Connect to the Big Idea

Have students look at the photograph of the polar bear in its icy habitat. Ask them what the bear’s habitat consists of. (mostly ice and water) Tell them that water is essential not only to polar bears but to all living things as it allows them to carry out basic life processes. This is because water has certain chemical properties that make it unique. Then, have students anticipate the answer to the question, What are the basic chemical principles that affect living things?

Have students read over the Chapter Mystery. Connect the Chapter Mystery to the Big Idea of Matter and Energy by explaining that most organisms—including ice fish—need oxygen for many body processes. For example, oxygen is needed to break down food molecules for energy. Ask students to predict how liquid blood could carry oxygen gas without hemoglobin to bind with the oxygen. As a hint, tell students that, in carbonated liquids, the bubbles they see are made up of carbon dioxide gas that has come out of the liquid.

Have students preview the chapter vocabulary terms using the Flash Cards.

Understanding by Design

Chapter 2 introduces the molecular basis of life, and thereby advances students’ comprehension of the Enduring Understanding: The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere. The Big Idea, Essential Question, and Guiding Questions, listed in the graphic organizer at the right, provide a framework for how students can explore the chemical principles that underlie life processes—from atoms to enzymes.

PERFORMANCE GOALS

In Chapter 2, students will use diagrams, lab activities, and analogies to learn about the chemistry of life. In the Chapter Mystery, they will apply basic chemical principles to understand how certain fish can survive without oxygen-carrying red blood cells. At the end of the chapter, students will demonstrate their understanding of the molecular basis of life by creating a storybook on the topic for a lower grade.
Water is locked in ice in the Svalbard islands of Norway—home to the polar bear. Even in such an extreme environment, organisms are able to obtain the matter and energy they need to survive.

THE GHOSTLY FISH

Most fish, just like you and other vertebrates, have red blood. Red blood cells carry oxygen, a gas essential for life. The cells' red color comes from an oxygen-binding protein called hemoglobin.

But a very small number of fish don't have such cells. Their blood is clear—almost transparent. Because they live in cold antarctic waters and have a ghostly appearance, they are nicknamed “ice fish.” How do these animals manage to survive without red blood cells?

As you read this chapter, look for clues to help you explain the ice fish's unusual feature. Think about the chemistry that might be involved. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the fishy mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

What's Online

Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY

In The Ghostly Fish, students can investigate the chemistry involved in an organism that lacks red blood cells.

UNTAMED SCIENCE VIDEO

Follow the Untamed Science crew as they explore the unique chemistry of water.

ART REVIEW

This drag-and-drop activity lets students explore ionic and covalent bonds.

ART IN MOTION

This animation shows the process of salt crystals dissolving in water.

DATA ANALYSIS

Students can analyze data about the ecological impact of acid rain.

VISUAL ANALOGY

Using this animation, students can further explore the lock-and-key analogy for an enzyme and its substrates.
Getting Started

Objectives

2.1.1 Identify the three subatomic particles found in atoms.

2.1.2 Explain how all of the isotopes of an element are similar and how they are different.

2.1.3 Explain how compounds are different from their component elements.

2.1.4 Describe the two main types of chemical bonds.

Student Resources

Study Workbooks A and B, 2.1 Worksheets
Spanish Study Workbook, 2.1 Worksheets
Lab Manual A, 2.1 Quick Lab Worksheet
Lab Manual B, 2.1 Hands-On Activity Worksheet

Lesson Overview • Lesson Notes
• Activity: Art Review • Assessment: Self-Test, Lesson Assessment

For corresponding lesson in the Foundation Edition, see pages 28–32.

The Nature of Matter

THINK ABOUT IT What are you made of? Just as buildings are made from bricks, steel, glass, and wood, living things are made from chemical compounds. But it doesn't stop there. When you breathe, eat, or drink, your body uses the substances in air, food, and water to carry out chemical reactions that keep you alive. If the first task of an architect is to understand building materials, then what would be the first job of a biologist? Clearly, it is to understand the chemistry of life.

Atoms

What three subatomic particles make up atoms?

The study of chemistry begins with the basic unit of matter, the atom. The concept of the atom came first from the Greek philosopher Democritus, nearly 2500 years ago. Democritus asked a simple question: If you take an object like a stick of chalk and break it in half, are both halves still chalk? The answer, of course, is yes. But what happens if you break it in half again and again and again? Can you continue to divide without limit, or does there come a point at which you cannot divide the fragment of chalk without changing it into something else? Democritus thought that there had to be a limit. He called the smallest fragment the atom, from the Greek word atomos, which means "unable to be cut."

Atoms are incredibly small. Placed side by side, 100 million atoms would make a row only about 1 centimeter long—about the width of your little finger! Despite its extremely small size, an atom contains subatomic particles that are even smaller. Figure 2–1 shows the subatomic particles in a carbon atom. The subatomic particles that make up atoms are protons, neutrons, and electrons.

Protons and Neutrons Protons and neutrons have about the same mass. However, protons are positively charged particles (+) and neutrons carry no charge at all. Strong forces bind protons and neutrons together to form the nucleus, at the center of the atom.

Electrons The electron is a negatively charged particle (−) with only 1/1840 the mass of a proton. Electrons are in constant motion in the space surrounding the nucleus. They are attracted to the positively charged nucleus but remain outside the nucleus because of the energy of their motion. Because atoms have equal numbers of electrons and protons, their positive and negative charges balance out, and atoms themselves are electrically neutral.

Teach for Understanding

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION What is the matter in organisms made of?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand the chemical basis of the matter that makes up living things. Divide the class into groups, and ask each group to write a poem in which they answer the Key Questions of the lesson and use each of the lesson vocabulary terms. Give groups a chance to perform their poems for the class.
Elements and Isotopes

How are all of the isotopes of an element similar?

A chemical element is a pure substance that consists entirely of one type of atom. More than 100 elements are known, but only about two dozen are commonly found in living organisms. Elements are represented by one- or two-letter symbols. C, for example, stands for carbon, H for hydrogen, Na for sodium, and Hg for mercury. The number of protons in the nucleus of an element is called its atomic number. Carbon's atomic number is 6, meaning that each atom of carbon has six protons and, consequently, six electrons. See Appendix E, The Periodic Table, which shows the elements.

Isotopes

Atoms of an element may have different numbers of neutrons. For example, although all atoms of carbon have six protons, some have six neutrons, some seven, and a few have eight. Atoms of the same element that differ in the number of neutrons they contain are known as isotopes. The total number of protons and neutrons in the nucleus of an atom is called its mass number. Isotopes are identified by their mass numbers. Figure 2–3 shows the subatomic composition of carbon-12, carbon-13, and carbon-14 atoms. The weighted average of the masses of an element's isotopes is called its atomic mass. "Weighted" means that the abundance of each isotope in nature is considered when the average is calculated. Because they have the same number of electrons, all isotopes of an element have the same chemical properties.

Radioactive Isotopes

Some isotopes are radioactive, meaning that their nuclei are unstable and break down at a constant rate over time. The radiation these isotopes give off can be dangerous, but radioactive isotopes have a number of important scientific and practical uses. Geologists can determine the ages of rocks and fossils by analyzing the isotopes found in them. Radiation from certain isotopes can be used to detect and treat cancer and to kill bacteria that cause food to spoil. Radioactive isotopes can also be used as labels or "tracers" to follow the movements of substances within organisms.

Isotopes of Carbon

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Number of Protons</th>
<th>Number of Electrons</th>
<th>Number of Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon-12</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Carbon-13</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

Radioactive isotopes have a mass number of either 20 or 22. They are identified by the total number of protons and neutrons in the nucleus: carbon–12, carbon–13, and carbon–14. Clue: Which isotope of carbon is radioactive?

FIGURE 2–2 Droplets of Mercury

Mercury, a silvery-white metallic element, is liquid at room temperature and forms droplets. It is extremely poisonous.

FIGURE 2–3 Carbon Isotopes

Isotopes of carbon all have 6 protons but different numbers of neutrons—6, 7, or 8. They are identified by the total number of protons and neutrons in the nucleus: carbon–12, carbon–13, and carbon–14. Clue: Which isotope of carbon is radioactive?

Teach

Use Models

Have students model isotopes using beads of two different colors to represent protons and neutrons. Tell them to place six beads of one color and six beads of the other color together in a pile on their desk. Explain that each pile of beads represents the nucleus of a carbon-12 atom. Then, tell students to select more beads as needed to model the nuclei of carbon-13 and carbon-14 isotopes.

Ask How many protons does each isotope have? (six) How many electrons? (six)

Add a proton bead to a student's model of carbon-14.

Ask Do the beads still model the nucleus of a carbon isotope? (No; carbon isotopes have six protons.)

DIFFERENTIATED INSTRUCTION

Struggling Students

Have students use a different element to make sure they understand the general relationship between atoms and isotopes. Tell students that an atom of helium has two protons and two neutrons in its nucleus.

Ask How many protons and neutrons are in the nucleus of the isotope helium-5? (two protons and three neutrons)

Ask How many electrons do helium and helium-5 have? (two)

Focus on ELL: Extend Language

BEGINNING AND INTERMEDIATE SPEAKERS

Have students complete an ELL Frayer Model for each vocabulary term as it is introduced in the lesson. They should define each term in their own words. For example, they might define the term atom as "the tiniest particle that makes up matter." Their drawing of an atom might be based on Figure 2–1, and they might list a carbon atom as an example. If possible, have students translate each term into their own language, or have them write a definition of the term in their native language.

Study Wkbsks A/B, Appendix S26, ELL Frayer Model. Transparencies, GO10.

Answers

FIGURE 2–3 carbon-14

IN YOUR NOTEBOOK Students' diagrams should resemble Figure 2–1 but show an atom with two protons, two neutrons, and two electrons.
LESSON 2.1

GO17.

Map.

Transparencies,

Appendix S32, Vocabulary Word

Study Wkbks A/B,

cuss the difference between the two terms.

atom.

and chemical properties,

atoms held together

and

elements in definite proportions, unique physical

attributes as

Their word maps for

compound

Vocabulary Word Map

for the term

compound

a

discern compounds and elements, have them make

BUILD Vocabulary

RELATED WORD FORMS The verb

react means to act in response to

something. The adjective reactive
describes the tendency to respond or react.

