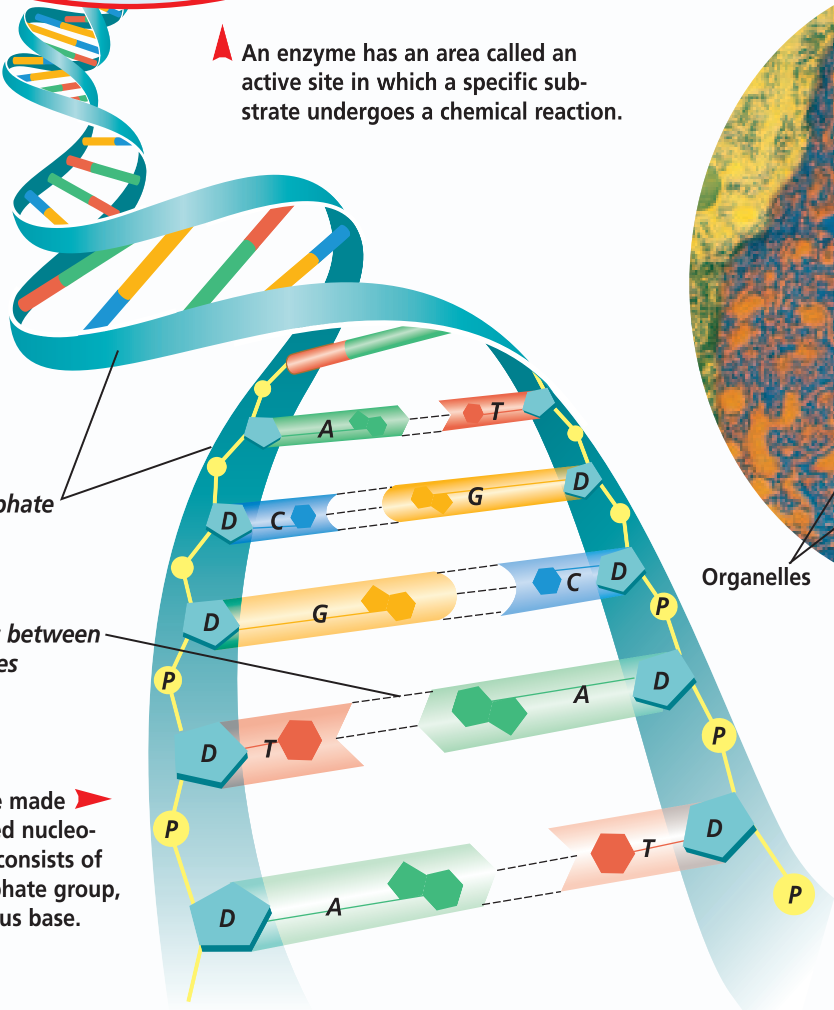


An enzyme has an area called an active site in which a specific substrate undergoes a chemical reaction.

Color-enhanced TEM Magnification: 4800×



A eukaryotic cell contains membrane-bound organelles.



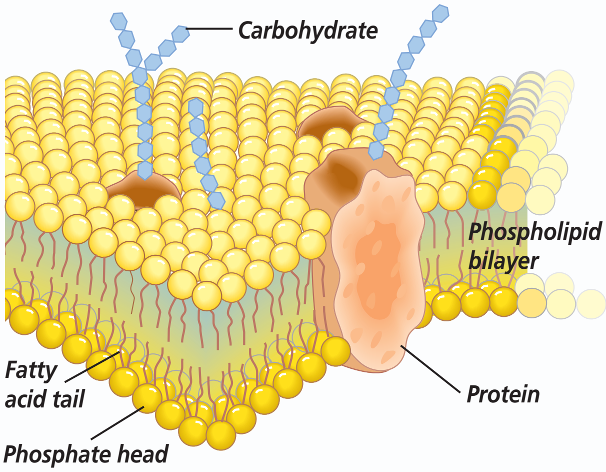
Nucleic acids are made of subunits called nucleotides. Each one consists of a sugar, a phosphate group, and a nitrogenous base.

Cell Organelles

The organelles of a cell work together to carry out the functions necessary for cell survival.

Gateway to the Cell

According to the fluid mosaic model, the plasma membrane is formed by two layers of phospholipids with the fatty acid chains facing each other; the phosphate groups face the cell's internal and external environments, and proteins are embedded in the membrane.



The plasma membrane is composed of a lipid bilayer with embedded proteins.

