After you have finished reading this chapter, you should be able to:

**Explain** how chlorophyll captures light energy; list five factors that affect the rate of photosynthesis.

**Describe** how cellular respiration releases the energy stored in food.

**Compare** the processes of aerobic respiration and fermentation.

**Outline** the three stages of cellular respiration.

*Plant life sustains the living world; more precisely, chlorophyll does. . . . All else obeys the thermodynamic laws that energy forever runs down hill, is lost and degraded. . . . This is the law of diminishing returns, and it is obeyed by the cooling stars as by man and all the animals. Only chlorophyll fights up against the current.*

Donald Culross Peattie

**Introduction**

You are sitting at your desk, next to the window, reading this book. Sunlight is shining through the window and falling on your desk. Next to your book is your afternoon snack, a partially eaten apple. Is there a connection among you, the sunlight, and the apple? There most certainly is. It is a connection that lies at the very center of the theme of life as energy, matter, and organization.

**FOOD: MATTER AND ENERGY**

The apple is food. It contains complex organic compounds, atoms held together as molecules by chemical bonds that are rich in stored energy.
You eat the apple, getting both the matter and the energy you need to build your body and to stay alive.

The apple tree that produced the fruit represents one group of living organisms, the group called **autotrophs**, a word that means “self feeding.” Unlike humans, the apple tree does not eat. It makes its own food, taking the inorganic substances carbon dioxide and water and changing them into organic compounds such as sugars and starches. Humans are representatives of the other group, organisms that cannot make their own food. Because organisms such as ourselves and all other animals must get complex organic compounds from other organisms, we belong to the group called **heterotrophs**, meaning “other feeding.” (See Figure 7-1.)

How does sunlight connect the apple to humans? The connection is energy, of course. For the apple tree to combine inorganic raw materials such as carbon dioxide and water into organic compounds such as sugar and starch, it needs a source of energy. The rays of sunlight, as they fall on the leaves of the apple tree, provide that energy. The process of making this food, by using light as the source of energy, is **photosynthesis**. All green plants are photosynthetic autotrophs.

---

**PHOTOSYNTHESIS**

What does a plant need to grow? If you have ever cared for a plant in a flower pot, in a garden, or on a farm, you will probably say: water, soil, and sunlight. Where does a plant get the food it needs to grow? Until 1600, everyone would have said the soil. Animals take in food through their mouths, and people assumed that plants take in food from the soil through their roots.

In one of the first recorded science experiments, Belgian physician
Jean Baptiste van Helmont decided to test this assumption. No one knows for sure why a doctor was interested in this. Maybe it was an overwhelming curiosity that needed to be satisfied. Helmont thought about the question he wanted to study: Do plants get the matter they use to grow from the soil? He took a young willow tree, removed all the soil from its roots, and weighed it. He planted the tree in a tub of soil, which he had also carefully weighed. He then let the tree grow for five years, watering it regularly during that time. After five years, he weighed both the tree and the soil again and discovered that the tree had increased in weight by 74 kilograms while the soil had decreased in weight by only 57 grams (0.057 kilogram). The willow had grown into a healthy, much taller tree and had increased its weight 1000 times more than the soil’s weight had decreased. Helmont had found that plants do not get bigger by simply taking an equivalent amount of matter from the soil. (See Figure 7-2.)

Many other experiments have been conducted since Helmont’s time by a wide variety of curious people, including a clergyman, an engineer, and a biochemist. What is now known about photosynthesis, the process by which plants make their own food, is very different from what people once thought was true.

Plants, as autotrophs, are able to make their own energy-rich carbon compounds. In particular, they make the simple sugar glucose, whose chemical formula is $C_6H_{12}O_6$. Plants get the carbon for these glucose molecules from inorganic carbon dioxide, $CO_2$, in the air. We also know that plants release oxygen, $O_2$, a gas that can help a candle burn and that animals need to stay alive. The fact that plants give off oxygen was supported by other important experiments done in the 1700s. The final piece of the puzzle was added in the 1940s, when scientists discovered that the oxy-
gen plants produce comes from water molecules that get split apart, not from carbon dioxide.