DIFFERENTIATED INSTRUCTION

Struggling Students To further help students

discern compounds and elements, have them make a

Vocabulary Word Map for the term compound.

Their word maps for compound might include such

attributes as combination of two or more elements,

elements in definite proportions, unique physical

and chemical properties, and atoms held together

by chemical bonds. Then, have them make another

word map for element. Have pairs of students
discuss the difference between the two terms.

Study Wkbks A/B, Appendix S32, Vocabulary Word

Map. Transparencies, GO17.

Address Misconceptions

Atomic Models The use of atomic models, like the

Bohr models in Figure 2–4, can lead to student mis-

conceptions. For example, students may think that

electrons travel in fixed orbits around the nucleus of

an atom, similar to the way planets revolve around

the sun. Rather, electrons travel about in an electron

cloud—a “fuzzy” area around the nucleus where

electrons are only likely to be found. Help them

appreciate that models are just representations, not

reality. Use the analogy of a model car to make this

point by discussing as a class how a model car differs

from a real car. Then, explain some of the ways that

simple atomic models differ from real atoms.

Chemical Compounds

In what ways do compounds differ from their component elements?

In nature, most elements are found combined with other elements

in compounds. A chemical compound is a substance formed by the

chemical combination of two or more elements in definite propor-

tions. Scientists show the composition of compounds by a kind of

shorthand known as a chemical formula. Water, which contains two

atoms of hydrogen for each atom of oxygen, has the chemical formula

H₂O. The formula for table salt, NaCl, indicates that the elements that

make up table salt—sodium and chlorine—combine in a 1 : 1 ratio.

The physical and chemical properties of a compound are

usually very different from those of the elements from which it is

formed. For example, hydrogen and oxygen, which are gases at room

temperature, can combine explosively and form liquid water. Sodium

is a silver-colored metal that is soft enough to cut with a knife. It reacts

explosively with water. Chlorine is very reactive, too. It is a poisonous,

yellow-greenish gas that was used in battles during World War I. Sodium

chloride, table salt, is a white solid that dissolves easily in water. As you

know, sodium chloride is not poisonous. In fact, it is essential for the

survival of most living things.

Chemical Bonds

What are the main types of chemical bonds?

The atoms in compounds are held together by various types of chemi-

cal bonds. Much of chemistry is devoted to understanding how and

when chemical bonds form. Bond formation involves the electrons

that surround each atomic nucleus. The electrons that are available to

form bonds are called valence electrons. The main types of

chemical bonds are ionic bonds and covalent bonds.

Model an Ionic Compound

1. You will be assigned to represent either a sodium atom

or a chlorine atom.

2. Obtain the appropriate number of popcorn kernels

and arrange them in the model of the crystal.

3. Find a partner with whom you can form the ionic

compound sodium chloride—table salt.

4. In table salt, the closely packed sodium and chloride ions

form an orderly structure called a crystal. With all your

classmates, work as a class to model a sodium chloride crystal.

Analyze and Conclude

1. Relate Cause and Effect Describe the exchange of popcorn kernels (electrons)

that took place as you formed the ionic bond. What electrical charges resulted

from the exchange?

2. Use Models How were the “ions” arranged in the model of the crystal? Why did you and your classmates

choose this arrangement?

Quick Lab

PURPOSE Students will model the

attraction between oppositely charged

ions in an ionic compound.

MATERIALS bags of popcorn

kernels, paper

SAFETY Tell students not to eat any of

the popcorn kernels and to wash their

hands after they finish the lab.

PLANNING Review how bonds hold

together the atoms in compounds. Have

students create labels for themselves—

either Na or Cl—that they then hold up

during the activity.

ANALYZE AND CONCLUDE

1. Students representing Na lose

one kernel and become positive. Students representing Cl gain

one kernel and become negative.

2. Sample answer: We huddled close
together to represent Na⁺ ions surrounding Cl⁻ ions, and Cl⁻ ions

surrounding Na⁺ ions. Describe how the ions are closely packed to form a

crystal lattice.
Ionic Bonds An ionic bond is formed when one or more electrons are transferred from one atom to another. Recall that atoms are electrically neutral because they have equal numbers of protons and electrons. An atom that loses electrons becomes positively charged. An atom that gains electrons has a negative charge. These positively and negatively charged atoms are known as ions.

Figure 2–4A shows how ionic bonds form between sodium and chlorine in table salt. A sodium atom easily loses its one valence electron and becomes a sodium ion (Na⁺). A chlorine atom easily gains an electron and becomes a chloride ion (Cl⁻). In a salt crystal, there are trillions of sodium and chloride ions. These oppositely charged ions have a strong attraction, forming an ionic bond.

Covalent Bonds Sometimes electrons are shared by atoms instead of being transferred. What does it mean to share electrons? It means that the moving electrons actually travel about the nuclei of both atoms, forming a covalent bond. When the atoms share two electrons, the bond is called a single covalent bond. Sometimes the atoms share four electrons and form a double bond. In a few cases, atoms can share six electrons, forming a triple bond. The structure that results when atoms are joined together by covalent bonds is called a molecule. The molecule is the smallest unit of most compounds. The diagram of a water molecule in Figure 2–4B shows that each hydrogen atom is joined to water's lone oxygen atom by a single covalent bond. When atoms of the same element join together, they also form a molecule. Oxygen molecules in the air you breathe consist of two oxygen atoms joined by covalent bonds.

**In Your Notebook** In your own words, describe the differences between ionic and covalent bonds.

**Check for Understanding**

**VISUAL REPRESENTATION**

Ask small groups of students to create a Concept Map that relates the following concepts: atom, proton, neutron, electron, element, isotope, compound, ionic bond, ion, covalent bond, and molecule.

**Study Wkbks A/B, Appendix S21, Concept Map. Transparencies, GO4.**

**ADJUST INSTRUCTION**

If students’ concept maps are incorrect or show that they are confused, have students work in small groups. Ask group members to compare concept maps. If they disagree about how any of the concepts are related, have them refer to the text.

**Build Study Skills**

Use familiar phenomena as analogies to help students understand and distinguish between ionic and covalent bonds. After students have read about the two types of bonds, explain that ionic bonding can be summed up as “opposites attract.” Electrons are transferred from one atom to the other, forming positive and negative ions that attract and bind with one another like the north and south poles of two magnets. You may want to use magnets to demonstrate this type of attraction. Then, explain that covalent bonding involves the sharing of electrons. When electrons are shared between atoms, the atoms bind together like two people sharing the same umbrella. Challenge students to think of other analogies for covalent bonds in which two people or objects are held together by sharing something between them.

**DIFFERENTIATED INSTRUCTION**

**Less Proficient Readers** Have students work together in pairs to make a Venn Diagram for ionic and covalent bonds. Similarities might include that they hold atoms together. Differences might include that ionic bonds involve the transfer of electrons, whereas covalent bonds involve the sharing of electrons.

**Study Wkbks A/B, Appendix S33, Venn Diagram. Transparencies, GO18.**

**Advanced Students** Challenge creative students to develop three-dimensional or computer-generated models of ionic and covalent bonds. Their models should show how the two types of bonds form and how they differ. Ask students to present their models to the class.

Students should respond that the atoms in an oxygen molecule are joined together by covalent bonds. Ask them to predict what factors might affect how much oxygen will dissolve in water. Students can go online to Biology.com to gather their evidence.

**Students can use drag-and-drop labels to further explore ionic and covalent bonding in Art Review: Ionic and Covalent Bonding.**

**Answers**

**IN YOUR NOTEBOOK** Ionic bonds are formed when electrons are transferred from one atom to another. Covalent bonds are formed when atoms share electrons, which hold the atoms together in a molecule.
Assess and Remediate

EVALUATE UNDERSTANDING
Write the chemical formula for water (H₂O) on the board. Then, ask students to draw and label a model of a water molecule that shows how the atoms in a water molecule “stick” together. (Students should make and label a drawing similar to Figure 2–4B.) Then, have them complete the 2.1 Assessment.

REMEDIATION SUGGESTION
1a. Struggling Students If students have trouble with Question 5, have them reread the first paragraph of the lesson.

Assessment Answers
1a. An atom is an extremely small particle with a nucleus in the center. The nucleus is formed of smaller particles called protons, which are positively charged, and neutrons, which have no charge. Smaller particles called electrons, which are negatively charged, are in constant motion in the space surrounding the nucleus.

1b. 20 electrons

2a. because they all have the same number of protons and electrons

2b. Carbon-12 and carbon-14 each have six protons and six electrons. However, carbon-12 has six neutrons, whereas carbon-14 has eight neutrons.

3a. a substance formed by the chemical combination of two or more elements in definite proportions

3b. The two compounds have different properties because they contain hydrogen and oxygen in different proportions.

4a. ionic bonds and covalent bonds

4b. an ionic bond

5. Sample answer: Like all matter, living things are made up of elements and chemical compounds. In addition, the survival of living things depends on chemical reactions that take place within and outside their bodies. Therefore, to understand living things, biologists need to have a good understanding of chemistry.
A Nature-Inspired Adhesive

People who keep geckos as pets have always marveled at the way these little lizards can climb up vertical surfaces, even smooth glass walls, and then hang on by a single toe despite the pull of gravity. How do they do it? No, they do not have some sort of glue on their feet and they don’t have suction cups. Incredibly, they use van der Waals forces.

A gecko foot is covered by as many as half a million tiny hairlike projections. Each projection is further divided into hundreds of tiny, flat-surfaced fibers. This design allows the gecko’s foot to come in contact with an extremely large area of the wall at the molecular level. Van der Waals forces form between molecules on the surface of the gecko’s foot and molecules on the surface of the wall. This allows the gecko to actually balance the pull of gravity.

If it works for the gecko, why not for us? That’s the thinking of researchers at the Massachusetts Institute of Technology, who have now used the same principle to produce a bandage. This new bandage is held to tissue by van der Waals forces alone. Special materials make it possible for the new bandage to work even on moist surfaces, which means that it may be used to reseal internal tissues after surgery. By learning a trick or two from the gecko, scientists may have found a way to help heal wounds, and even save lives in the process.