Control of Cell Functions

The nucleus contains the master plans for proteins, which are then produced by organelles called ribosomes. The nucleus also controls cellular functions.

Assembly, Transport, and Storage

The cytoplasm suspends the cell's organelles, including endoplasmic reticulum, Golgi apparatus, vacuoles, and lysosomes. The endoplasmic reticulum and Golgi apparatus transport and modify proteins.

Energy Transformers

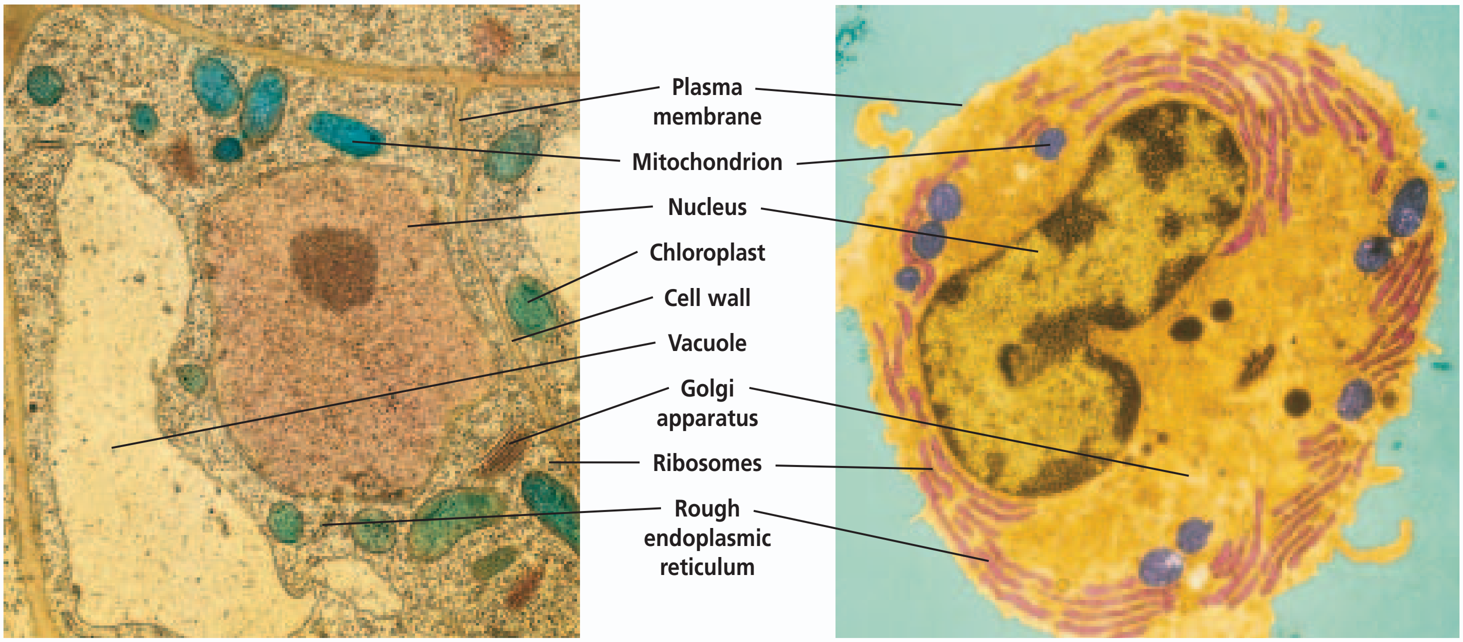
Chloroplasts are found in plant cells. They capture the sun's light energy so it can be transformed into useable chemical energy. Mitochondria are found in both animal and plant cells. They transform the food you eat into a useable energy form.

Support and Locomotion

A network of microfilaments and microtubules attach to the plasma membrane to give the cell structure. Cilia are short, numerous projections that move like the oars of a boat. Flagella are longer projections that move in a whiplike fashion to propel a cell.

Plant cell

Animal cell



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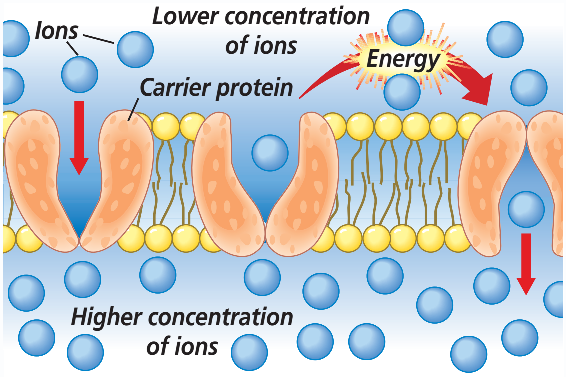
Diffusion and Osmosis

The selectively permeable plasma membrane allows only certain substances to cross. Diffusion is the movement of a substance from an area of higher concentration to an area of lower concentration. Diffusion of water across a selectively permeable membrane is called osmosis.