Other important information about the process of photosynthesis was learned during the 1800s. Experiments showed that plants must have light to convert inorganic carbon dioxide to glucose and to produce oxygen. Finally, scientists found that photosynthesis also requires the green pigment **chlorophyll**. The chemical reactions of photosynthesis occur within the chlorophyll-containing chloroplasts found in plant leaves and stems. (See Figure 7-3.)

This, then, is the process of photosynthesis. Some consider it the single most important chemical reaction that occurs on Earth. This all-important reaction can be summarized by the following chemical equation:

\[
\text{LIGHT ENERGY} \quad \text{CHLOROPHYLL} \\
6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \quad \overset{\text{LIGHT ENERGY}}{\rightarrow} \quad \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2
\]

Light energy and chlorophyll are needed for this reaction, but the chlorophyll is not used up and the light energy is not a substance. That is why they are written over and under the reaction arrow, rather than with the substances used in the reaction.
Photosynthesis links the nonliving and the living worlds. Almost every organism on Earth depends on photosynthesis as its source of nutrients. Without the marvelous biochemistry of photosynthesis in plants, animals would have no constant source of food. The sun could continue to pour its light energy on Earth without limit. But without plants to capture this light energy and convert it into the chemical forms we call food, we and most other animals would not exist.

**CHLOROPHYLL: THE SUN TRAP**

The sunlight shining on your desk was produced 8 minutes ago by thermonuclear reactions in the sun, about 150 million kilometers away. After traveling that enormous distance through the emptiness of space, the light energy is now striking your book, or the leaf of the apple tree.

Just as elements consist of fundamental particles called atoms, light energy consists of packets of energy called photons. Photons cannot be further divided. You may have used a prism to separate visible (white) light into the spectrum of colors that make it up. Each color in the spectrum has a different wavelength. The visible light that comes from the sun has wavelengths that vary from the 700 nanometers found in red light to the 400 nanometers found in violet light. The amount of energy in light depends on its wavelength. The shorter the light’s wavelength, the higher its energy level. For example, a photon of violet light has more energy than a photon of red light. The range of colors in the spectrum of visible light includes red, orange, yellow, green, blue, and violet (ROYGBV). Our eyes are able to detect these colors. The pigments in plants are sensitive to the same visible colors of light. (See Figure 7-4.)

Objects either absorb or reflect a particular color of light. A red apple absorbs all colors of light except red. It reflects red light, sending it away from its surface. That is why the apple appears red. The photosynthetic pigment chlorophyll absorbs all colors of light except green. Plant leaves appear green because they reflect green light. Both the red lower-energy light and the blue higher-energy light are absorbed by chlorophyll. A graph can show the amount of light energy absorbed by chlorophyll at different wavelengths. This is called the absorption spectrum for chlorophyll. (See Figure 7-5.)

Through evolution, plants have developed other pigments that use some of the wavelengths of light that chlorophyll does not. These pigments absorb green and blue light but reflect yellow, orange, and red. We
do not usually see these pigments because the chlorophyll in the leaves hides the other colors. However, plants need warm weather to make chlorophyll. When summer passes into autumn and cool temperatures arrive, plants stop making chlorophyll. The chlorophyll begins to break down and green light is no longer reflected. The other pigments last a little longer, though, and the glorious colors of yellow, orange, and red

Figure 7-4 A prism separates white light into its spectrum of colors.

Figure 7-5 The absorption spectrum for chlorophyll.
become visible. The colors of autumn leaves are a result of the chemistry of pigments, the physics of light, and the biology of leaves all working together.

**LEAVES: PHOTOSYNTHETIC FACTORIES**

You have already seen in Chapter 3 how the structures present inside the leaf are well organized. Such organization allows cells that contain chlorophyll to get maximum exposure to light. At the same time, the leaf controls the amount of water lost to the air. It also makes possible the movement of CO$_2$ and O$_2$ into and out of the leaf.