If you are a doctor reviewing this new bandage for its potential applications. In what ways might you use such a bandage? Present your ideas as a list.

Suppose you are a doctor reviewing this new bandage for its potential applications. In what ways might you use such a bandage? Present your ideas as a list.

Teach

Connect to the Real World

After students read the feature, have them discuss their own experiences with adhesive bandages.

Ask What are some situations in which adhesive bandages don’t stay on very well? (When they are placed on hands or other surfaces that often get wet; when they are placed on knees and other places that bend often)

Ask Why don’t bandages stay on well in these situations? (The adhesive stops sticking after it gets wet or is loosened repeatedly by a joint bending.)

Ask Why might the new bandages described in the text work better in these situations? (They stay in place with van der Waals forces even without adhesives.)

Ask What do doctors typically use to hold together tissues after surgery? (Stitches or staples)

Ask Why might bandages be a better alternative? (They might cause less pain and bleeding; they might hold tissues together more smoothly and with fewer gaps than stitches or staples.)

DIFFERENTIATED INSTRUCTION

L1 Special Needs Students may have difficulty relating the nanostructures in the images to the surface of the bandage and the gecko’s feet. Let them manipulate a material that has similar projections but on a larger, more comprehensible scale. Bring a small piece of velvet fabric to class. Pass the fabric around, and have students feel the tiny fibers extending from its surface and examine them with a hand lens. Explain how the fibers on the fabric are similar to the nanostructures on the bandage and the gecko’s feet.

Quick Facts

NANOSTRUCTURE BANDAGES

The bandage described in the feature is covered with nanostructures—like those on a gecko’s foot—that dramatically increase the amount of surface area in contact with the body and, thus, the strength of van der Waals forces holding it in place. The developers of the bandage have tested it in living tissues and found that it is twice as strong as bandages without nanostructures. In addition to its superior adhesion, even on wet tissues, the bandage is waterproof. It is also biodegradable, so it does not have to be removed after surgery. It is biocompatible, as well, which means that it does not cause allergic reactions or other tissue responses. Because it is elastic, the bandage can conform to the irregular shapes of organs and other body structures. It can also be used as a patch to deliver healing medications directly to tissues.

Answers

WRITING Sample answer: to hold together internal tissues after surgeries; to hold together external tissues that are exposed to water or that bend frequently

NATIONAL SCIENCE EDUCATION STANDARDS

UCP I, V

CONTENT B.2, E.2

INQUIRY A.2.c
Getting Started

Objectives
2.2.1 Discuss the unique properties of water.
2.2.2 Differentiate between solutions and suspensions.
2.2.3 Explain what acidic solutions and basic solutions are.

Student Resources
Study Workbooks A and B, 2.2 Worksheets
Spanish Study Workbook, 2.2 Worksheets

Build Background
Play a guessing game with the class to build background about water and its importance to living things. Tell students the following statements. After each, give volunteers a chance to guess what “it” is.

• We take it for granted, but there would be no life on Earth without it.
• It makes up about 60 percent of the human body.
• It is nicknamed the “universal solvent.”

Properties of Water

THINK ABOUT IT Looking back at our beautiful planet, an astronaut in space said that if other beings have seen the Earth, they must surely call it “the blue planet.” He referred, of course, to the oceans of water that cover nearly three fourths of Earth’s surface. The very presence of liquid water tells a scientist that life may also be present on such a planet. Why should this be so? Why should life itself be connected so strongly to something so ordinary that we often take it for granted? The answers to those questions suggest that there is something very special about water and the role it plays in living things.

The Water Molecule

How does the structure of water contribute to its unique properties?

Water is one of the few compounds found in a liquid state over most of the Earth’s surface. Like other molecules, water (H2O) is neutral. The positive charges on its 10 protons balance out the negative charges on its 10 electrons. However, there is more to the story.

Polarity

With 8 protons in its nucleus, an oxygen atom has a much stronger attraction for electrons than does a hydrogen atom with its single proton. Thus, at any moment, there is a greater probability of finding the shared electrons in water close to its oxygen atom than near its hydrogen atoms. Because of the angles of its chemical bonds, the oxygen atom is on one end of the molecule and the hydrogen atoms are on the other, as shown in Figure 2–6. As a result, the oxygen end of the molecule has a slight negative charge and the hydrogen end of the molecule has a slight positive charge.

A molecule in which the charges are unevenly distributed is said to be “polar,” because the molecule is a bit like a magnet with two poles. The charges on a polar molecule are written in parentheses, (–) or (+), to show that they are weaker than the charges on ions such as Na⁺ and Cl⁻.

FIGURE 2–6 A Water Molecule

A water molecule is polar because there is an uneven distribution of electrons between the oxygen and hydrogen atoms. The negative pole is near the oxygen atom and the positive pole is between the hydrogen atoms.

Key Questions

- How does the structure of water contribute to its unique properties?
- How does water’s polarity influence its properties as a solvent?
- Why is it important for cells to buffer solutions against rapid changes in pH?

Vocabulary

hydrogen bond • cohesion • adhesion • mixture • solution • solute • solvent • suspension • pH scale • acid • base • buffer

Taking Notes

Venn Diagram As you read, draw a Venn diagram showing the differences between solutions and suspensions and the properties that they share.

UNIFYING CONCEPTS AND PROCESSES

I, III

CONTENT

B.1, B.2, B.3, B.4

INQUIRY

A.1.b

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION Why are the properties of water important to organisms?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand the properties of water that are important to organisms. Have pairs of students create three labeled diagrams to illustrate: (1) why water molecules are polar, (2) how they form hydrogen bonds, and (3) how they dissolve other polar or ionic substances.
Hydrogen Bonding  Because of their partial positive and negative charges, polar molecules such as water can attract each other. The attraction between a hydrogen atom on one water molecule and the oxygen atom on another is known as a hydrogen bond. Hydrogen bonds are not as strong as covalent or ionic bonds, and they can form in other compounds as well.  Because water is a polar molecule, it is able to form multiple hydrogen bonds, which account for many of water’s special properties.

- Cohesion  Cohesion is an attraction between molecules of the same substance. Because a single water molecule may be involved in as many as four hydrogen bonds at the same time, water is extremely cohesive. Cohesion causes water molecules to be drawn together, which is why drops of water form beads on a smooth surface. Cohesion also produces surface tension, explaining why some insects and spiders can walk on a pond’s surface, as shown in Figure 2–7.

- Adhesion  On the other hand, adhesion is an attraction between molecules of different substances. Have you ever been told to read the volume in a graduated cylinder at eye level? As shown in Figure 2–8, the surface of the water in the graduated cylinder dips slightly in the center because the adhesion between water molecules and glass molecules is stronger than the cohesion between water molecules. Adhesion between water and glass also causes water to rise in a narrow tube against the force of gravity. This effect is called capillary action. Capillary action is one of the forces that draws water out of the roots of a plant and up into its stems and leaves. Cohesion holds the column of water together as it rises.

- Heat Capacity  Another result of the multiple hydrogen bonds between water molecules is that it takes a large amount of heat energy to cause those molecules to move faster, which raises the temperature of the water. Therefore, water’s heat capacity, the amount of heat energy required to increase its temperature, is relatively high. This allows large bodies of water, such as oceans and lakes, to absorb large amounts of heat with only small changes in temperature. The organisms living within are thus protected from drastic changes in temperature. At the cellular level, water absorbs the heat produced by cell processes, regulating the temperature of the cell.

In Your Notebook  Draw a diagram of a meniscus. Label where cohesion and adhesion occur.

Quick Facts

WATER AND LIFE ON EARTH

In addition to the properties described in the text, water has other unique properties that are important to life on Earth. One property is its high boiling point. Because of this property, water remains in a liquid state over most of Earth’s surface. This is crucial for life, because virtually all organisms need liquid water to survive. Unlike most other compounds, water is less dense as a solid than it is as a liquid. This causes ice to float on water in temperate zone lakes in the winter. The floating ice insulates the water beneath it and prevents it from freezing. This, in turn, allows aquatic organisms that live in the water to survive during cold weather.

Teach

Build Study Skills

Tell students that visualization is a good way to remember material they are studying. Suggest they form mental images of the major concepts introduced on this page. For example, to remember cohesion, they might envision water forming beads on a waxed car. Have the class brainstorm ideas for mental images to help them remember adhesion and high heat capacity.

DIFFERENTIATED INSTRUCTION

- Less Proficient Readers  Draw a Cause and Effect Diagram on the board with one Cause box, and three Effect boxes. Ask students to redraw this diagram on a sheet of paper. Then, have them fill it in to help them relate hydrogen bonding with water’s properties of cohesion, adhesion, and high heat capacity. Suggest they use simple sketches to represent hydrogen bonding and each of its effects.

Study Wkbks A/B, Appendix S18, Cause and Effect Diagram. Transparencies, GO1.

- Focus on ELL: Access Content

ALL SPEAKERS  Pair beginning and intermediate speakers with advanced or advanced high speakers. Have partners use the lesson figures to preview the properties of water that are described in the lesson. Tell students to write one or two questions that are raised by each figure. For example, for Figure 2–6, they might write, What is a polar molecule? As students read the lesson, they should try to find answers to their questions. At the end of the lesson, as you review lesson content, ask partners to share their questions and answers with the class.

Answers

- FIGURE 2–7  The hydrogen atoms have a slight negative charge, and the oxygen atoms have a slight positive charge.

IN YOUR NOTEBOOK  Diagrams should resemble Figure 2–8, with the meniscus curving downward. Arrows should point to where water meets glass (adhesion), and to the water (cohesion).
Struggling Students

To better understand the concept of solution, have students focus on the \( \text{Na}^+ \) and \( \text{Cl}^- \) ions in the beaker at right in Figure 2–9. Suggest students draw a simple diagram showing a solution in which all the salt has dissolved. (Each \( \text{Na}^+ \) and \( \text{Cl}^- \) ion is surrounded by water molecules. The ions are evenly distributed throughout the solution.)

