LIVING BY CHEMISTRY

SECOND EDITION

Angelica M. Stacy

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Professor of Chemistry
University of California at Berkeley

SECOND EDITION

with

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HOW TO USE THIS BOOK

Next generation chemistry brought to life.

- Chapter-opening pages introduce the main ideas and learning goals of the chapter.

CHAPTER 4

Moving Electrons

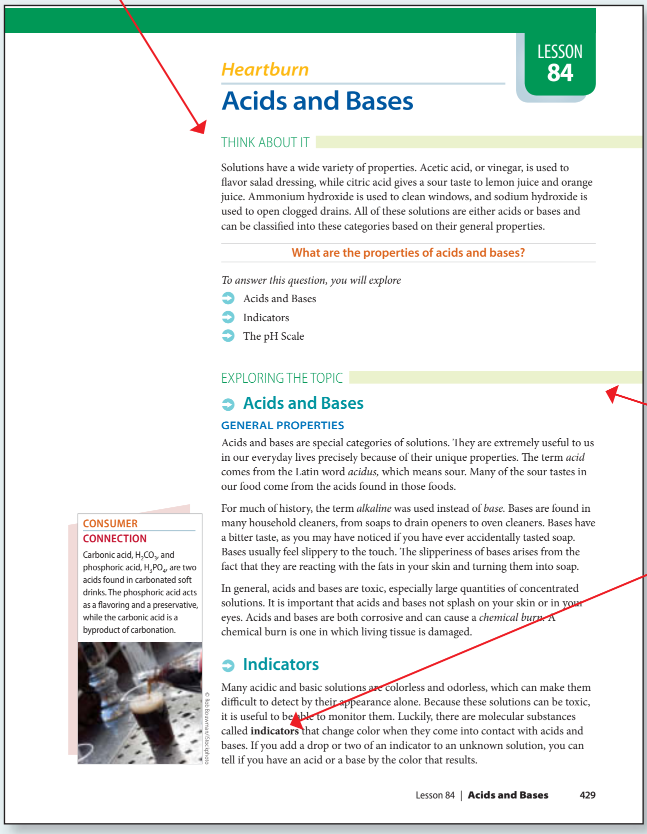
In this chapter, you will study

- the systematic arrangement of electrons in an atom
- how ionic compounds are formed
- valence electrons and ionic bonding

When heated, different metal atoms produce flames of different colors. That is what causes the many brilliant colors of a fireworks display.

While the nucleus of an atom can be difficult to change, the electrons are a different story. Electrons can be moved around within an atom or transferred between atoms. When atoms transfer electrons, they become ions with positive and nega...

- **THINK ABOUT IT** prepares you to read about chemistry. Take a moment to reflect on the lesson question and topic outline before you read the lesson.



LESSON 84

Heartburn

Acids and Bases

THINK ABOUT IT

Solutions have a wide variety of properties. Acetic acid, or vinegar, is used to flavor salad dressing, while citric acid gives a sour taste to lemon juice and orange juice. Ammonium hydroxide is used to clean windows, and sodium hydroxide is used to open clogged drains. All of these solutions are either acids or bases and can be classified into these categories based on their general properties.

What are the properties of acids and bases?

To answer this question, you will explore

- Acids and Bases
- Indicators
- The pH Scale

EXPLORING THE TOPIC

Acids and Bases

GENERAL PROPERTIES

Acids and bases are special categories of solutions. They are extremely useful to us in our everyday lives precisely because of their unique properties. The term *acid* comes from the Latin word *acidus,* which means sour. Many of the sour tastes in our food come from the acids found in those foods.

For much of history, the term *alkaline* was used instead of *base.* Bases are found in many household cleaners, from soaps to drain openers to oven cleaners. Bases have a bitter taste, as you may have noticed if you have ever accidentally tasted soap. Bases usually feel slippery to the touch. The slipperiness of bases arises from the fact that they are reacting with the fats in your skin and turning them into soap.

In general, acids and bases are toxic, especially large quantities of concentrated solutions. It is important that acids and bases not splash on your skin or in your eyes. Acids and bases are both corrosive and can cause a *chemical burn.* A chemical burn is one in which living tissue is damaged.

Indicators

Many acidic and basic solutions are colorless and odorless, which can make them difficult to detect by their appearance alone. Because these solutions can be toxic, it is useful to be able to monitor them. Luckily, there are molecular substances called **indicators** that change color when they come into contact with acids and bases. If you add a drop or two of an indicator to an unknown solution, you can tell if you have an acid or a base by the color that results.

CONSUMER CONNECTION

Carbonic acid, H_2CO_3, and phosphoric acid, H_3PO_4, are two acids found in carbonated soft drinks. The phosphoric acid acts as a flavoring and a preservative, while the carbonic acid is a byproduct of carbonation.

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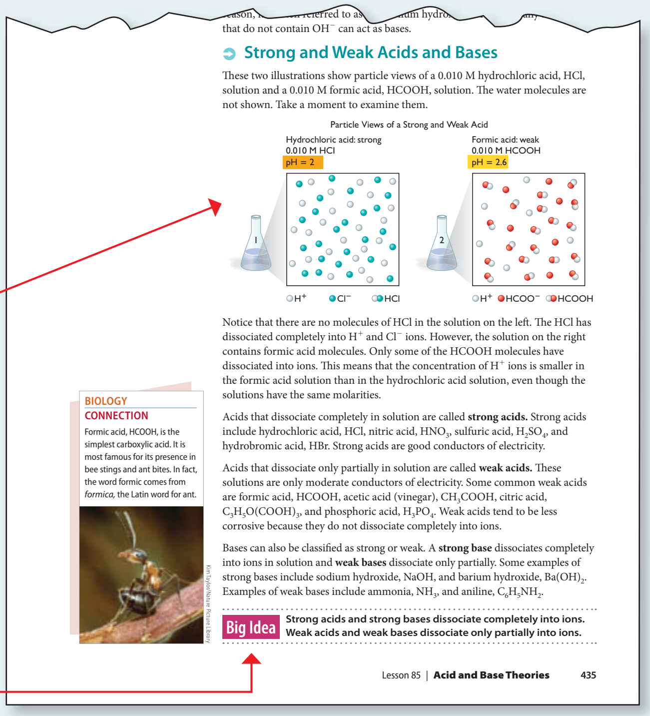
Lesson 84 | **Acids and Bases** 429

- **EXPLORING THE TOPIC** allows you to review and practice the chemistry at the right pace. Each lesson follows in step with the daily hands-on, inquiry-based lesson from your class.

- Look at the **key terms** in bold. Find definitions in English and Spanish at the end of the book.

- Develop the science practice of using visual representations and models to explain chemistry by studying the **figures, diagrams,** and **illustrations** used throughout the book.

- Pay attention to **Big Ideas,** especially when you are reviewing for a quiz or exam. These are fundamental concepts of chemistry.



that do not contain OH^- can act as bases.