This organization, on which life depends, becomes even more obvious when we look at the **chloroplasts**, organelles in the leaf cells that contain chlorophyll. A typical leaf cell may contain as many as 60 chloroplasts. (See Figure 7-6.) A cross section of an individual chloroplast shows many stacks of membranes. One of the two main steps of photosynthesis occurs in these membranes; the other step occurs in the liquid material in the spaces between the membranes.

Photons of light energy are captured by chlorophyll molecules embedded in the membranes. In the molecules, the sun’s energy is converted from light energy to chemical energy, in the form of ATP and another related molecule, NADPH. The process that occurs on these membranes also involves the splitting of water molecules and the release of oxygen. Because light is needed for these steps, these are called the light-dependent reactions. The splitting of water that occurs here in the presence of light is called **photolysis**. Within the liquid material in the spaces between the membranes, a complex set of enzymes catalyze reactions that use the energy stored in ATP and NADPH molecules to produce glucose. These reactions make glucose from CO$_2$ and water. They do not use light and so are called light-independent reactions. Since free-floating carbon
from CO\textsubscript{2} gets combined into the carbon backbone of glucose molecules in these steps, this process is also called **carbon fixation**.

Carbon fixation is the single most important way in which inorganic matter from the world around us, mainly CO\textsubscript{2} in the air, gets turned into organic carbon compounds that make up the bodies of all living things. (See Figure 7-7.)

**THE RATE OF PHOTOSYNTHESIS**

As with any chemical reaction, the reactions of photosynthesis can occur at different rates. What factors affect the rate at which photosynthesis occurs?

- **Temperature.** When temperature increases, molecules move more quickly. The rate at which a reaction occurs also increases. However, at temperatures higher than 35°C, the rate of photosynthesis reactions decreases. Higher temperatures begin to destroy the enzymes needed for the reactions. (See Figure 7-8, graph A, on page 148.)

- **Light intensity.** An increase in light intensity increases the rate of photosynthesis in a leaf until a maximum rate of photosynthesis is reached. Beyond that level, additional light has no further effect. (See Figure 7-8, graph B, on page 148.)

- **CO\textsubscript{2} concentration.** Because CO\textsubscript{2} is used by plants in photosynthesis reactions, increasing the concentration of CO\textsubscript{2} in the air around a plant usually increases the rate of photosynthesis.
Water. Even though only a small amount of water is needed for photosynthesis, a shortage of water slows the process. Also, when water is scarce, the stomates close. The rate at which the gases CO$_2$ and O$_2$ can be exchanged is therefore reduced, and photosynthesis is slowed.

Minerals. Certain minerals are important for photosynthesis reactions. For example, magnesium and nitrogen are needed to make chlorophyll molecules. Zinc, manganese, iron, and copper are needed for some of the reactions. Actually, it was the removal of these minerals from the soil that caused the slight decrease in soil weight in Helmont’s experiment. The total absence of any one of these minerals would have a negative effect on the entire process of photosynthesis.

**DISCOVERIES OF LIFE ON THE OCEAN BOTTOM**

In 1977, researchers from the Woods Hole Oceanographic Institution in Cape Cod, Massachusetts, led by scientist Robert Ballard, used a camera on a small remote-controlled submarine to record observations made on the seafloor, deep in the Pacific Ocean near the Galápagos Islands. The researchers knew that there was a crack in Earth’s crust at this place. Hot water, rich in chemicals, was escaping from vents in the crack into the surrounding ocean water. To their great surprise, the researchers found a very busy scene of life clustered around the vents. Viewed through a television camera, the large numbers of organisms looked like they had escaped from a science-fiction movie. Giant red tube worms, huge clams, and blind white crabs were found in the water near the vents. The scientists took water samples near the vents and found great concentrations of bacteria.
**Drifters in the Sea**

We walk on land. Even the very name Earth is used to mean land. But look at a world map and you will see a lot of blue space. In fact, more than 70 percent of Earth’s surface is covered by water, mostly oceans. Unseen in these waters—drifting along with waves and currents—are countless numbers of tiny organisms. Photosynthetic bacteria, protists, and plants are included in these drifters. Some of these unicellular species are so small that if 12 million cells were lined up in a row, the line would be only about 1 centimeter long. In some places in the oceans, these microscopic organisms are so numerous that a cup of seawater may hold 24 million individuals of a single species, and that cup would contain other species as well!