Students should conclude that the cold temperature of antarctic waters would increase the amount of dissolved oxygen available for ice fish. Explain that oxygen dissolves in water when oxygen molecules are surrounded by water molecules. Challenge students to infer why more oxygen molecules dissolve in water at lower temperatures. (At lower temperatures, oxygen molecules have less energy on average and are less likely to escape the effects of intermolecular attractions in the solution.) Students can go online to Biology.com to gather their evidence.

Have students further explore solutions using Art in Motion: A Salt Solution.

Answers

**FIGURE 2–9** The ions are surrounded by water molecules, separating the sodium and chloride in solution. Eventually, the ions become evenly distributed throughout the solution.
**Acids, Bases, and pH**

Why is it important for cells to buffer solutions against rapid changes in pH?

Water molecules sometimes split apart to form ions. This reaction can be summarized by a chemical equation in which double arrows are used to show that the reaction can occur in either direction.

\[
\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^- \quad \text{water} \quad \text{hydrogen ion + hydroxide ion}
\]

How often does this happen? In pure water, about 1 water molecule in 550 million splits to form ions in this way. Because the number of positive hydrogen ions produced is equal to the number of negative hydroxide ions produced, pure water is neutral.

**The pH Scale** Chemists devised a measurement system called the **pH scale** to indicate the concentration of H⁺ ions in solution. As Figure 2–10 shows, the pH scale ranges from 0 to 14. At a pH of 7, the concentration of H⁺ ions and OH⁻ ions is equal. Pure water has a pH of 7. Solutions with a pH below 7 are called acidic because they have more H⁺ ions than OH⁻ ions. The lower the pH, the greater the acidity. Solutions with a pH above 7 are called basic because they have more OH⁻ ions than H⁺ ions. The higher the pH, the more basic the solution. Each step on the pH scale represents a factor of 10. For example, a liter of a solution with a pH of 4 has 10 times as many H⁺ ions as a liter of a solution with a pH of 5.

**In Your Notebook** Order these items in order of increasing acidity: soap, lemon juice, milk, acid rain.

**Quick Lab**

**GUIDED INQUIRY**

**Acidic and Basic Foods**

1. Predict whether the food samples provided are acidic or basic.
2. Tear off a 2-inch piece of pH paper for each sample you will test. Place these pieces on a paper towel.
3. Construct a data table in which you will record the name and pH of each food sample.

**Use a scalpel to cut a piece off each solid.**

**CAUTION:** Be careful not to cut yourself. Do not eat the food. Touch the cut surface of each sample to a square of pH paper. Use a dropper pipette to place a drop of any liquid sample on a square of pH paper. Record the pH of each sample in your data table.

**Analyze and Conclude**

1. **Analyze Data** Were most of the samples acidic or basic?
2. **Evaluate** Was your prediction correct?

**Quick Lab**

**PURPOSE** Students will make and test predictions about which foods are acidic and which are basic.

**MATERIALS** Solid foods and fruit juices, pH paper, paper towel, scalpel, dropper pipette

**SAFETY** Warn students to handle scalpsels with care. Remind them not to eat any of the foods tested in the lab.

**PLANNING** Prepare small samples of a variety of solid foods and fruit juices. Most foods are at least slightly acidic, but there are a few exceptions, including egg white and tofu. You may want to include one of these foods. If you use egg white, cook it first to kill any bacteria. Items can be placed in small, paper sample cups available from restaurant or party supply stores.

**ANALYZE AND CONCLUDE**

1. **Answers will vary depending on the food and juice samples tested.**
2. **Students’ predictions were correct if they agree with the pH test results.**

**Address Misconceptions**

**Corrosive Properties of Bases** Most students know that strong acids are harsh solutions that may “eat away” other substances, but many do not realize that bases can be corrosive too. Show the class a bottle of drain cleaner. Point out that it contains sodium hydroxide, a base. Sodium hydroxide will “eat away” at the clog, eliminating it.

**Answers**

**IN YOUR NOTEBOOK** soap, milk, acid rain, lemon juice

**Use Visuals**

Use Figure 2–10 to familiarize students with acids, bases, and pH. Point out that pH is a measure of hydrogen ion concentration. Then, explain that acids have a higher hydrogen ion concentration and bases have a lower hydrogen ion concentration than pure water. Have students find the value for pure water on the pH scale. After explaining that the pH of pure water is the point of neutrality on the scale, have students find the pH of stomach acid and bleach.

**Ask** How does the hydrogen ion concentration of stomach acid and bleach compare with that of pure water? (H⁺ ion concentration is higher for stomach acid and lower for bleach.)

**DIFFERENTIATED INSTRUCTION**

**Struggling Students** It may seem counterintuitive to students that pH, which measures hydrogen ion concentration, decreases as the hydrogen ion concentration increases. To reinforce the fact that hydrogen ion concentration and pH have an inverse relationship, have students create a simple, **Two-Column Table** to help them remember the relationship between pH and hydrogen ion concentration. Students should make a column for pH and another for Hydrogen ion concentration. Then, ask them to fill in “high” and “low” accordingly in the table, to show that low pH = high H⁺ concentration, and high pH = low H⁺ concentration.

**Study Wkbks A/B, Appendix S31, Two-Column Table. Transparencies, GO16.**

**BIOLOGY.com** Have students access Data Analysis: Acid Rain to use data to learn more about the ecological impact of acid rain.
Connect to Health Science

Explain that normal blood pH is between 7.35–7.45. A lower or higher blood pH can be a sign of ill health. Have students discuss why regulating blood pH is vital to maintaining homeostasis.

DIFFERENTIATED INSTRUCTION

Advanced Students Explain that the acidity of blood is reduced by the actions of the kidneys and lungs. The kidneys filter out and excrete excess H+ ions from the blood, while the lungs exhale more CO2 when blood acid levels are high. Ask students how blood pH might be affected by a disease that reduced lung function. (The blood might be more acidic.)

Assess and Remediate

EVALUATE UNDERSTANDING

Have students write a paragraph that explains how the concentration of hydrogen ions determines the acid-base properties of a solution. Then, have them complete the 2.2 Assessment.

REMEDICATION SUGGESTION

Special Needs If students have difficulty answering Question 1c, remind them that a polar molecule is like a magnet: it has a positive end and a negative end. Then, have them study Figure 2–7.

Biology.com Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. A molecule is polar when there is an uneven distribution of electrons between its atoms. This causes the molecule to have an area with a slight negative charge and an area with a slight positive charge.

1b. A hydrogen bond occurs when the slight positive charge on a hydrogen atom in one water molecule is attracted to the slight negative charge on the oxygen atom in another water molecule.

1c. With eight protons in its nucleus, the oxygen atom in a water molecule has a much stronger attraction for electrons than do the hydrogen atoms in the molecule. The oxygen atom is on one end of the molecule, and the hydrogen atoms are on the other end. Therefore, the oxygen end of the molecule is slightly negative while the hydrogen end is slightly positive—resulting in a polar molecule.

2a. Water is such a good solvent because of its polarity. It can dissolve both ionic compounds and other polar molecules.

2b. A solution is a mixture of two or more substances in which the molecules of the substances are evenly distributed. A suspension is a mixture of water and nondissolved materials.

2c. A buffer is a compound that forms hydrogen ions in solution. A base forms hydroxide ions in solution.

3a. An acid is a compound that forms

3b. The pH of the solution will be less than 7.

3c. A drop in blood pH is countered by chemical buffers such as bicarbonate and phosphate ions.

WRITE ABOUT SCIENCE

Creative Writing 4. Suppose you are a writer for a natural history magazine for children. This month’s issue will feature insects. Write a paragraph explaining why some bugs, such as the water strider, can walk on water.
THINK ABOUT IT In the early 1800s, many chemists called the compounds created by organisms’ “organic,” believing they were fundamentally different from compounds in nonliving things. Today we understand that the principles governing the chemistry of living and nonliving things are the same, but the term “organic chemistry” is still around. Today, organic chemistry means the study of compounds that contain bonds between carbon atoms, while inorganic chemistry is the study of all other compounds.

The Chemistry of Carbon

What elements does carbon bond with to make up life’s molecules? Why is carbon so interesting that a whole branch of chemistry should be set aside just to study carbon compounds? There are two reasons for this. First, carbon atoms have four valence electrons, allowing them to form strong covalent bonds with many other elements.

Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life. Living organisms are made up of molecules that consist of carbon and these other elements.

Even more important, one carbon atom can bond to another, which gives carbon the ability to form chains that are almost unlimited in length. These carbon-carbon bonds can be single, double, or triple covalent bonds. Chains of carbon atoms can even close up on themselves to form rings, as shown in Figure 2–12. Carbon has the ability to form millions of different large and complex structures. No other element even comes close to matching carbon’s versatility.

FIGURE 2–12 Carbon Structures Carbon can form single, double, or triple bonds with other carbon atoms. Each line between atoms in a molecular drawing represents one covalent bond. Observing How many covalent bonds are there between the two carbon atoms in acetylene?

Teach for Understanding

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION How do organisms use different types of carbon compounds?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand the functions of the different types of carbon compounds in organisms. Ask each student to create a four-page brochure, with each page devoted to one of the four major types of carbon compounds in living things. For each type of compound, students should diagram its general structure and describe its functions in organisms.
LESSON 2.3

Connect to Chemistry

After students read about polymerization, tell them that polymerization commonly occurs in one of two ways: addition polymerization or condensation polymerization. Explain that in addition polymerization, monomers join together without any change in their molecules. In condensation polymerization, a small molecule—often a water molecule—is released each time monomers join together. Next, write the chemical formulas for glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$) on the board. Remind students that glucose is a monosaccharide and sucrose is a disaccharide.

Ask Is carbohydrate polymerization an example of addition or condensation polymerization? (condensation polymerization)

You may wish to draw a sketch of the reaction on the board, as shown below:

![Polymerization Diagram](image)

Ask Condensation reactions are sometimes known as dehydration reactions. Why? (A water molecule is lost. Dehydration means loss of water.) Next, show students the opposite of a dehydration reaction, called a hydrolysis reaction:

![Hydrolysis Diagram](image)

Explain to your students that dehydration and hydrolysis reactions are extremely common in biochemical processes.