Strong and Weak Acids and Bases

These two illustrations show particle views of a 0.010 M hydrochloric acid, HCl, solution and a 0.010 M formic acid, HCOOH, solution. The water molecules are not shown. Take a moment to examine them.

Particle Views of a Strong and Weak Acid

Notice that there are no molecules of HCl in the solution on the left. The HCl has dissociated completely into H^+ and Cl^- ions. However, the solution on the right contains formic acid molecules. Only some of the HCOOH molecules have dissociated into ions. This means that the concentration of H^+ ions is smaller in the formic acid solution than in the hydrochloric acid solution, even though the solutions have the same molarities.

Acids that dissociate completely in solution are called **strong acids.** Strong acids include hydrochloric acid, HCl, nitric acid, HNO_3, sulfuric acid, H_2SO_4, and hydrobromic acid, HBr. Strong acids are good conductors of electricity.

Acids that dissociate only partially in solution are called **weak acids.** These solutions are only moderate conductors of electricity. Some common weak acids are formic acid, HCOOH, acetic acid (vinegar), CH_3COOH, citric acid, $C_3H_5O(COOH)_3$, and phosphoric acid, H_3PO_4. Weak acids tend to be less corrosive because they do not dissociate completely into ions.

Bases can also be classified as strong or weak. A **strong base** dissociates completely into ions in solution and **weak bases** dissociate only partially. Some examples of strong bases include sodium hydroxide, NaOH, and barium hydroxide, $Ba(OH)_2$. Examples of weak bases include ammonia, NH_3, and aniline, $C_6H_5NH_2$.

Big Idea Strong acids and strong bases dissociate completely into ions. Weak acids and weak bases dissociate only partially into ions.

BIOLOGY CONNECTION

Formic acid, HCOOH, is the simplest carboxylic acid. It is most famous for its presence in bee stings and ant bites. In fact, the word formic comes from *formica,* the Latin word for ant.

Kim Taylor/Nature Picture Library

Lesson 85 | **Acid and Base Theories** 435

Practice makes perfect.

- **Important to Know** highlights ideas that you should retain for further use throughout the course.

Important to Know All temperatures must be converted to the Kelvin scale when completing gas law problems.

So far you've been introduced to three of the gas laws. These gas laws apply when any two of the variables, *P*, *V*, or *T*, are changed and everything else stays the same.

Charles's law	$V = kT$	*P* and amount of gas do not change.	$k = \frac{V}{T}$
Gay-Lussac's law	$P = kT$	*V* and amount of gas do not change.	$k = \frac{P}{T}$
Boyle's law	$P = k\left(\frac{1}{V}\right)$	*T* and amount of gas do not change.	$k = PV$

Note that the proportionality constant, *k*, is a generic symbol and is different for each gas sample and for each gas law.

Example 2

Balloon with Air

Imagine that you fill a balloon with air to a volume of 1.5 L. The air is at a temperature of 20 °C. You place the balloon in a refrigerator for half an hour until the air in the balloon is at a temperature of 10 °C. What is the new volume of the balloon?

Solution

First figure out which gas law to use. The external pressure on the balloon remains the same because the air pressure in the refrigerator is the same as the air pressure outside. Use Charles's law. You can predict that *V* will decrease because *T* decreases.

Initial Conditions		Final Conditions
$P_1 = 1.0$ atm	→	$P_2 = 1.0$ atm
$T_1 = 20$ °C		$T_2 = 10$ °C
$V_1 = 1.5$ L		$V_2 = ?$

Convert temperature to the Kelvin scale.

$$K = 273 + C$$
$$T_1 = 273 + 20 = 293\text{ K}$$
$$T_2 = 273 + 10 = 283\text{ K}$$

Determine the value of *k*.

$$k = \frac{V_1}{T_1} = \frac{1.5\text{ L}}{293\text{ K}} = 0.0050\text{ L/K}$$

Use *k* to determine V_2.

$$V_2 = k\,T_2 = 0.0050\text{ L/K} \cdot 283\text{ K} = 1.4\text{ L}$$

The balloon has shrunk to a volume of 1.4 L.

312 Chapter 11 | **Pressing Matter**

- Lessons offer critical math support. The **examples** show you how to solve problems step by step. Try to answer the question yourself before reading the solution to check your understanding.

- The **LESSON SUMMARY** recaps the main ideas of the lesson that answer the opening question. Reading the lesson summaries is a good way to review for a quiz or an exam.

LESSON SUMMARY

How do meteorologists keep track of the amount of rainfall?

KEY TERMS
proportional
proportionality constant

Everywhere around the world, the amount of rainfall is measured by its height. If volume were used to report rainfall, each meteorologist would report a different number, depending on the area of the base of the rain gauge used. Height and volume for a specific rain gauge are related by a proportionality constant, *k*.

- Doing the **Exercises** will help you practice what you learn each day.

- Answer the Reading Questions to make sure you understood the main ideas.

- Answer the Reason and Apply questions to practice problem solving and using evidence-based reasoning to justify answers.

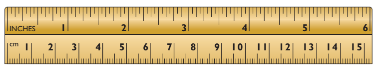
Exercises

Reading Questions

1. Suppose you have a cylindrical rain gauge with a base area of 2.0 cm^2. Explain two different ways you can determine the volume when the height of water is 3.0 cm.
2. Explain in your own words why meteorologists prefer to measure rain in inches or centimeters, not in milliliters or cubic centimeters.

Reason and Apply

3. If the amount of rainfall increases, do both the volume and height of water in the rain gauge keep track of this increase? Explain your thinking.
4. If you use a beaker for a rain gauge and the weather station uses a graduated cylinder, will both instruments give the same volume? The same height?
5. If a large washtub, a dog's water dish, and a graduated cylinder were left outside during a rainstorm, would the three containers all have the same volume of water in them after the storm? Explain why or why not.
6. Inches are used in the United States, but centimeters are used by scientists and in the rest of the world. Look at a ruler that is marked in both inches and centimeters.
   a. Make a graph of centimeters versus inches so that the *y*-axis is centimeters and the *x*-axis is inches.



   b. Convert 12 in. to centimeters.
   c. How many inches is 10 cm?
   d. How many inches is 1 cm?
7. A student placed the same empty rain gauge outside before five different rainstorms. She measured the height and volume of the water in the gauge after each storm. Her results are in the table.