Simple diffusion occurs by random movement of molecules or ions. In facilitated diffusion, proteins bind to and move molecules across a membrane. Active transport uses energy to move molecules against a concentration gradient.



Active transport

Vital Statistics

Cellular Environments

Isotonic solution: same number of dissolved substances inside and outside the cell
Hypotonic solution: more dissolved substances inside the cell; water enters the cell
Hypertonic solution: fewer dissolved substances inside the cell; water leaves the cell

Energy in a Cell

Adenosine triphosphate (ATP) is the most common energy source in a cell. Two organelles help form ATP from other sources of energy.

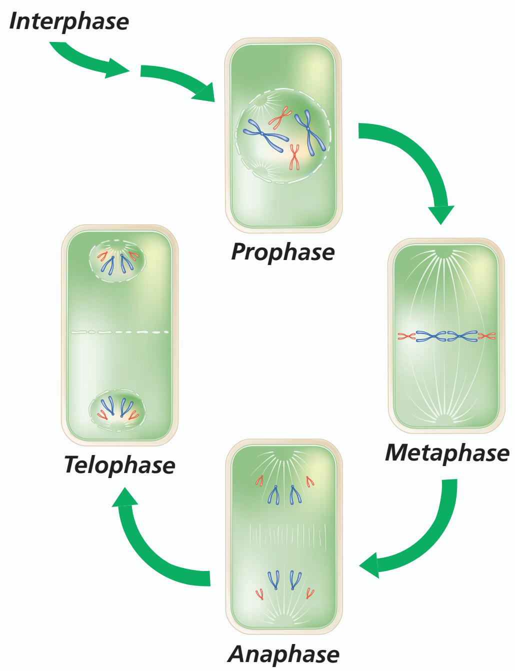
Chloroplasts in plant cells convert energy from the sun's rays into ATP using light-dependent reactions and store that energy in sugars via light-independent reactions and the Calvin cycle.

Mitochondria in both plant and animal cells convert food energy into ATP through a series of chemical reactions including glycolysis, the citric acid cycle, and the electron transport chain.

Mitosis

As cells grow, they reach a size where the plasma membrane cannot transport enough nutrients and wastes to maintain cell growth. At this point, the cell undergoes mitosis and divides.

The period prior to mitosis, called interphase, is one of intense metabolic activity. The first stage of mitosis is prophase, when the duplicated chromosomes condense and the mitotic spindle forms. The chromosomes line up in the center of the cell during metaphase and slowly separate during anaphase. In telophase the nucleus divides followed by cytokinesis, which separates the daughter cells.



During the stages of mitosis, chromosomes are separated into two daughter cells.

Vital Statistics

ATP production for each molecule of glucose

Glycolysis: produces a net gain of two ATP, two NADH, and two H^+
Citric acid cycle (Krebs cycle): produces two ATP, six NADH, and two $FADH_2$
Electron transport chain: produces 32 ATP from NADH and $FADH_2$
Lactic acid fermentation: produces two ATP and lactic acid

Standardized Test Practice

The Princeton Review

TEST-TAKING TIP

When Eliminating, Cross It Out

List the answer choice letters on scratch paper and, with your pencil, cross out choices you've eliminated. You'll stop yourself from choosing an answer you've mentally eliminated.

Part 1 Multiple Choice

Use the table below to answer questions 1–3.

Chromosome Comparison of Four Organisms				
Organism	Human	Rye	Potato	Guinea pig
Number of chromosomes in body cells	46	14	48	64
Number of chromatids during metaphase	92	A	96	128
Number of chromosomes in daughter cells	46	14	48	64

1. What number belongs in the space labeled *A* under "Rye" in the table?
- **A.** 14
- **B.** 28
- **C.** 7
- **D.** 21

2. If one pair of chromatids failed to separate during mitosis in rye cells, how many chromosomes would end up in the two daughter cells?
- **A.** 28 and 28
- **B.** 14 and 14
- **C.** 7 and 8
- **D.** 13 and 15

3. What is the relationship between the number of chromosomes in body cells and the complexity of an organism?
- **A.** The more complex the organism, the more chromosomes it has.
- **B.** The more complex the organism, the fewer chromosomes it has.
- **C.** There is no relationship.
- **D.** The number of chromosomes is determined by the sex of the organism.