DIFFERENTIATED INSTRUCTION

Less Proficient Readers Have students read the Build Vocabulary feature on this page. Tell them that a saccharide is a sugar and the prefix di- means “two.” Then, ask them to predict the meanings of the terms monosaccharide, disaccharide, and polysaccharide. (one sugar, two sugars, and many sugars, respectively)

Answers

**FIGURE 2–13** Links are small units that are joined together to form a chain. In a similar way, monomers are small compounds that are joined together to form large compounds called polymers.

**FIGURE 2–14** Carbohydrates Single sugar molecules are also known as monosaccharides. Besides glucose, monosaccharides include galactose, which is a component of milk, and fructose, which is found in many fruits. Ordinary table sugar, sucrose, consists of glucose and fructose. Sucrose is a disaccharide, a compound made by joining two simple sugars together.

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**Biology In-Depth**

**MORE FUNCTIONS OF CARBOHYDRATES**

In recent years, researchers have found that carbohydrates have more functions in living things than just providing energy and helping to give organisms structure. They have discovered that carbohydrates also play important roles in the interactions of cells within organisms. Simple sugar molecules attached to larger protein molecules appear to act like ID tags on the larger molecules. For example, these “glycoproteins” may allow sperm to recognize egg cells during fertilization and fetuses to avoid detection and attack by the maternal immune system during gestation. The sugar molecules may also help white blood cells identify infected tissues. Errors in the formation of sugar ID molecules have been implicated in some autoimmune disorders.
Lipids Lipids are a large and varied group of biological molecules that are generally not soluble in water. Lipids are made mostly from carbon and hydrogen atoms. The common categories of lipids are fats, oils, and waxes. Lipids can be used to store energy. Some lipids are important parts of biological membranes and waterproof coverings. Steroids synthesized by the body are lipids as well. Many steroids, such as hormones, serve as chemical messengers.

Many lipids are formed when a glycerol molecule combines with compounds called fatty acids, as shown in Figure 2–15. If each carbon atom in a lipid’s fatty acid chains is joined to another carbon atom by a single bond, the lipid is said to be saturated. The term saturated is used because the fatty acids contain the maximum possible number of hydrogen atoms.

If there is at least one carbon-carbon double bond in a fatty acid, the fatty acid is said to be unsaturated. Lipids whose fatty acids contain more than one double bond are said to be polyunsaturated. If the terms saturated and polyunsaturated seem familiar, you have probably seen them on food package labels. Lipids that contain unsaturated fatty acids, such as olive oil, tend to be liquid at room temperature. Other cooking oils, such as corn oil, sesame oil, canola oil, and peanut oil, contain polyunsaturated lipids.

In Your Notebook Compare and contrast saturated and unsaturated fats.

![Lipid structure](image)

**FIGURE 2–15** Lipids Lipid molecules are made up of glycerol and fatty acids. Liquid lipids, such as olive oil, contain mainly unsaturated fatty acids.

**Check for Understanding**

**QUESTION BOX**

Ask students to write a question they have about carbohydrates or lipids on a scrap of paper. Then, pass an empty shoe box around the room, and have students place their questions in the box. This will give students who are uncomfortable asking questions aloud in class a chance to have their questions answered.

**ADJUST INSTRUCTION**

Review students’ questions, and select the most important or fundamental questions that students have raised. Read the questions aloud in class, and call on volunteers to answer them.

**Answers**

**IN YOUR NOTEBOOK** Both types of fats are lipids that form when a glycerol molecule combines with fatty acid compounds. In saturated fats, each carbon atom in the fatty acid chains is joined to another carbon atom by a single bond. In unsaturated fats, at least one carbon atom in the fatty acid chains is joined to another carbon atom by a double bond. At room temperature, saturated fats tend to be solids and unsaturated fats tend to be liquids.

**Build Reading Skills**

Ask students if they ever heard the expression, “A picture is worth 1000 words.” Tell them that looking at the photographs, diagrams, and graphs in their textbook when they read can help them understand the material. When they read about carbohydrates, have them examine Figure 2–14, and when they read about lipids, have them look at Figure 2–15. The figures will help students understand the structures of the two types of macromolecules. For example, Figure 2–15 will show them the composition of lipids and help them understand how saturated and unsaturated lipids differ. Suggest they check their comprehension by asking themselves: What makes the lipid in Figure 2–15 unsaturated?

**DIFFERENTIATED INSTRUCTION**

**Special Needs** Use Cloze Prompts to help students focus on the most important information about lipids. Have them write the following prompts on a sheet of paper and try to fill in the missing words as they read:

- Lipids are made mostly from carbon and ______. (hydrogen atoms)
- Lipids can be used to store ______. (energy)
- Lipids are part of biological ______. (membranes and waterproof coverings)
- Lipids contain glycerol and ______. (fatty acids)
- Lipids that are liquid at room temperature contain ______ fatty acids. (unsaturated)

**Study Wkbks A/B, Appendix S2, Cloze Prompts.**

**Advanced Students** Have students learn about the roles of saturated and unsaturated lipids in nutrition and health. Then, ask them, to share what they learn in a presentation to the class. In their presentation, they should include recommendations for food choices that have healthy amounts and types of lipids.
LESSON 2.3

Use Models

Challenge individual students to use materials of their choice to create a three-dimensional model of a nucleic acid or a protein. For example, a student might use interlocking brick construction toys in different colors and shapes to represent nitrogenous bases, phosphate groups, and 5-carbon sugars, and join the bricks together in the correct arrangement to model a nucleic acid. Other materials students might use include modeling clay, toothpicks, and beads. Tell students to make a key for their model showing what each part represents. Have students display their models in the classroom as you work through the lesson.

DIFFERENTIATED INSTRUCTION

ELL Struggling Students Have students work in small groups to create models of a nucleic acid and a protein. Suggest they talk about the structure of each molecule and write down a quick plan for how they will model it before they begin construction.

Focus on ELL: Build Background

ALL SPEAKERS Show students visuals of carbohydrates, lipids, nucleic acids, and proteins. Then, have them apply the Think-Pair-Share strategy. Give students time to think about what they learned from the visuals. Then, pair beginning and intermediate speakers with advanced and advanced high speakers. Have partners discuss the visuals to help them make a list of descriptive terms and examples that are associated with each type of macromolecule. Ask partners to share their lists with the class.

Study Wkbks A/B, Appendix S14, Think-Pair-Share.
Assess and Remediate

EVALUATE UNDERSTANDING

Ask a volunteer to explain what macromolecules are. Ask another student to go to the board and list the four main groups of macromolecules found in organisms. Call on one student after another to describe the structure or identify a function of one of the groups of macromolecules. Then, have students complete the 2.3 Assessment.

REMEDIATION SUGGESTION

LPR Less Proficient Readers If students have trouble with Question 2c, have them reread the definition of polymer. Then, have them look closely at the structure of lipids in Figure 2–15 and the structure of proteins in Figure 2–18.

Students can check their understanding of lesson concepts with the Self-Test assessment. They can then take an online version of the Lesson Assessment.

Assessment Answers

1a. carbon, hydrogen, oxygen, phosphorus, sulfur, and nitrogen

1b. Carbon atoms can bond to the atoms of many other elements. Carbon atoms can also readily bond to one another to form short chains, long chains, or rings, and these bonds can be single, double, or triple covalent bonds. This means that carbon atoms can be combined to make millions of different types of structures.

2a. carbohydrates, lipids, nucleic acids, and proteins

2b. Sample answer: Carbohydrates provide energy, lipids store energy, nucleic acids store and transmit hereditary information, and proteins control the rate of reactions and regulate cell processes.

2c. Proteins are considered polymers because they are made of chains of amino acids. Lipids are not considered polymers because they are not made of chains of smaller units; they are made of a glycerol molecule combined with fatty acids.

3a. carbon, hydrogen, and oxygen

3b. carbohydrates
Chemical Reactions and Enzymes

Key Questions

What happens to chemical bonds during chemical reactions?

How do energy changes affect whether a chemical reaction will occur?

What role do enzymes play in living things and what affects their function?

Vocabulary

chemical reaction • reactant • product • activation energy • catalyst • enzyme • substrate

Taking Notes

Concept Map As you read, make a concept map that shows the relationship among the vocabulary terms in this lesson.

THINK ABOUT IT

Living things, as you have seen, are made up of chemical compounds—some simple and some complex. But chemistry isn’t just what life is made of—chemistry is also what life does. Everything that happens in an organism—its growth, its interaction with the environment, its reproduction, and even its movement—is based on chemical reactions.

Chemical Reactions

A chemical reaction is a process that changes, or transforms, one set of chemicals into another. An important scientific principle is that mass and energy are conserved during chemical transformations. This is also true for chemical reactions that occur in living organisms. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form an iron oxide called rust. Other reactions occur quickly. The elements or compounds that enter into a chemical reaction are known as reactants. The elements or compounds produced by a chemical reaction are known as products. Chemical reactions involve changes in the chemical bonds that join atoms in compounds. An important chemical reaction in your bloodstream that enables carbon dioxide to be removed from the body is shown in Figure 2–19.

FIGURE 2–19 Carbon Dioxide in the Bloodstream As it enters the blood, carbon dioxide reacts with water to produce carbonic acid \( \text{H}_2\text{CO}_3 \), which is highly soluble. This reaction enables the blood to carry carbon dioxide to the lungs. In the lungs, the reaction is reversed and produces carbon dioxide gas, which you exhale.

Body Tissues Lungs

Capillary

\( \text{CO}_2 \) + \( \text{H}_2\text{O} \) \( \text{H}_2\text{CO}_3 \)

Air sac

\( \text{CO}_2 \)

Think for Understanding

ENDURING UNDERSTANDING The process of science helps biologists investigate how nature works at all levels, from the molecules in cells to the biosphere.

GUIDING QUESTION How do chemicals combine and break apart inside living things?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how enzymes work. Ask small groups of students to use various small items (such as different shapes of dry pasta and modeling clay) to create a three-dimensional model of an enzyme-catalyzed reaction. Their model should include symbols for the substrates, enzyme, and products. It should represent each step of the reaction and show how the enzyme is unchanged and ready to catalyze another reaction after it releases the products.
**Energy in Reactions**

How do energy changes affect whether a chemical reaction will occur?