Storm number	Height (cm)	Volume (cm^3)
1	1.0 cm	2.5 cm^3
2	2.5 cm	6.3 cm^3
3	0.5 cm	1.1 cm^3
4	8.0 cm	20.0 cm^3
5	5.0 cm	12.5 cm^3

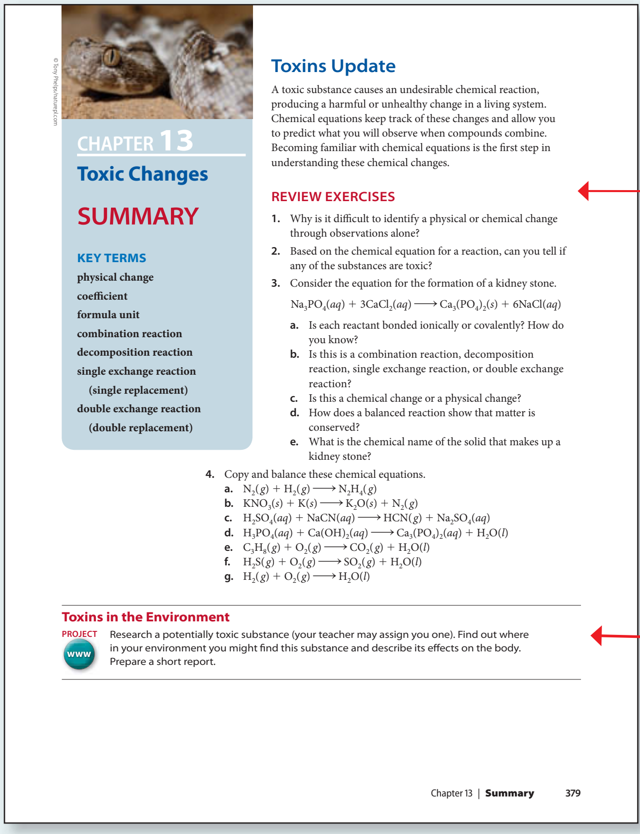
   a. Which rainstorm dropped the most rain? Did you use height or volume to answer this question? Why?
   b. What pattern do you notice?
   c. Draw a graph of the data to show that the volume and height are proportional.
   d. Explain why the data points do not all lie exactly on a straight line.
   e. Predict the volume for a height of 6.0 cm. Show your work.

266 Chapter 10 | **Physically Changing Matter**

Review and prepare for quizzes and exams.

- The **Chapter Summary and Review Exercises** help you review after each group of lessons.

- **Projects** may be assigned by your teacher to give you a chance to do some research on your own.



CHAPTER 13

Toxic Changes

SUMMARY

KEY TERMS

physical change
coefficient
formula unit
combination reaction
decomposition reaction
single exchange reaction (single replacement)
double exchange reaction (double replacement)

Toxins Update

A toxic substance causes an undesirable chemical reaction, producing a harmful or unhealthy change in a living system. Chemical equations keep track of these changes and allow you to predict what you will observe when compounds combine. Becoming familiar with chemical equations is the first step in understanding these chemical changes.

REVIEW EXERCISES

1. Why is it difficult to identify a physical or chemical change through observations alone?
2. Based on the chemical equation for a reaction, can you tell if any of the substances are toxic?
3. Consider the equation for the formation of a kidney stone.

$$Na_3PO_4(aq) + 3CaCl_2(aq) \longrightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$$

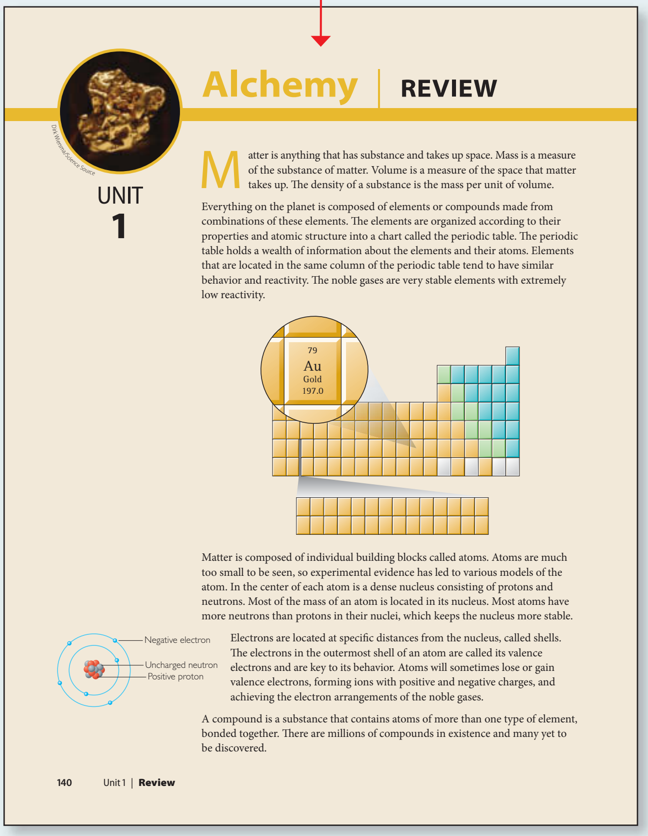
   a. Is each reactant bonded ionically or covalently? How do you know?
   b. Is this is a combination reaction, decomposition reaction, single exchange reaction, or double exchange reaction?
   c. Is this a chemical change or a physical change?
   d. How does a balanced reaction show that matter is conserved?
   e. What is the chemical name of the solid that makes up a kidney stone?
4. Copy and balance these chemical equations.
   a. $N_2(g) + H_2(g) \longrightarrow N_2H_4(g)$
   b. $KNO_3(s) + K(s) \longrightarrow K_2O(s) + N_2(g)$
   c. $H_2SO_4(aq) + NaCN(aq) \longrightarrow HCN(g) + Na_2SO_4(aq)$
   d. $H_3PO_4(aq) + Ca(OH)_2(aq) \longrightarrow Ca_3(PO_4)_2(aq) + H_2O(l)$
   e. $C_3H_8(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(l)$
   f. $H_2S(g) + O_2(g) \longrightarrow SO_2(g) + H_2O(l)$
   g. $H_2(g) + O_2(g) \longrightarrow H_2O(l)$

Toxins in the Environment

PROJECT Research a potentially toxic substance (your teacher may assign you one). Find out where in your environment you might find this substance and describe its effects on the body. Prepare a short report.

Chapter 13 | **Summary** 379

- The **Unit Review** summarizes what you learned in that unit.



UNIT 1

Alchemy | REVIEW

Matter is anything that has substance and takes up space. Mass is a measure of the substance of matter. Volume is a measure of the space that matter takes up. The density of a substance is the mass per unit of volume.

Everything on the planet is composed of elements or compounds made from combinations of these elements. The elements are organized according to their properties and atomic structure into a chart called the periodic table. The periodic table holds a wealth of information about the elements and their atoms. Elements that are located in the same column of the periodic table tend to have similar behavior and reactivity. The noble gases are very stable elements with extremely low reactivity.