4. The isotopes of the element magnesium differ in their number of ________.
- **A.** proteins
- **B.** electrons
- **C.** neutrons
- **D.** protons

5. Which of the following organelles are found in all cells?
- **A.** plasma membrane and ribosomes
- **B.** mitochondria and chloroplasts
- **C.** microtubules and lysosomes
- **D.** Golgi apparatus and endoplasmic reticulum

6. During late interphase, the chromosomes double to form chromatids that are attached to each other. During which phase of mitosis do the chromatids separate?
- **A.** prophase
- **B.** metaphase
- **C.** anaphase
- **D.** telophase

7. Plants must have a constant supply of ________ for photosynthesis, but they provide ________ for cellular respiration.
- **A.** water—carbon dioxide
- **B.** carbon dioxide—water
- **C.** carbon dioxide—oxygen
- **D.** oxygen—water

8. Which type of bond involves the sharing of electrons?
- **A.** covalent
- **B.** ionic
- **C.** hydrogen
- **D.** electrostatic

9. The primary organelle used for storing information in a cell is the ________.
- **A.** cell wall
- **B.** endoplasmic reticulum
- **C.** mitochondria
- **D.** nucleus

10. A biologist studies cells under a microscope that have been drawn from an unknown solution. The cells appear shriveled. What can the biologist conclude about the solution?
- **A.** It is hypotonic.
- **B.** It is isotonic.
- **C.** It is hypertonic.
- **D.** It is polar.

11. Which helps capture the sun's energy?
- **A.** light-dependent reactions
- **B.** citric acid cycle
- **C.** Calvin cycle
- **D.** light-independent reactions

Use the word equation below to answer questions 12–14.

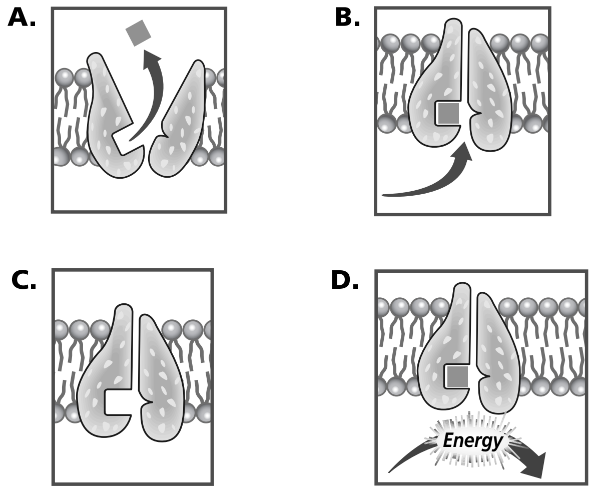
sucrose + water → glucose + fructose

12. The reaction above illustrates the ________.
- **A.** hydrolysis of sucrose
- **B.** condensation of sucrose
- **C.** hydrolysis of glucose
- **D.** condensation of fructose

13. The product(s) of this reaction is/are ________.
- **A.** sucrose
- **B.** water
- **C.** glucose and fructose
- **D.** sucrose and water

14. Glucose and fructose are ________.
- **A.** disaccharides
- **B.** polysaccharides
- **C.** monosaccharides
- **D.** starches

Use the figure below to answer questions 15–17.



15. The illustrations above demonstrate the transport of an ion across the plasma membrane, but they are out of sequence. In what order do they belong?
- **A.** D-C-B-A
- **B.** A-B-D-C
- **C.** C-B-D-A
- **D.** A-D-B-C

16. What statement is true about diagram D?
- **A.** The ion movement is random.
- **B.** Energy is required.
- **C.** The fatty acids in the plasma membrane could also move apart to allow the ion through.
- **D.** The concentration of ions is higher at the top of diagram D than at the bottom.

17. Which process is best represented by these diagrams?
- **A.** diffusion
- **B.** active transport
- **C.** endocytosis
- **D.** passive transport

Part 2 Constructed Response/Grid In

Record your answers on your answer document.

18. Open Ended How is an ionic bond different from a covalent bond?

19. Open Ended Describe the role of transport proteins in plasma membranes.

20. Open Ended Compare the functions of mitochondria and chloroplasts in cells. Be sure to include ATP in your answer.

21. Open Ended Describe the cellular process of mitosis.