Energy is released or absorbed whenever chemical bonds are formed or broken. This means that chemical reactions also involve changes in energy.

**Energy Changes** Some chemical reactions release energy, and other reactions absorb it. Energy changes are one of the most important factors in determining whether a chemical reaction will occur.

Chemical reactions that release energy occur on their own, or spontaneously. Chemical reactions that absorb energy do not occur without a source of energy. An example of an energy-releasing reaction is the burning of hydrogen gas, in which hydrogen reacts with oxygen to produce water vapor.

$$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$$

The energy is released in the form of heat, and sometimes—when hydrogen gas explodes—light and sound.

The reverse reaction, in which water is changed into hydrogen and oxygen gases, absorbs much energy that it generally doesn’t occur by itself. In fact, the only practical way to reverse the reaction is to pass an electrical current through water to decompose water into hydrogen gas and oxygen gas. Thus, in one direction the reaction produces energy, and in the other direction the reaction requires energy.

**Energy Sources** In order to stay alive, organisms need to carry out reactions that require energy. Because matter and energy are conserved in chemical reactions, every organism must have a source of energy to carry out chemical reactions. Plants get energy by trapping and storing the energy from sunlight in energy-rich compounds. Animals get their energy when they consume plants or other animals. Humans release the energy needed to grow tall, to breathe, to think, and to dream through the chemical reactions that occur when we metabolize, or break down, digested food.

**Activation Energy** Chemical reactions that release energy do not always occur spontaneously. That’s a good thing because if they did, the pages of this book might burst into flames. The cellulose in paper burns in the presence of oxygen and releases heat and light. However, paper burns only if you light it with a match, which supplies enough energy to get the reaction started. Chemists call the energy that is needed to get a reaction started the activation energy. As Figure 2–20 shows, activation energy is involved in chemical reactions regardless of whether the overall chemical reaction releases energy or absorbs energy.

**Teach**

**Use Visuals**

Use Figure 2–20 to help students understand energy changes in reactions. Have each student copy the two graphs in the figure, including all the arrows and labels. When they finish copying the graphs, have them point out the arrows that represent activation energy in the graphs. Then, have students draw similar arrows to represent the difference in energy between the reactants and products in the two reactions. Call on volunteers to describe, in their own words, the difference between the two graphs.

**Ask** What happens during a chemical reaction when products contain more energy than the reactants? (Energy is released.)

**Ask** What happens during a chemical reaction when products contain less energy than the reactants? (Energy is absorbed.)

**Ask** Which graph could represent a reaction in which food is broken down for energy? (the energy-releasing reaction)

**DIFFERENTIATED INSTRUCTION**

**ELL** English Language Learners Remind students that reactants are the chemicals at the beginning of a reaction and products are the chemicals at the end of a reaction. One mnemonic device to help the students remember which is which, would be: “Reactants react to produce products.”

**Address Misconceptions**

Spontaneous Chemical Reactions Students may tend to equate “spontaneous” with “fast.” Explain to students that spontaneous reactions do not necessarily occur quickly. A spontaneous reaction proceeds on its own without an added source of energy, but it could take quite a long time. For example, diamonds spontaneously decay into graphite, but this process takes millions of years!

**Biology In-Depth**

**CHEMICAL REACTIONS OF METABOLISM**

Metabolism is the sum of all the chemical reactions that take place in living cells. The reactions include both exothermic (energy-releasing) and endothermic (energy-absorbing) reactions. Exothermic reactions make up catabolism—reactions that break down molecules and release energy. An example of catabolism is the breakdown of ATP to form ADP and a phosphate group. This reaction releases about 13 kilocalories of energy per mole and provides most of the energy used by cells. Endothermic reactions make up anabolism—reactions that synthesize macromolecules and absorb energy. An example of anabolism is the synthesis of ATP from ADP and a phosphate group.

**Answers**

**FIGURE 2–20** Energy-absorbing reaction—the energy of the reactants is less than the energy of the products; Energy-releasing reaction—the energy of the reactants is greater than the energy of the products.
Use Visuals

Discuss the importance of enzymes and the way enzymes work. Ask students how the reaction represented by Figure 2–21 is different with the enzyme than without it. (The enzyme lowers the activation energy.) Explain how lowering the activation energy speeds up the reaction by allowing many more molecules to react. Have students look at Figure 2–22, and point out the cyclic nature of the diagram.

Ask Why is a cycle diagram appropriate to show how an enzyme works? (The enzyme can be used over and over again, which allows the process to keep repeating.)

DIFFERENTIATED INSTRUCTION

L1 Struggling Students Have students make a simplified Cycle Diagram of Figure 2–22 to show the sequence of steps in an enzyme-catalyzed reaction. For each step in the diagram, they should write a sentence describing in their own words what happens in that step.


VISUAL ANALOGY

Discuss Figure 2–23, the lock-and-key analogy, with the class. Have students identify what the lock, key, and keyhole represent in the analogy. (lock—enzyme; key—substrate; keyhole—active site) Tell students that the analogy is a simplified representation of what happens when substrates bind to the active site of an enzyme. For example, rather than being rigid like a keyhole, the active site may actually change shape when substrates bind to it.

With the Visual Analogy: Lock and Key, students can interact with an animation to learn more about enzymes and substrates.

Answers

FIGURE 2–22 The carbonic anhydrase is free to catalyze another reaction.

Enzymes

What role do enzymes play in living things and what affects their function?

Some chemical reactions that make life possible are too slow or have activation energies that are too high to make them practical for living tissue. These chemical reactions are made possible by a process that would make any chemist proud—cells make catalysts. A catalyst is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction’s activation energy.

Nature’s Catalysts Enzymes are proteins that act as biological catalysts. Enzymes speed up chemical reactions that take place in cells. Like other catalysts, enzymes act by lowering the activation energies, as illustrated by the graph in Figure 2–21. Lowering the activation energy has a dramatic effect on how quickly the reaction is completed. How big an effect does it have? Consider the reaction in which carbon dioxide combines with water to produce carbonic acid.

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3
\]

Left to itself, this reaction is so slow that carbon dioxide might build up in the body faster than the bloodstream could remove it. Your bloodstream contains an enzyme called carbonic anhydrase that speeds up the reaction by a factor of 10 million. With carbonic anhydrase on the job, the reaction takes place immediately and carbon dioxide is removed from the blood quickly.

Enzymes are very specific, generally catalyzing only one chemical reaction. For this reason, part of an enzyme’s name is usually derived from the reaction it catalyzes. Carbonic anhydrase gets its name because it also catalyzes the reverse reaction that removes water from carbonic acid.

The Enzyme-Substrate Complex How do enzymes do their jobs? For a chemical reaction to take place, the reactants must collide with enough energy so that existing bonds will be broken and new bonds will be formed. If the reactants do not have enough energy, they will be unchanged after the collision.

Enzymes provide a site where reactants can be brought together to react. Such a site reduces the energy needed for reaction. The reactants of enzyme-catalyzed reactions are known as substrates. Figure 2–22 provides an example of an enzyme-catalyzed reaction.
The substrates bind to a site on the enzyme called the active site. The active site and the substrates have complementary shapes. The fit is so precise that the active site and substrates are often compared to a lock and key, as shown in Figure 2–23.

**Regulation of Enzyme Activity** Enzymes play essential roles in controlling chemical pathways, making materials that cells need, releasing energy, and transferring information. Because they are catalysts for reactions, enzymes can be affected by any variable that influences a chemical reaction. Temperature, pH, and regulatory molecules can affect the activity of enzymes.

Many enzymes are affected by changes in temperature. Not surprisingly, those enzymes produced by human cells generally work best at temperatures close to 37°C, the normal temperature of the human body. Enzymes work best at certain ionic conditions and pH values. For example, the stomach enzyme pepsin, which begins protein digestion, works best under acidic conditions. In addition, the activities of most enzymes are regulated by molecules that carry chemical signals within cells, switching enzymes “on” or “off” as needed.

### 2.4 Assessment

**Review Key Concepts**

1. **a. Review** What happens to chemical bonds during chemical reactions?
   
   **b. Apply Concepts** Why is the melting of ice not a chemical reaction?

2. **a. Review** What is activation energy?
   
   **b. Compare and Contrast** Describe the difference between a reaction that occurs spontaneously and one that does not.

3. **a. Review** What are enzymes?
   
   **b. Explain** Explain how enzymes work, including the role of the enzyme-substrate complex.

4. **c. Use Analogies** A change in pH can change the shape of a protein. How might a change in pH affect the function of an enzyme such as carbonic anhydrase? (Hint: Think about the analogy of the lock and key.)

**Visual Thinking**

Make a model that demonstrates the fit between an enzyme and its substrate. Show your model to a friend or family member and explain how enzymes work using your model.

---

**Assessment Answers**

1a. The bonds change—often they are formed or broken.

1b. because new chemicals are not formed

2a. the energy that is needed to get a reaction started

2b. A reaction that occurs spontaneously releases energy. A reaction that does not occur spontaneously absorbs energy.

3a. proteins that act as biological catalysts

3b. Enzymes provide a site where reactants, called substrates, can be brought together to react. The substrates bind to a site on the enzyme called the active site, forming an enzyme-substrate complex. This reduces the activation energy needed for the reaction.

3c. If a change in pH changes the shape of an enzyme, it might result in the enzyme and substrates no longer fitting together properly. As a result, the enzyme would no longer be able to speed up the chemical reaction.

---

**Visual Thinking**

4. Students’ models should show that the substrates and the active site of the enzyme fit together because they have complementary shapes like a lock and key or like two adjacent pieces of a jigsaw puzzle.
Pre-Lab

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

Lab

Tell students they will perform the chapter lab Temperature Affects Enzymes described in Lab Manual A.

Struggling Students A simpler version of the chapter lab is provided in Lab Manual B.