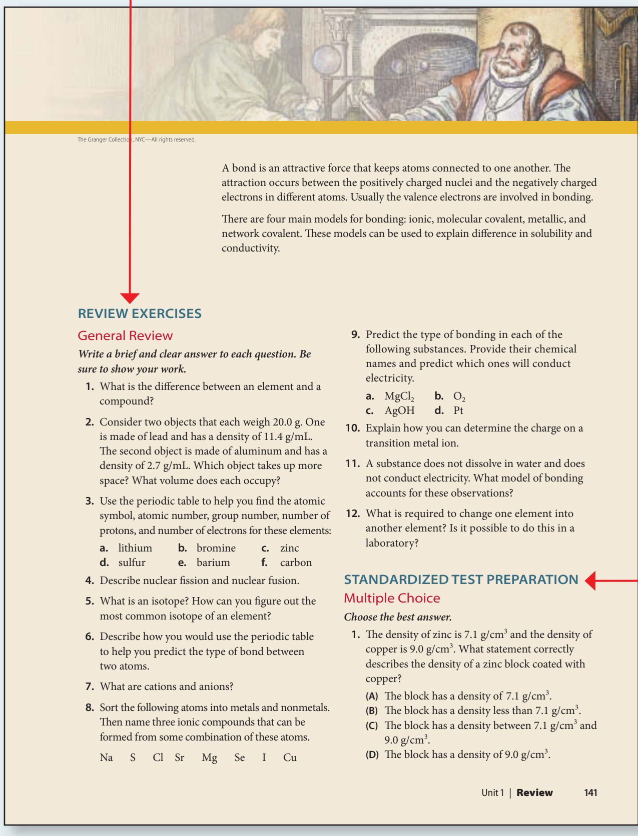
Matter is composed of individual building blocks called atoms. Atoms are much too small to be seen, so experimental evidence has led to various models of the atom. In the center of each atom is a dense nucleus consisting of protons and neutrons. Most of the mass of an atom is located in its nucleus. Most atoms have more neutrons than protons in their nuclei, which keeps the nucleus more stable.

Electrons are located at specific distances from the nucleus, called shells. The electrons in the outermost shell of an atom are called its valence electrons and are key to its behavior. Atoms will sometimes lose or gain valence electrons, forming ions with positive and negative charges, and achieving the electron arrangements of the noble gases.

A compound is a substance that contains atoms of more than one type of element, bonded together. There are millions of compounds in existence and many yet to be discovered.

140 Unit 1 | **Review**

- Two kinds of **Review Exercises** help you to review the unit, starting with **General Review** exercises covering the major concepts in the chapters.



The Granger Collection, NYC—All rights reserved.

A bond is an attractive force that keeps atoms connected to one another. The attraction occurs between the positively charged nuclei and the negatively charged electrons in different atoms. Usually the valence electrons are involved in bonding.

There are four main models for bonding: ionic, molecular covalent, metallic, and network covalent. These models can be used to explain difference in solubility and conductivity.

REVIEW EXERCISES

General Review

Write a brief and clear answer to each question. Be sure to show your work.

1. What is the difference between an element and a compound?
2. Consider two objects that each weigh 20.0 g. One is made of lead and has a density of 11.4 g/mL. The second object is made of aluminum and has a density of 2.7 g/mL. Which object takes up more space? What volume does each occupy?
3. Use the periodic table to help you find the atomic symbol, atomic number, group number, number of protons, and number of electrons for these elements:
   a. lithium b. bromine c. zinc
   d. sulfur e. barium f. carbon
4. Describe nuclear fission and nuclear fusion.
5. What is an isotope? How can you figure out the most common isotope of an element?
6. Describe how you would use the periodic table to help you predict the type of bond between two atoms.
7. What are cations and anions?
8. Sort the following atoms into metals and nonmetals. Then name three ionic compounds that can be formed from some combination of these atoms.

   Na S Cl Sr Mg Se I Cu
9. Predict the type of bonding in each of the following substances. Provide their chemical names and predict which ones will conduct electricity.
   a. $MgCl_2$ b. O_2
   c. AgOH d. Pt
10. Explain how you can determine the charge on a transition metal ion.
11. A substance does not dissolve in water and does not conduct electricity. What model of bonding accounts for these observations?
12. What is required to change one element into another element? Is it possible to do this in a laboratory?

STANDARDIZED TEST PREPARATION

Multiple Choice

Choose the best answer.

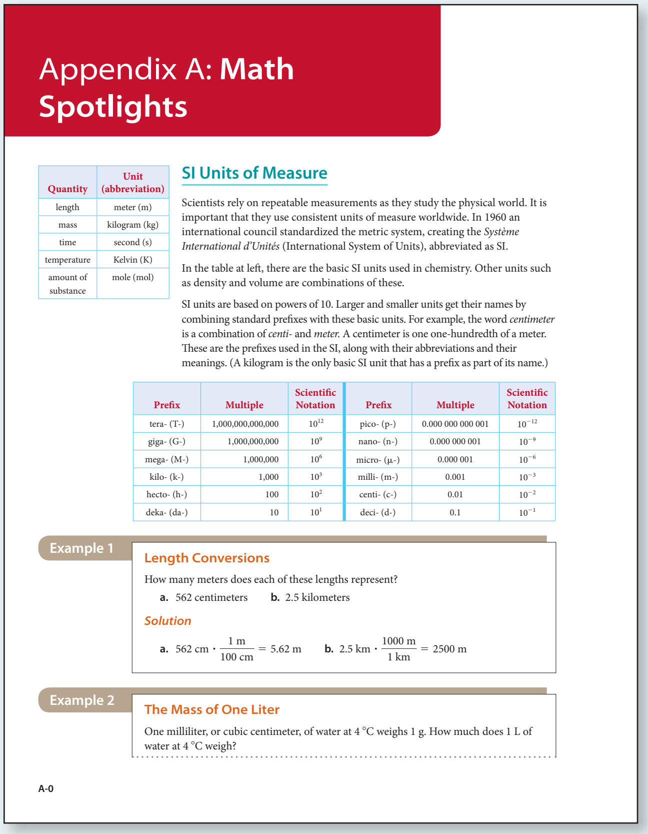
1. The density of zinc is 7.1 g/cm^3 and the density of copper is 9.0 g/cm^3. What statement correctly describes the density of a zinc block coated with copper?
   (A) The block has a density of 7.1 g/cm^3.
   (B) The block has a density less than 7.1 g/cm^3.
   (C) The block has a density between 7.1 g/cm^3 and 9.0 g/cm^3.
   (D) The block has a density of 9.0 g/cm^3.

Unit 1 | **Review** 141

- The **Standardized Test Preparation** section contains multiple-choice questions. Each Exercise has a stem and four possible answers.

Extra support when you need it.

- When you see a note about **Math Spotlights** in a lesson you can turn to the back of the book for a quick review of that math topic.



Appendix A: Math Spotlights

Quantity	Unit (abbreviation)
length	meter (m)
mass	kilogram (kg)
time	second (s)
temperature	Kelvin (K)
amount of substance	mole (mol)

SI Units of Measure

Scientists rely on repeatable measurements as they study the physical world. It is important that they use consistent units of measure worldwide. In 1960 an international council standardized the metric system, creating the *Système International d'Unités* (International System of Units), abbreviated as SI.

In the table at left, there are the basic SI units used in chemistry. Other units such as density and volume are combinations of these.

SI units are based on powers of 10. Larger and smaller units get their names by combining standard prefixes with these basic units. For example, the word *centimeter* is a combination of *centi-* and *meter.* A centimeter is one one-hundredth of a meter. These are the prefixes used in the SI, along with their abbreviations and their meanings. (A kilogram is the only basic SI unit that has a prefix as part of its name.)