These species are very small, but their importance to the overall life on the planet is huge. Tiny sea-dwelling organisms are the beginning food source for almost all living things in the oceans. It is easy for us land dwellers to understand that many animals eat plants to get food. We have seen cattle and sheep grazing on grasses in a pasture. The drifting cells in the ocean could be called the grass fields or pastures of the sea. Just like grass on land, the sea drifters capture energy from the sun and convert inorganic CO$_2$ and water into organic molecules, which become important foods for other organisms. On land, plants bloom with wild displays of colorful flowers in spring. The photosynthetic drifters in the pastures of the seas are said to “bloom” in the spring, too, as the water warms and nutrients from ocean depths are brought to the surface by currents. A great deal has been learned recently about the seasonal explosive growth of these photosynthetic cells in the ocean from photographs taken by orbiting satellites.

These organisms perform another vital function for life on Earth. They are our planet’s most important absorbers of CO$_2$ from the air as they photosynthesize. People have been changing Earth’s atmosphere by burning enormous quantities of coal, oil, and gas as fuels. Burning these fossil fuels increases CO$_2$ levels in the air. This change is thought to be increasing the average temperature of Earth. The tiny photosynthetic cells drifting in the oceans are absolutely necessary to help prevent global warming, since they absorb the CO$_2$. So the drifters of the seas are vitally important for all life on Earth, not only life in the oceans.
How does this fantastic array of life survive in the total darkness thousands of meters below the ocean’s surface? The bacteria were the key. They were the food source for the other organisms. The bacteria made their own food from the chemicals present in the hot water escaping from the vents. Because chemical reactions involving inorganic substances, and not light, are used as the source of energy, the process is called chemosynthesis. Chemosynthetic bacteria are also found in other places, such as the mud in marshes at Earth’s surface.

Much research has continued on hot-water vents over the past 25 years. In 2002, scientists were investigating how the unique organisms found at the many ocean vents, which are widely separated from each other on the ocean floor, got to these various locations in the first place.

**CELLULAR RESPIRATION:**
**RELEASING THE STORED ENERGY IN FOOD**

We have spent some time considering the relationship between the sunlight that falls on the leaves of an apple tree and the chemical process of photosynthesis. During photosynthesis, the light energy of the sun is converted into the stored chemical energy of glucose in the apple. After we eat the apple, our cells are ready to use that stored chemical energy. How does this happen?

We know that the release of energy cannot occur all at once. For example, if you hold a lighted match to a marshmallow, the carbohydrates in the marshmallow will burst into flames. Energy is being released, and quickly, too. Obviously this quick energy release is not what happens inside our cells. Instead, the release of energy occurs in a series of enzyme-controlled small steps. The energy stored in organic compounds is eventually converted to a usable form, the energy currency of all cells, ATP. This process is known as cellular respiration. (See Figure 7-9.)

Cellular respiration is basically the opposite of photosynthesis. Instead of building energy-rich glucose molecules, glucose molecules are taken apart to release their stored energy. We have said that we can consider the glucose molecules like money stored in the bank. The energy the cell needs to do the many different tasks involved in living is like the pocket money you need to buy groceries and clothes. Cellular respiration converts the energy stored in glucose into the easily spent energy currency called ATP.

Cellular respiration occurs in several stages. The first stage releases only a small amount of the stored energy from glucose. This partial breakdown of glucose occurs in the absence of oxygen. To completely take apart glu-
cose to produce carbon dioxide and water, and to release a large amount of energy, oxygen must be present. Respiration that occurs in the presence of oxygen is called **aerobic respiration**.

Glucose, with a large amount of energy stored in it, can be compared to an object on top of a high hill. Allowing the object to move all the way down the hill releases all of its stored energy. This is what happens after aerobic respiration. Moving the object just a little way down the hill releases a small amount of energy. The object now has less stored energy in it. This is the case after fermentation.