SAFETY

Remind students to wear goggles, gloves, and aprons during the lab, because hydrogen peroxide irritates skin and bleaches clothing. Tell them that the puréed liver is raw and may contain bacteria, so it is very important for them to wash their hands after they finish the lab.

Look online for Editable Lab Worksheets.

For corresponding pre-lab in the Foundation Edition, see page 46.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP I, II, III
CONTENT B.3, C.1.d
INQUIRY A.1.b

Pre-Lab Answers

BACKGROUND QUESTIONS

a. Reactions in cells are often too slow or require an activation energy that is not practical for living tissue. Enzymes lower the activation energy of reactions.
b. pH, temperature, and regulatory molecules
c. Sample answer: The frying pan is like an enzyme. It provides a location where the eggs can be cooked. The control knob allows the user to control the temperature of the frying pan, which affects how fast the eggs cook.

PRE-LAB QUESTIONS

1. I will observe bubbles of oxygen on the surface of the liver. The filter paper disk will rise to the top of the puree.
2. temperature; reaction time
3. Oxygen produced in the reaction causes the disk to float. The rate of the reaction that produces the oxygen depends on the activity of the enzyme. The more active the enzyme, the faster the oxygen is produced, and the quicker the disk will rise.

Pre-Lab: Temperature Affects Enzymes

Problem How does temperature affect the rate of an enzyme-catalyzed reaction?
Materials raw liver, forceps, petri dish, dropper pipette, 1% hydrogen peroxide solution, 25-mL graduated cylinder, 50-mL beaker, puréed liver, filter paper disks, paper towels, clock or watch with a second hand, water baths, thermometers, beaker tongs

Lab Manual Chapter 2 Lab
Skills Focus Form a Hypothesis, Design an Experiment, Measure, Interpret Graphs

Connect to the Big idea Many chemical reactions in living organisms could not take place without enzymes. Enzymes catalyze the reactions that release energy from nutrients. They also catalyze the synthesis of the complex molecules that organisms need to grow and stay healthy. One factor that affects the action of enzymes is temperature. Think about why people store some foods in a refrigerator. The cold temperature limits the ability of enzymes to break down, or spoil, those foods.

Do high temperatures have the opposite effect on enzymes? Do they become more and more active as the temperature rises? In this lab, you will investigate the effect of temperature on an enzyme-catalyzed reaction.

Background Questions

a. Review Why do many reactions that occur in cells require enzymes? How do enzymes speed up chemical reactions?
b. Review Name three variables that can affect enzyme activity.
c. Use Analogies Use eggs and a frying pan on a stove as an analogy for reactants and an enzyme. Use the control knob on the stove burner as an analogy for how a variable can affect the action of an enzyme.

Pre-Lab Questions

1. Relate Cause and Effect How will you know that a chemical reaction is taking place in Part A? How will you know in Part B?
2. Control Variables In Part B of the lab, which variable will you manipulate? Which variable is the dependent variable?
3. Relate Cause and Effect How is the time required for the filter-paper disk to float related to the activity of the enzyme?
2 Study Guide

Big Idea: Matter and Energy
Chemical bonds join together the molecules and compounds of life. Water and carbon compounds play essential roles in organisms, which carry out chemical reactions in their daily life processes.

2.1 The Nature of Matter
The subatomic particles that make up atoms are protons, neutrons, and electrons. All isotopes of an element have the same chemical properties, because they have the same number of electrons. The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed. The main types of chemical bonds are ionic bonds and covalent bonds.

atom (34) ionic bond (37)
nucleus (34) ion (47)
electron (34) covalent bond (37)
element (35) molecule (37)
isotope (35) van der Waals forces (38)
compound (36)

2.2 Properties of Water
Water is a polar molecule. Therefore, it is able to form multiple hydrogen bonds, which account for many of its special properties. Water’s polarity gives it the ability to dissolve both ionic compounds and other polar molecules. Buffers play an important role in maintaining homeostasis in organisms.

hydrogen bond (41) solution (42) pH scale (43)
cohesion (41) solute (42) acid (44)
adhesion (41) solvent (42) base (44)
mixture (42) suspension (42) buffer (44)

2.3 Carbon Compounds
Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life.

2.4 Chemical Reactions and Enzymes
Chemical reactions always involve changes in the chemical bonds that join atoms in compounds. Chemical reactions that release energy often occur spontaneously. Chemical reactions that absorb energy will not occur without a source of energy. Enzymes speed up chemical reactions that take place in cells. Temperature, pH, and regulatory molecules can affect the activity of enzymes.

chemical reaction (50) catalyst (52)
reactant (50) enzyme (52)
product (50) substrate (52)
activation energy (51)

Think Visually Create a table in which you compare the structures and functions of the following macromolecules: carbohydrates, lipids, proteins, and nucleic acids.

Performance Tasks

SUMMATIVE TASK Have students work in pairs to create a simple storybook for younger children on the chemistry of living things. In addition to introducing basic concepts such as atoms, molecules, and chemical reactions, students should describe the structure and functions of the four groups of carbon compounds in living things.

TRANSFER TASK Introduce inherited defects in enzymes that are needed for metabolism, or the chemical reactions inside cells. Explain that inherited defects of metabolism can cause serious health problems. Have students work in small groups to identify a particular metabolism defect, such as phenylketonuria (PKU), and create a presentation about it. In their presentation, students should identify the enzyme that is defective, its normal role in metabolism, and how a defect in the enzyme affects metabolism and health.

Answers

THINK VISUALLY
Student tables should show that
• carbohydrates consist of simple sugars called monosaccharides or chains of sugars called polysaccharides; they provide energy or structure.
• lipids consist of glycerol and fatty acids; they store energy or are part of membranes and waterproof coverings.
• nucleic acids consist of chains of nucleotides; they store and transmit genetic information.
• proteins consist of chains of amino acids; they control the rate of reactions, regulate cell processes, form cell structures, transport substances into or out of cells, or help fight disease.

The Chemistry of Life 55
Lesson 2.1

UNDERSTAND KEY CONCEPTS
1. c  2. d  3. b
4. Elements are composed of atoms. Compounds are composed of atoms of two or more elements combined in definite proportions.
5. A radioactive isotope is an isotope with an unstable nucleus that breaks down at a constant rate over time. Scientific uses of radioactive isotopes include determining the age of rocks, treating cancer, killing bacteria in food, and tracing the movements of substances within organisms.
6. Atoms in a compound are held together by chemical bonds.
7. Two electrons are shared in a single covalent bond, four in a double bond, and six in a triple bond.

THINK CRITICALLY
8. The diagram should show that hydrogen and chlorine form a covalent bond. Students can use the chlorine atom in Figure 2–4 as a starting point and pair one of the seven electrons in its outer level with hydrogen’s single electron.
9. 0.1 nm; If 100 million atoms lined up are 1 cm in length, then the diameter of one atom equals 1 cm divided by 100,000,000. This yields $1 \times 10^8$ cm, or $1 \times 10^{-10}$ m, which equals 0.1 nm.

Lesson 2.2

UNDERSTAND KEY CONCEPTS
10. b  11. b  12. c
13. Cohesion is an attraction between molecules of the same substance. An example is water molecules drawing together, forming beads on a smooth surface. Adhesion is an attraction between molecules of different substances. An example is capillary action.
14. A solution is a mixture in which one substance is dissolved in another. The solute is the substance that is dissolved. The solvent is the substance in which the solute is dissolved.
15. An acid is a compound that forms hydrogen ions in solution. Acidic solutions have pH values less than 7. A base is a compound that forms hydroxide ions in solution. Basic solutions have pH values greater than 7.

Lesson 2.3

UNDERSTAND KEY CONCEPTS
18. c  19. c
20. Polymers are large macromolecules made up of smaller molecules called monomers. For example, monomers called monosaccharides join together to form polymers called polysaccharides.
21. Proteins control the rate of chemical reactions, regulate cell processes, form important cellular structures, transport substances into or out of cells, and help fight disease.
20. Explain the relationship between monomers and polymers, using polysaccharides as an example.
21. Identify three major roles of proteins.
22. Describe the parts of a nucleotide.

Think Critically
23. Design an Experiment Suggest one or two simple experiments to determine whether a solid white substance is a lipid or a carbohydrate. What evidence would you need to support each hypothesis?
24. Infer Explain what the name “carbohydrate” might indicate about the chemical composition of sugars.

2.4 Chemical Reactions and Enzymes

Understand Key Concepts
25. An enzyme speeds up a reaction by
   a. lowering the activation energy.
   b. raising the activation energy.
   c. releasing energy.
   d. absorbing energy.
26. In a chemical reaction, a reactant binds to an enzyme at a region known as the
   a. catalyst.
   b. substrate.
   c. product.
   d. active site.
27. Describe the two types of energy changes that can occur in a chemical reaction.
28. What relationship exists between an enzyme and a catalyst?
29. Describe some factors that may influence enzyme activity.

Think Critically
30. Infer Why is it important that energy-releasing reactions take place in living organisms?
31. Predict Changing the temperature or pH can change an enzyme’s shape. Describe how changing the temperature or pH might affect the function of an enzyme.
32. Use Analogies Explain why a lock and key are used to describe the way an enzyme works. Describe any ways in which the analogy is not perfect.

THE GHOSTLY FISH

The oxygen-binding abilities of hemoglobin enable the blood of most fish to carry nearly 50 times the oxygen it would without the protein. The ghostly white appearance of the antarctic ice fish results from its clear blood—blood without hemoglobin. Ice fish, however, are able to survive without hemoglobin because of the unique properties of water at low temperatures. Oxygen from the air dissolves in seawater, providing the oxygen that fish need to survive. Fish absorb dissolved oxygen directly through their gills, where it passes into their bloodstream. The solubility of oxygen is much greater at low temperatures. Therefore, the icy cold antarctic waters are particularly rich in oxygen.

The large, well-developed gills and scaleless skin of ice fishes allow them to absorb oxygen efficiently from the water. Compared to red-blooded fishes, ice fishes have a higher blood volume, thinner blood, and larger hearts. So, their blood can carry more dissolved oxygen and the large hearts can pump the thinner blood through the body faster. These and other physical features, combined with the chemistry of oxygen in water at low temperatures, enable ice fish to survive where many other organisms cannot.