Prefix	Multiple	Scientific Notation	Prefix	Multiple	Scientific Notation
tera- (T-)	1,000,000,000,000	10^{12}	pico- (p-)	0.000 000 000 001	10^{-12}
giga- (G-)	1,000,000,000	10^{9}	nano- (n-)	0.000 000 001	10^{-9}
mega- (M-)	1,000,000	10^{6}	micro- (μ-)	0.000 001	10^{-6}
kilo- (k-)	1,000	10^{3}	milli- (m-)	0.001	10^{-3}
hecto- (h-)	100	10^{2}	centi- (c-)	0.01	10^{-2}
deka- (da-)	10	10^{1}	deci- (d-)	0.1	10^{-1}

Example 1

Length Conversions

How many meters does each of these lengths represent?

a. 562 centimeters **b.** 2.5 kilometers

Solution

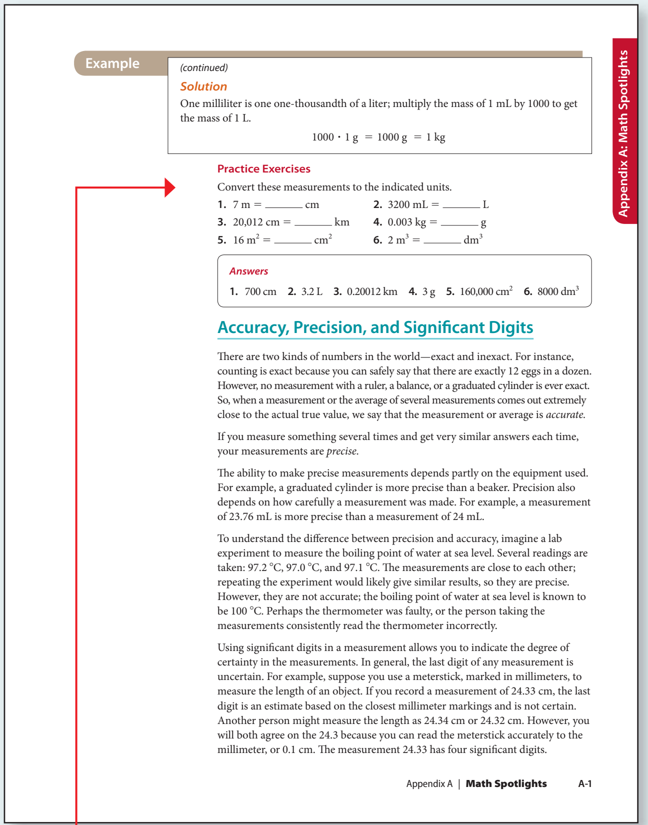
a. $562 \text{ cm} \cdot \frac{1 \text{ m}}{100 \text{ cm}} = 5.62 \text{ m}$ **b.** $2.5 \text{ km} \cdot \frac{1000 \text{ m}}{1 \text{ km}} = 2500 \text{ m}$

Example 2

The Mass of One Liter

One milliliter, or cubic centimeter, of water at 4 °C weighs 1 g. How much does 1 L of water at 4 °C weigh?

A-0



Appendix A: Math Spotlights

Example

(continued)

Solution

One milliliter is one one-thousandth of a liter; multiply the mass of 1 mL by 1000 to get the mass of 1 L.

$$1000 \cdot 1 \text{ g} = 1000 \text{ g} = 1 \text{ kg}$$

Practice Exercises

Convert these measurements to the indicated units.

1. 7 m = ______ cm **2.** 3200 mL = ______ L

3. 20,012 cm = ______ km **4.** 0.003 kg = ______ g

5. 16 m^2 = ______ cm^2 **6.** 2 m^3 = ______ dm^3

Answers

1. 700 cm **2.** 3.2 L **3.** 0.20012 km **4.** 3 g **5.** 160,000 cm^2 **6.** 8000 dm^3

Accuracy, Precision, and Significant Digits

There are two kinds of numbers in the world—exact and inexact. For instance, counting is exact because you can safely say that there are exactly 12 eggs in a dozen. However, no measurement with a ruler, a balance, or a graduated cylinder is ever exact. So, when a measurement or the average of several measurements comes out extremely close to the actual true value, we say that the measurement or average is *accurate.*

If you measure something several times and get very similar answers each time, your measurements are *precise.*

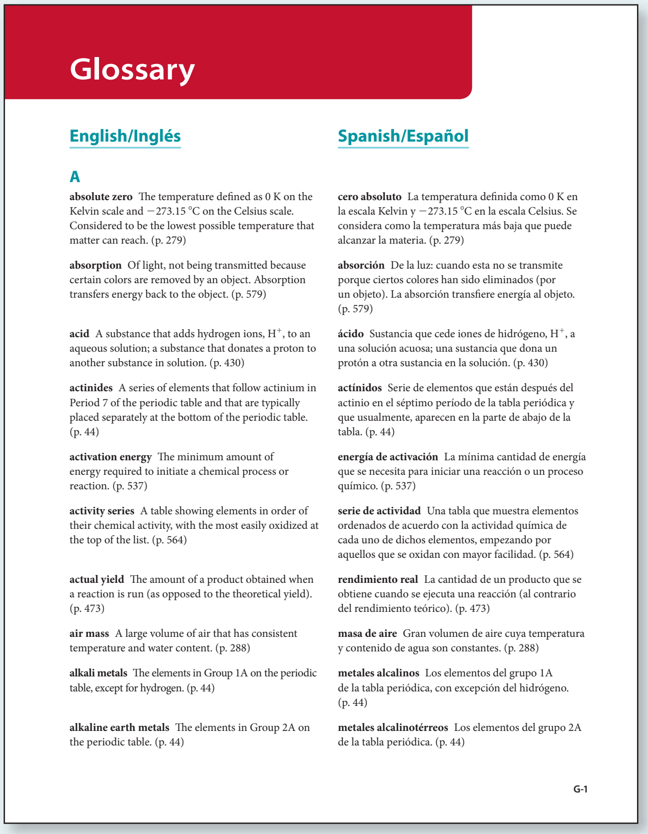
The ability to make precise measurements depends partly on the equipment used. For example, a graduated cylinder is more precise than a beaker. Precision also depends on how carefully a measurement was made. For example, a measurement of 23.76 mL is more precise than a measurement of 24 mL.

To understand the difference between precision and accuracy, imagine a lab experiment to measure the boiling point of water at sea level. Several readings are taken: 97.2 °C, 97.0 °C, and 97.1 °C. The measurements are close to each other; repeating the experiment would likely give similar results, so they are precise. However, they are not accurate; the boiling point of water at sea level is known to be 100 °C. Perhaps the thermometer was faulty, or the person taking the measurements consistently read the thermometer incorrectly.