**Check Your Understanding**

In what ways are cellular respiration and photosynthesis opposite reactions?

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**FERMENTATION**

Every baker knows that living yeast cells can turn a lump of dough into a loaf of bread that is then baked. Every winemaker knows that growing yeast cells turn grape juice into wine. These are **fermentation** reactions. Microorganisms such as yeast and bacteria are capable of fermentation.

Fermentation begins with the splitting of a glucose molecule that has six carbon atoms into two molecules, each with three carbon atoms. This glucose-splitting process is called **glycolysis**. During glycolysis, ten individual chemical reactions take place, each reaction controlled by a different enzyme. The net result is the release of energy in the form of two ATP molecules for every glucose molecule that is split in half. No oxygen
is used in these reactions. In yeast, the anaerobic process known as alcoholic fermentation produces alcohol and carbon dioxide. The alcohol produced turns grape juice into wine. The bubbles of CO$_2$ make bread dough rise and make the inside of a loaf of bread look like a sponge.

Our own cells also carry out fermentation under certain conditions. How many push-ups can you do? You could try right now if you don’t know. Can you keep on doing more and more push-ups until you decide to stop? Try it. You will find that no matter how determined or how strong you are, your muscles will continue to work only until a certain point. (Some people will reach this point sooner than others.) Then your muscles will stop working for you. You will reach a point where you can do no more push-ups. Why? (See Figure 7-10.)

In order for your muscles to do work, you need oxygen to release the energy from glucose through aerobic respiration. If you work your muscles strenuously enough, glycolysis occurs in the muscle cells faster than oxygen can be delivered to them. In the absence of oxygen, the muscles switch to fermentation to produce energy. In muscles, the final product of this fermentation is not alcohol but a compound called lactic acid. When lactic acid builds up in muscle cells, the pH becomes more acidic, the muscles get tired, and cramps develop.

**AEROBIC RESPIRATION: GETTING THE MOST OUT OF IT**

Under normal conditions, when the supply of oxygen is sufficient, cells can carry out aerobic respiration. This process begins with the same ten steps of glycolysis. The fact that the same ten chemical reactions, in
exactly the same order, occur in each of our cells and in microorganisms such as bacteria and yeast is strong evidence that these chemical processes developed long ago before single-celled organisms evolved into multicellular organisms.

What is so special about being able to go beyond the steps of glycolysis and limited energy release to the process of aerobic respiration? Remember the object on a hill, which moved only a short way down during fermentation? In that example, the glucose was split into only two pieces. Now, in the presence of oxygen, the molecule of glucose can roll all the way down the hill. The glucose molecule gets completely taken apart. The result is the release of a large amount of energy. Rather than only the two molecules of ATP produced during glycolysis and fermentation, we now get an average of 36 ATP molecules for every glucose molecule. For large, active, multicellular organisms like ourselves, aerobic respiration is a necessity. Fermentation, with its low level of energy production, may be enough to provide for a single yeast cell living in grape juice or bread dough. However, only the high-energy production of aerobic respiration is sufficient to meet the energy needs of active animals and plants.

THE THREE STAGES OF CELLULAR RESPIRATION

To understand cellular respiration, we need to resume our tour of the eukaryotic cell. Let’s imagine that we can see glucose molecules being transported into the cell. These glucose molecules might have come from your apple. They eventually arrived in one of the muscle cells in your arm. To get into the cell, they were transported across the cell membrane by carrier proteins.

Inside the cell, the first stage of respiration occurs. Enzymes responsible for the ten chemical reactions of glycolysis are present in the cytoplasm. To proceed to the second stage of cellular respiration, the products of glycolysis are transported to numerous membrane-filled organelles called mitochondria. These are the powerhouses of the cell. In the mitochondria, the second stage of aerobic respiration will begin only if oxygen is present.