1. Relate Cause and Effect Ice fish produce anti-freeze proteins to keep their blood from freezing; their body temperature stays below 0°C. How does low body temperature affect the blood’s ability to carry dissolved oxygen?
2. Infer People living at high altitudes generally have more hemoglobin in their blood than people living at sea level. Why do you think this is so?
3. Predict If the antarctic oceans were to warm up, how might this affect ice fish?
4. Connect to the Big Idea The chemical reactions in all living things slow down at low temperatures. Since some of the most important reactions in our body require oxygen, how would low temperatures affect the ice fish’s need for oxygen?

Lesson 2.4

UNDERSTAND KEY CONCEPTS
25. a 26. d
27. A chemical reaction can either release or absorb energy.
28. An enzyme is a biological catalyst.
29. Factors that may influence enzyme activity include pH, temperature, and regulatory molecules that switch enzymes “on” or “off” as needed.

22. a 5-carbon sugar, a phosphate group, and a nitrogenous base

THINK CRITICALLY
23. Sample answer: Students might suggest trying to dissolve the solid in water, because lipids are generally not water soluble. They also might suggest warming the solid to see if it would soften, because solid lipids tend to soften when heated.
24. “Carbo” indicates that carbon is present; “hydrate” suggests oxygen and hydrogen are present.

After students have read through the Chapter Mystery, call on volunteers to summarize facts about antarctic waters and ice fish that help explain how the fish can survive without hemoglobin in their blood.

Ask How does the low temperature of the water help ice fish survive? (The cold temperature allows the water to dissolve more oxygen. The cold temperature also slows the fishes’ metabolism so they need less oxygen.)

Ask What physical adaptations in ice fish help them survive? (Large gills and scaleless skin allow the fish to absorb more oxygen into their blood. High blood volume, thin blood, and a large heart allow the blood to be pumped around the body faster.)

CHAPTER MYSTERY ANSWERS
1. Low body temperature would increase the blood’s ability to carry dissolved oxygen.
2. At high altitudes, less oxygen is available in the atmosphere than at low altitudes. Therefore, people (and other organisms) need more hemoglobin to ensure that enough oxygen is obtained to supply the tissues of the body.
3. Sample answer: There would be less dissolved oxygen available for the ice fish, and at the same time, their need for oxygen would increase because warmer water temperatures would speed the fish’s metabolism. The fish might migrate to colder waters farther south to avoid the temperature change. If, however, colder waters could not be found, the fish would not thrive and might even go extinct. Or, if the change is gradual, the fish may evolve methods to transport oxygen and survive in warmer water.
4. Low temperatures would reduce the ice fish’s need for oxygen.

Have students take a video field trip with the Untamed Science crew to learn more about the unique properties of water in Not a Drop to Drink.
THINK CRITICALLY

30. To carry out all life processes, living things need the energy released in chemical reactions.

31. If changing the temperature or pH changed the enzyme's shape, the enzyme might lose its ability to bind with substrates, and an enzyme-substrate complex would not form. As a result, the enzyme would not be able to speed up the reaction it normally catalyzed.

32. The fit of an enzyme and its substrates at the enzyme's active site is so precise that the substrates are like a key and the enzyme is like a lock. Similar to a key in a lock, only substrates of a certain shape can fit into the active site of the enzyme. The analogy isn't perfect because inserting a key into a lock is a physical process, whereas the binding of substrates at the active site of an enzyme is a chemical process. Also, the way substrates fit enzymes is not a rigid process.

33. Interpret Graphs
At which temperature was the greatest amount of product formed?

34. Draw Conclusions
Describe the results of each reaction. How can you explain these results?

35. Predict
A student performs the same chemical reaction at 30°C. Approximately how much product can she expect to obtain?

Write About Science

36. Explanation
Write a paragraph that includes the following:
(a) a description of the four major classes of organic compounds found in living things, and
(b) a description of how these organic compounds are used by the human body.

37. Assess the
What properties of carbon allow it to play such a major role in the chemistry of living things?

38. Interpret Graphs
At what time of day is the pond most acidic?

39. Form a Hypothesis
Which of the following is the most reasonable hypothesis based on the results obtained?

A student measured the pH of water from a small pond at several intervals throughout the day. Use the graph to answer questions 38 and 39.

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39. Form a Hypothesis
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Standardized Test Prep

Multiple Choice

1. The elements or compounds that enter into a chemical reaction are called
   A products.       C active sites.
   B catalysts.      D reactants.

2. Chemical bonds that involve the total transfer of electrons from one atom or group of atoms to another are called
   A covalent bonds.
   B ionic bonds.
   C hydrogen bonds.
   D van der Waals bonds.

3. Which of the following is NOT an organic molecule found in living organisms?
   A protein
   B nucleic acid
   C sodium chloride
   D lipid

4. Which combination of particle and charge is correct?
   A proton: positively charged
   B electron: positively charged
   C neutron: negatively charged
   D electron: no charge

5. In which of the following ways do isotopes of the same element differ?
   A in number of neutrons only
   B in number of protons only
   C in numbers of neutrons and protons
   D in number of neutrons and mass

6. Which of the following molecules is made up of glycerol and fatty acids?
   A sugars
   B starches
   C lipids
   D nucleic acids

7. Nucleotides consist of a phosphate group, a nitrogenous base, and a
   A fatty acid
   B lipid
   C 5-carbon sugar
   D 6-carbon sugar

Questions 8–9

The enzyme catalase speeds up the chemical reaction that changes hydrogen peroxide into oxygen and water. The amount of oxygen given off is an indication of the rate of the reaction.

8. Based on the graph, what can you conclude about the relationship between enzyme concentration and reaction rate?
   A Reaction rate decreases with increasing enzyme concentration.
   B Reaction rate increases with decreasing enzyme concentration.
   C Reaction rate increases with increasing enzyme concentration.
   D The variables are indirectly proportional.

9. Which concentration of catalase will produce the fastest reaction rate?
   A 5%
   B 10%
   C 15%
   D 20%

Open-Ended Response

10. List some of the properties of water that make it such a unique substance.

Answers

1. D
2. B
3. C
4. A
5. D
6. C
7. C
8. C
9. D
10. Sample answer: Properties of water that make it such a unique substance include the polarity of its molecules, which allows them to form hydrogen bonds with each other. Because of these properties, water exhibits cohesion, adhesion, high heat capacity, and the ability to dissolve many substances.

Test-Taking Tip

USE TIME WISELY

Advise students to skip to the next question if they get stuck on a difficult one. Suggest they respond to the questions they can answer easily first, and then go back to questions they have trouble answering. For these difficult ones, make sure they take the time to reread the entire question before attempting to answer it.
Plan Ahead
After students have read what their task will be in the Unit 1 Project, suggest they review how to design a controlled experiment and what independent and dependent variables are. Also, make sure students understand acids, bases, and pH. If students haven’t already tested pH during a previous activity, consider demonstrating how pH paper is used. You may want to direct students to selected experiments in a lab manual to help familiarize them with experimental procedures.

Monitor the Project
Suggest students begin by writing a hypothesis for the first of their three experiments. Briefly check that each student’s hypothesis can be tested with a controlled experiment. Then, as they design their experiments, ask individual students questions that will help them identify variables, write a procedure, and think of ways to collect and record data to test the hypothesis.

Ask
What are the independent and dependent variables in your experiment?

Ask
How will data be collected in this experiment to show whether the medication actually neutralizes stomach acid?

Project Assessment
Make sure students use the rubric and reflection questions to assess their work. Then, use the rubric to assign a final score. Note that it is important to value the creativity of students’ work as well as the content when you score their projects. If desired, talk with students about any differences between their self-assessment scores and your assigned score.

Unit Project
Design the Experiment
Did you ever wonder how a medication goes from the lab to your local drug store shelf? A lot of research and experimentation by scientists goes into testing a new medication to make sure it is safe and effective. Imagine you are a scientist working for a pharmaceutical company. Your current project is to test a new medication for heartburn. Heartburn is a painful condition in which acid inside the stomach backs up into the esophagus—the connection between your throat and stomach. This new medication helps neutralize stomach acid to prevent irritation.

Your Task
Design three possible experiments to test the safety and effectiveness of the new heartburn medication. Before you begin, think about how you will know if the medication actually neutralizes stomach acid. Once you’ve written your procedures, you will propose the experiments to your company’s Executive Board for Research and Development.

Assessment Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Scientific Content</th>
<th>Quality of Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Correctly and extensively applies knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are clever and effectively test the hypotheses. Experimental conditions are carefully controlled and variables are correctly identified.</td>
</tr>
<tr>
<td>3</td>
<td>Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are logical and test the hypotheses. Experimental conditions are controlled and variables are correctly identified.</td>
</tr>
<tr>
<td>2</td>
<td>Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) incompletely to experimental designs and predictions.</td>
<td>Experimental designs need some revisions—some parts are unclear or do not fully test the hypotheses. Variables and controls need corrections.</td>
</tr>
<tr>
<td>1</td>
<td>Does not correctly apply knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.</td>
<td>Experimental designs are unclear and do not test the hypotheses. Variables and controls listed are incorrect or absent.</td>
</tr>
</tbody>
</table>

Reflection Questions
1. Score your experimental designs using the rubric below. What score did you give yourself?
2. What did you do well in this project?
3. What about your designs needs improvement?
4. Are there any ethical dilemmas related to your experiments? Explain.

21st Century Skills
To be successful in the 21st century, students need skills and learning experiences that extend beyond subject area mastery. The Unit 1 Project helps students build the following 21st Century Skills: Critical Thinking and Systems Thinking; Problem Identification, Formulation, and Solution; Self-Direction; and Accountability and Adaptability.

FOCUS ON COMMUNICATION
Extend this Unit Project by having small groups of students design and create a magazine advertisement for a hypothetical heartburn medication. Suggest that the advertisement not only extol the virtues of the medication but also teach the consumer about heartburn medications by briefly describing an experiment that supports the medication’s effectiveness. Have groups present their ads to the class.

For more practice building 21st Century Skills, see The Chapter Mystery pages in Study Workbook A.