Using significant digits in a measurement allows you to indicate the degree of certainty in the measurements. In general, the last digit of any measurement is uncertain. For example, suppose you use a meterstick, marked in millimeters, to measure the length of an object. If you record a measurement of 24.33 cm, the last digit is an estimate based on the closest millimeter markings and is not certain. Another person might measure the length as 24.34 cm or 24.32 cm. However, you will both agree on the 24.3 because you can read the meterstick accurately to the millimeter, or 0.1 cm. The measurement 24.33 has four significant digits.

Appendix A | **Math Spotlights** A-1

- Do the **Practice Exercises** for a quick refresher. Answers are provided directly below so you can check your understanding.



Glossary

English/Inglés

A

absolute zero The temperature defined as 0 K on the Kelvin scale and −273.15 °C on the Celsius scale. Considered to be the lowest possible temperature that matter can reach. (p. 279)

absorption Of light, not being transmitted because certain colors are removed by an object. Absorption transfers energy back to the object. (p. 579)

acid A substance that adds hydrogen ions, H^+, to an aqueous solution; a substance that donates a proton to another substance in solution. (p. 430)

actinides A series of elements that follow actinium in Period 7 of the periodic table and that are typically placed separately at the bottom of the periodic table. (p. 44)

activation energy The minimum amount of energy required to initiate a chemical process or reaction. (p. 537)

activity series A table showing elements in order of their chemical activity, with the most easily oxidized at the top of the list. (p. 564)

actual yield The amount of a product obtained when a reaction is run (as opposed to the theoretical yield). (p. 473)

air mass A large volume of air that has consistent temperature and water content. (p. 288)

alkali metals The elements in Group 1A on the periodic table, except for hydrogen. (p. 44)

alkaline earth metals The elements in Group 2A on the periodic table. (p. 44)

Spanish/Español

cero absoluto La temperatura definida como 0 K en la escala Kelvin y −273.15 °C en la escala Celsius. Se considera como la temperatura más baja que puede alcanzar la materia. (p. 279)

absorción De la luz: cuando esta no se transmite porque ciertos colores han sido eliminados (por un objeto). La absorción transfiere energía al objeto. (p. 579)

ácido Sustancia que cede iones de hidrógeno, H^+, a una solución acuosa; una sustancia que dona un protón a otra sustancia en la solución. (p. 430)

actínidos Serie de elementos que están después del actinio en el séptimo período de la tabla periódica y que usualmente, aparecen en la parte de abajo de la tabla. (p. 44)

energía de activación La mínima cantidad de energía que se necesita para iniciar una reacción o un proceso químico. (p. 537)

serie de actividad Una tabla que muestra elementos ordenados de acuerdo con la actividad química de cada uno de dichos elementos, empezando por aquellos que se oxidan con mayor facilidad. (p. 564)

rendimiento real La cantidad de un producto que se obtiene cuando se ejecuta una reacción (al contrario del rendimiento teórico). (p. 473)

masa de aire Gran volumen de aire cuya temperatura y contenido de agua son constantes. (p. 288)

metales alcalinos Los elementos del grupo 1A de la tabla periódica, con excepción del hidrógeno. (p. 44)

metales alcalinotérreos Los elementos del grupo 2A de la tabla periódica. (p. 44)

G-1

- The **Glossary** contains all the key terms, defined in English and Spanish.

Laboratory Safety

Laboratory experiments are an important part of chemistry. Follow these safety precautions to avoid danger.

Before Working in the Lab

- Read and become familiar with the entire procedure before starting.
- Listen to instructions. When you are in doubt, ask your teacher.
- Know the location of emergency exits and escape routes.
- Learn the location and operation of all safety equipment in your laboratory, including the safety shower, eye wash, first aid kit, fire extinguishers, and fire blanket.

Emergencies and Accidents

- Immediately report any accident, however small, to your teacher.
- If you get chemicals on you, rinse the affected area with water.
- In case of chemicals on your face, wash off with plenty of water before removing your goggles. In case of chemicals in your eyes, remove contact lenses and wash eyes with water for at least 15 minutes.
- Minor skin burns should be held under cold, running water.

General Conduct

- Clear your bench top of all unnecessary materials, such as books and jackets, before starting work.
- Do not bring gum, food, or drinks into the laboratory.

Appropriate Apparel

- Always wear protective safety goggles when working in the laboratory.
- Avoid bulky, loose-fitting clothing; roll up long sleeves; and tie back loose hair. Lab coats or aprons may be required.
- Wear long pants and shoes that cover the whole foot (not sandals) so your feet are protected from accidental spills or broken glassware.

Using Glassware and Equipment

- Do not use chipped or cracked glassware or damaged equipment.
- Be careful when handling hot glassware or apparatus. Remember, hot glassware looks like cold glassware.

- Place hot glassware or apparatus (such as a crucible) on an appropriate cooling surface, such as a wire gauze.
- Never point the open end of a test tube toward yourself or anyone else.
- Never fill a pipette using mouth suction. Always use a bulb.
- Keep electrical equipment away from sinks and faucets to minimize the risk of electrical shock.

Using Chemicals

- Never taste substances in the laboratory and avoid touching them if possible.
- Check chemical labels twice to make sure you have the correct substance. Some chemical formulas and names differ by only a letter or a number.
- Read and follow all hazard classifications shown on the label.
- Never pour anything down the drain unless instructed to do so by your teacher.
- When transferring chemicals from a common container to your own test tube or beaker, take only what you need. Do not return any extra material to the original container, because this may contaminate the original.
- Mix all substances together slowly. Add concentrated solutions to dilute solutions. When working with acids and bases, always add concentrated acids and bases to water; never add water to a concentrated acid or base as this can cause dangerous spattering.
- If you are instructed to smell something, do so by wafting (fanning) some of the vapor toward your nose. Do not place your nose near the opening of the container.

Before Leaving the Lab

- Clean your lab station and return equipment to its proper place.
- Make sure that gas lines and water faucets are shut off.
- When discarding used chemicals, carefully follow the instructions provided.