The products that result from glycolysis, although smaller than molecules of glucose, still contain most of the original energy stored in the glucose. The energy associated with the electrons that form the chemical bonds in these molecules is still there. Once these products are inside the mitochondria, an entirely new process begins. This second stage, called the Krebs cycle, involves eight separate enzyme-catalyzed reactions
linked to one another in a circle. (See Figure 7-11.) The enzymes for the Krebs cycle are all found in the liquid interior of the mitochondria. Oxygen is required for the Krebs cycle; some ATP is produced, and CO$_2$ is released as the energy-containing molecules get broken down, with one carbon atom at a time being removed from them. The most important result of the Krebs cycle is the stripping away of hydrogen atoms from the energy-rich molecules. These hydrogen atoms are taken away by carrier molecules called NAD$^+$ and FAD, which become NADH and FADH$_2$, to the third and final stage of cellular respiration.

To find where this final stage occurs, we must take a closer look at the mitochondria. (See Figure 7-12.) You will see an inner membrane that is folded back and forth many times inside a mitochondrion’s outer membrane. These outer and inner membranes have the same phospholipid bilayer structure as the cell membrane. A series of carrier molecules is attached to the inner membrane. While some of the energy released during the Krebs cycle is used to make molecules of ATP, most of it is released as high-energy hydrogen atoms, which become attached to either NAD$^+$ or FAD. Each of these hydrogen atoms consists of one electron and one proton. These particles are high up on the “energy hill.” To get them to release their energy, other particles must be willing and able to accept
them at a much lower energy level. The high-energy hydrogen atoms begin to get passed from NADH and FADH$_2$ to the electron carriers attached to the inner membrane, moving from one carrier molecule to another along a chain. In terms of energy, this chain, called the **electron transport chain**, is moving downhill. The process works only if, at the end, something is waiting to accept the electrons. What do you suppose are the final electron-acceptor particles at the bottom of the hill? Take a deep breath. You just took them into your body.

Oxygen molecules are the final hydrogen and electron acceptors that make possible the efficient release of large amounts of stored energy from glucose molecules. What is the result of this final stage? As the oxygen accepts the electron/proton combinations (a hydrogen atom), the result is H$_2$O, or water. If you breathe out on a mirror, you will observe moisture on the glass. Some of this is the water produced during the final stage of cellular respiration. Most important, about 36 molecules of ATP are released from every molecule of glucose that is completely disassembled by aerobic cellular respiration.

We can now summarize cellular respiration in the following chemical equation:

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + 36 \text{ATP}$$

The ATP is the energy source in your cells, and every cell in your body uses it to do the work that keeps you in that highly organized state we call life.

---

**A FINAL VISIT BACK TO PLANTS**

Remember that apple and the tree it came from? The leaves of the tree are necessary in this entire flow of energy from the nonliving to the living world. Photosynthesis occurs in them, converting the sun’s energy into
energy stored in chemicals. In leaves, the carbon dioxide from the air gets transformed into organic glucose molecules, which get stored in the apple. We eat the apple, and the glucose is used in the process of cellular respiration that transforms the stored energy into a form we can use.

But does the apple tree specifically go through the process of photosynthesis in order to make food for us and other animals? The answer is a definite no! The apple tree is simply making food for itself to live long enough to reproduce successfully. The apples contain seeds, which may get carried away to new places by animals that eat the apples. This makes it possible for the apple tree to produce more apple trees in other places. However, most of the glucose made in the leaves of the tree does not go into storage in the form of apples. Rather, it gets taken to all the different parts of the tree and is used by the tree to stay alive. And what process does the tree use to get the energy it needs from the glucose it has made? The same process we just finished studying, cellular respiration.

To summarize: All plants are autotrophs and are able to make their own food by photosynthesis and use it for energy through cellular respiration. All animals are heterotrophs and must obtain food energy from other organisms. They use cellular respiration, just as plants do, to obtain energy from the food they eat.
LABORATORY INVESTIGATION 7
How Is Chromatography Used to Separate Pigments in Chlorophyll?