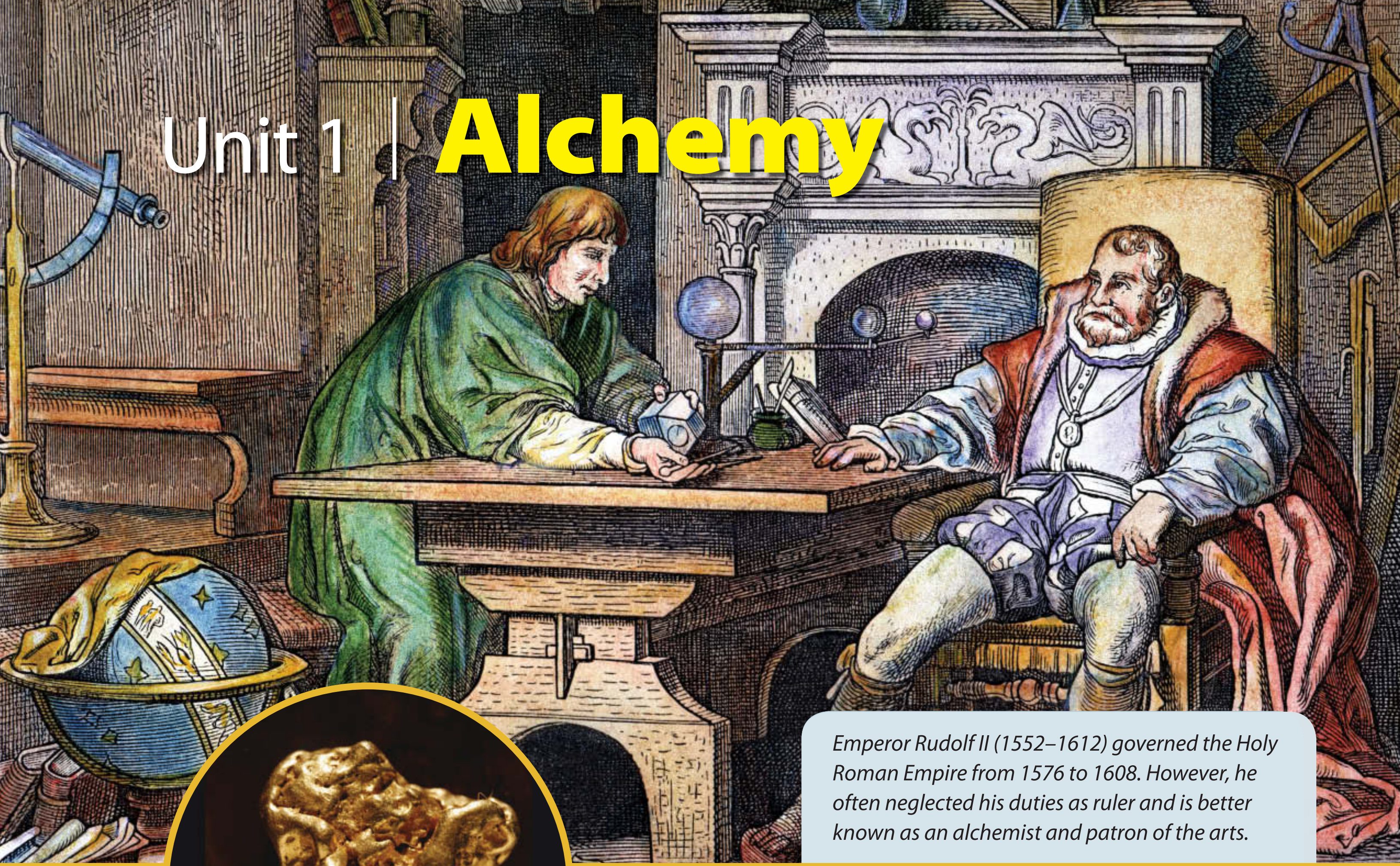
NOTE TO STUDENTS

Welcome to *Living by Chemistry*. In this course, you will actively participate in uncovering the chemistry in the laboratory and in the world around you. Rather than simply writing "correct" answers to chemistry questions and problems, you will learn to support answers with evidence. Learning chemistry is a bit like learning a new sport or dance—you will get better with practice. The more you participate, the deeper your understanding will be.

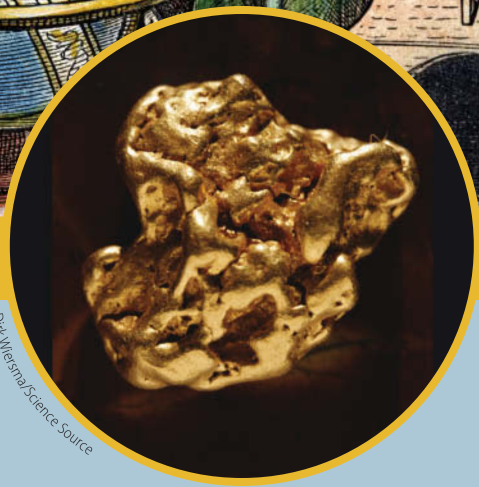
This textbook is designed to be used for reading and reference. The readings focus on the concepts you investigate in class. There are two or three pages of reading to go along with each day's activity, followed by homework exercises. The readings provide real-life examples to further explain and clarify the chemistry concepts. After each day's lesson, the reading and exercises will help you understand and remember what you learned in class. We designed this textbook to be highly readable and sincerely believe it will make the study of high school chemistry enjoyable for you.

Angelica M. Stacy

Unit 1 | Alchemy



Emperor Rudolf II (1552–1612) governed the Holy Roman Empire from 1576 to 1608. However, he often neglected his duties as ruler and is better known as an alchemist and patron of the arts.



Why Alchemy?

Chemistry has some of its roots in the ancient practice of alchemy. The alchemists experimented with trying to make gold out of ordinary substances. In the process, they learned a great deal about matter and about chemistry. When you understand the nature of matter and its composition, you will be able to answer the question, "Is it possible to turn ordinary substances into gold?"

In this unit, you will learn

- **what matter is composed of**
- **to use the language of chemistry**
- **to decode information contained in the periodic table**
- **how new substances with new properties are made**
- **what holds substances together**

De Agostini Picture Library/Getty Images

CHAPTER 1

Defining Matter

This photo shows gold. How can you find out if an object is made of solid gold or simply coated with gold? What makes gold different from other metals? How is it possible to identify a metal based on its properties?

In this chapter, you will study

- the tools of chemistry
- how matter is defined
- how to measure mass, volume, and density
- how types of matter differ from one another

With a simple procedure, you can make a copper penny look like gold. But is it really gold, or has something else been made? A way to tell real gold from other substances is to compare the properties of those substances with the properties of gold. Chemists study various properties of matter and use the results to compare and identify substances.

LESSON 1

Tools of the Trade

Lab Equipment and Safety

THINK ABOUT IT

A chef depends on a wide variety of gadgets and kitchenware to create delicious meals—from whisks and mixers, to ovens and saucepans. An auto mechanic relies on a toolbox of wrenches. In every profession, it is important to have the right tool for the job. Chemists have their own special tools and equipment that allow them to study the world around them. They also have a set of guidelines for using the tools safely.

What tools and equipment do chemists use?

To answer this question, you will explore

- The Tools Chemists Use
- Laboratory Safety

EXPLORING THE TOPIC

The Tools Chemists Use

Chemistry often brings to mind a laboratory filled with unusual glassware and bubbling beakers. Chemists depend on a variety of tools in their explorations. In particular, chemists need tools that allow them to measure the mass and volume of substances, mix them, heat and cool them, and observe and separate them. Take a moment to examine these illustrations to see some of the tools that are used for these purposes.

Ken Karp Photography

Tools for measuring mass: balance with weighing paper, spatula.

Tools for measuring volume: graduated cylinders, Erlenmeyer flask, burette attached to Erlenmeyer flask.

Ken Karp Photography

Tools for observing change: test-tube holder, test-tube rack, brush for cleaning.