INTRODUCTION
Chromatography is an important technique used by scientists to separate the components in a mixture. Some components dissolve more easily in one solvent than in another. If you place a mixture on a piece of paper and place the end of the paper in a solvent, the components of the mixture that are more soluble will be carried faster and farther up the paper. This technique is called paper chromatography.

Chlorophyll, the pigment that gives green plants their color, has been analyzed in this way. As a result of these studies, scientists have learned that chlorophyll is made up of several pigments: chlorophyll A (yellow-green), chlorophyll B (blue-green), carotenes (orange), and xanthophylls (yellow). In this investigation, you will use paper chromatography to separate the pigments in an artificial chlorophyll mixture.

MATERIALS
Filter paper, scissors, ruler, pencil, test tube, toothpicks, mixture of dyes (food colorings in water), solvent solution (2% concentrated ammonia, 3% isobutyl alcohol, and 95% water)

PROCEDURE
1. Cut a piece of filter paper about 2 centimeters wide and as long as the test tube. The paper strip should be just a little wider than the diameter of the test tube. Cut one end of the strip into a V.
2. Draw a pencil line across the width of the paper, 2 centimeters from the pointed end of the paper. DO NOT USE INK. Ink contains dyes that will interfere with your results.
3. Use a toothpick to place some of the dye mixture along the pencil line. Let the material dry for a few minutes. Repeat this process 10 times.
4. Carefully pour a small amount of the solvent mixture into the test tube, to a depth of 1 to 2 centimeters.
5. Slide the filter paper strip down the test tube until the point of the V touches the solvent. The line of dye on the strip must not touch the solvent.
6. Place the test tube in a rack. DO NOT shake the tube.
7. Record your observations immediately. Then record your observations after 2, 5, and 10 minutes.
8. Remove the paper strip after the solvent line has reached the top of the filter paper. If this happens before 10 minutes have passed, remove the paper immediately.

**INTERPRETIVE QUESTIONS**

1. What does the strip of filter paper look like at the end of this investigation?
2. How many different bands of colors can you see? List them, in order, from the bottom of the paper strip to the top.
3. The leaves of many varieties of Japanese maples are red all year long. How could you find out if chlorophyll is present in these leaves?
4. Why are the leaves of most deciduous trees green? Why do the leaves of these trees change color in the fall?
CHAPTER 7 REVIEW

Answer these questions on a separate sheet of paper.

VOCABULARY
The following list contains all of the boldfaced terms in this chapter. Define each of these terms in your own words.

absorption spectrum, aerobic respiration, autotrophs, carbon fixation, cellular respiration, chemosynthesis, chlorophyll, chloroplasts, electron transport chain, fermentation, glycolysis, heterotrophs, Krebs cycle, mitochondria, photolysis, photons, photosynthesis

PART A—MULTIPLE CHOICE
Choose the response that best completes the sentence or answers the question.

1. Which organism is an autotroph?  
   a. mushroom  
   b. oak tree  
   c. parrot fish  
   d. E. coli bacterium

2. Which of these processes takes place in the mitochondria?  
   a. Calvin cycle  
   b. Krebs cycle  
   c. glycolysis  
   d. photolysis

3. Carbon fixation and photolysis usually take place in a plant’s  
   a. roots  
   b. nuclei  
   c. seeds  
   d. chloroplasts.

4. Photosynthesis requires  
   a. light energy, chlorophyll, carbon dioxide, and water  
   b. light energy, soil, oxygen, and water  
   c. light energy, chlorophyll, oxygen, and water  
   d. light energy, chlorophyll, glucose, and oxygen.

5. The products of cellular respiration are  
   a. glucose and oxygen  
   b. carbon dioxide and alcohol  
   c. carbon dioxide, water, and energy  
   d. ATP, NADH, and FADH₂.

6. When water is scarce,  
   a. photosynthesis speeds up  
   b. the stomates close  
   c. CO₂ concentration inside the leaf increases  
   d. the mineral copper is used up at a faster rate.

7. The “energy currency of all cells” is  
   a. ATP  
   b. glucose  
   c. NADP  
   d. light.

8. For carbon fixation, deep-sea vent organisms depend on the process of  
   a. photolysis  
   b. photosynthesis  
   c. fermentation  
   d. chemosynthesis.

9. The absorption spectrum for chlorophyll reveals that it  
   a. reflects ultraviolet light  
   b. absorbs green light  
   c. absorbs red and blue light  
   d. reflects red and yellow light.
10. Glycolysis  
   a. produces a net gain of 2 ATP molecules  
   b. produces a net gain of 4 ATP molecules and 2 NADH molecules  
   c. uses 1 O\textsubscript{2} molecule  
   d. uses 2 CO\textsubscript{2} molecules.

11. The end products of fermentation in yeast are  
   a. carbon dioxide and water  
   b. glucose and oxygen  
   c. carbon dioxide and alcohol  
   d. alcohol and oxygen.

12. Which of the following would speed up photosynthesis?  
   a. an increase in light intensity  
   b. an increase in temperature above 35°C  
   c. the absence of zinc, manganese, iron, or copper  
   d. a decrease in CO\textsubscript{2} concentration

13. Which of the following statements is correct?  
   a. Glycolysis produces 2 ATP, and respiration produces 34 ATP.  
   b. Glycolysis produces 2 ATP, and respiration produces 26 ATP.  
   c. Glycolysis produces 10 ATP, and respiration produces 20 ATP.  
   d. Glycolysis produces 4 ATP, and respiration produces 32 ATP.

14. Most of the energy released during the Krebs cycle is  
   a. used to make ATP  
   b. used to build an electron transport chain  
   c. in the form of FADH\textsubscript{2} and NADH  
   d. in the form of high-energy hydrogen atoms.

15. Which of these events occurs during the light-dependent reaction?  
   a. ATP loses a phosphate group to form ADP  
   b. NADPH becomes NADP  
   c. photolysis  
   d. carbon fixation

PART B—CONSTRUCTED RESPONSE

Use the information in the chapter to respond to these items.

16. What are the names of the structures labeled A and B in the diagram? In which structure does photosynthesis take place?

17. Identify the numbered areas in which glycolysis, photolysis, and the Krebs cycle occur.

18. Why is photosynthesis considered a bridge between the nonliving and living worlds?

19. Explain how it is that muscle cramps and champagne originate from the same process.

20. Imagine that you are a carbon atom. Describe your journey from the air into a dandelion, then into a rabbit that eats the dandelion, and finally back into the air.
PART C—READING COMPREHENSION

Base your answers to questions 21 through 23 on the information below and on your knowledge of biology. Source: Science News (July 12, 2003): vol. 164, p. 29.

Flight Burns Less Fuel Than Stopovers

The first measurements of energy use in migrating songbirds have confirmed a paradox predicted by some computer models of bird migration: Birds burn more energy during stopovers along the way than during their total flying time.

Martin Wikelski of Princeton University and his colleagues monitored 38 Swainson’s and hermit thrushes during the nights of their spring migration through the northern United States. The researchers injected the radio-tagged birds with chemical-isotope tracers that enabled the scientists to measure the birds’ metabolism. The team members spent their nights driving a car, trying to keep up with a tagged bird. “We got stopped by a cop just about every night, not because we were speeding, but because they wanted to know what somebody was doing in a little town in Wisconsin at 4 A.M. with a giant antenna on the roof of a car,” says Wikelski.

A dozen birds took night flights covering up to 600 kilometers. The rest stayed put. The scientists determined that the birds that flew burned 71 kilojoules [kJ] of energy on an average night’s flight of 4.6 hours. The birds that didn’t fly burned energy at 88 kJ per day.

Since the birds spent about 24 days and nights on stopovers during a typical 42-day journey from Panama to Canada, actual flying consumed only 29 percent of the total energy budget for the migration, Wikelski and his coworkers report in the June 12 Nature.

21. How did researchers from Princeton University measure the metabolism of thrushes while they were migrating?

22. Explain what comparison the researchers were interested in making.

23. State the conclusion that was made by the scientists after they finished their investigation of the migratory birds.