Tools for mixing: stirring rod and beaker.

Ken Karp Photography

Tools for separating: Funnel with filter paper, wash bottle, beaker.

Ken Karp Photography

Tools for heating: Hot plate with beaker, boiling chips, and stirring rod, a thermometer.

© 1995 Richard Megna—Fundamental Photographs

Tools for heating: Bunsen burner with striker, ring stand with utility clamp, and a triangle holding crucible.

Measuring accurate amounts is important to chemists. They weigh solids on electronic balances and measure volumes of liquids in special glassware. You might notice that many of the containers chemists use are made of glass. Glass is a material of choice because substances in a glass container are visible. Chemists use tempered glass containers, which can be heated over flames without shattering. Also, glass containers are relatively easy to clean and reuse. Finally, notice that chemists use ring stands and special clamps to keep glassware from toppling. Spills can be hazardous.

R. Gino Santa Maria/Shutterstock

Laboratory Safety

The chemistry laboratory is a place for discovery. However, as in any workplace that uses specialized equipment, safety is always important. There are many situations in a lab that can become dangerous. Before participating in any chemistry activities, you should familiarize yourself with the safety equipment in your lab.

Take a moment to examine these illustrations. What safety equipment and precautions do you notice?

Ken Karp Photography

Know the location of the safety equipment and how to use it. Immediately report any laboratory accident, however small, to your teacher.

Ken Karp Photography

Never taste or touch chemicals. Never touch hot glassware. If you get chemicals on you, rinse with plenty of water.

CONSUMER CONNECTION

Like labware, bakeware is often made of tempered glass so that it can withstand rapid temperature changes and high temperatures without shattering.

Lew Robertson/Getty Images

A few do's and don'ts:

- When working in a lab, dress appropriately. Roll up your sleeves, tie back long hair, and wear closed-toe shoes.
- Be sure that you have read the instructions for the procedure carefully.
- Double-check that you are using the correct chemicals.
- Before you begin working with chemicals or glassware, put on safety goggles.
- Before leaving the lab, clean your lab station and return equipment to its proper place.
- Do not put chemicals back into the original bottle. Doing so might contaminate the chemicals in the bottle.
- Your teacher will provide waste containers; never put chemicals or solutions down the drain unless instructed to do so by your teacher.

LESSON SUMMARY

What tools and equipment do chemists use?

Chemists use their own specialized tools and equipment in the laboratory. These tools and equipment are designed to allow chemists to measure mass and volume, and to mix, heat, cool, observe, and separate substances. It is important to work safely and carefully. When working in a chemistry laboratory, always wear safety goggles. Always wear appropriate clothing and closed-toe shoes. Be prepared to know what to do in case of an accident.

Exercises

Reading Questions

1. Why are most chemistry containers made of glass?
2. Describe the appropriate clothing to wear in a chemistry lab.

Reason and Apply

3. List three things you should do before beginning any laboratory procedure.
4. Describe what you would do in the case of an accidental spill in class.
5. List three things you should do before leaving the laboratory.
6. What is a fire blanket used for? If necessary, do some research to find out.
7. What is a hood used for in the chemistry laboratory? If necessary, do some research to find out.
8. Why do chemists use clamps and ring stands?

A Penny for Your Thoughts

Purpose

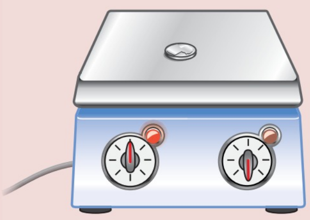
To observe a chemical transformation firsthand.

Materials and Safety

1. List the equipment used in the demonstration.
2. Briefly describe your observations of each substance used in the demonstration.
3. Safety is extremely important in the chemistry lab. Write three important safety considerations for this demonstration.

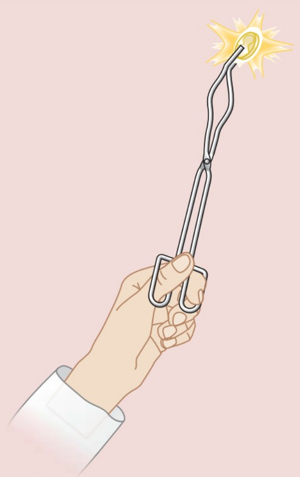
Procedure and Observations

Record your observations for each step of the demonstration.



1. Place a beaker containing zinc filings and sodium hydroxide on a hot plate set to 4.
2. Use tongs to pick up the penny and place it in the heated beaker.
3. While holding the beaker steady with tongs, remove the penny with the other tongs.
4. Put the hot penny in a beaker of cold water to cool and rinse it.
5. Use tongs to place the penny on the hot plate.
6. When the penny has changed color, use the tongs to place it in the beaker of cold water.

Analysis



Working with the students at your table, spend a few minutes discussing what you observed during the demonstration. Then answer the questions individually on your own paper.

7. Describe what happened to the penny during the demonstration.
8. What do you think turned the penny silver?
9. What do you think turned the penny gold?
10. **Making Sense** Do you think you made real gold? Why or why not? How could you find out?

LESSON 2

A Penny for Your Thoughts

Introduction to Chemistry

THINK ABOUT IT

Gold is worth a lot more than copper. If you could turn pennies into gold, you would be very rich. Beginning in ancient times, people known as alchemists tried to transform substances into other substances. In particular, some of them tried to turn ordinary metals into gold. Today, we recognize these alchemists as early chemists. In fact, the word *chemistry* is derived from Arabic *alkīmiyā'* and from Greek *khēmia,* meaning "the art of transmuting metals."

What is chemistry?

To answer this question, you will explore

- The Roots of Chemistry
- Chemistry: The Study of Matter and Change

HISTORY CONNECTION

The ancient art of alchemy has been traced to many different cultures and areas around the world. Some alchemists sought to turn lead into gold or find a potion that would bring eternal life. This painting shows alchemists at work in the late 19th century.

Alchemists, 1893 (oil on canvas), Mehdi (1870–99)/ Golestan Palace Library, Tehran, Iran/Giraudon/ The Bridgeman Art Library

EXPLORING THE TOPIC

The Roots of Chemistry

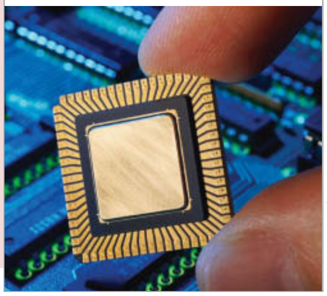
While trying to make gold, alchemists developed some of the first laboratory tools and chemistry techniques. They classified substances into categories and experimented with mixing and heating different substances to create something new. When alchemists succeeded in creating a new substance, they faced the challenge of figuring out whether or not that new substance was really gold. Often, alchemists were fooled into thinking that a substance was gold just because it looked like gold.

In class, you watched a procedure to make a "golden" penny.

During the procedure, when the silver-colored penny was heated, it turned a gold color. You came up with a **hypothesis** to explain what happened. A hypothesis is a possible explanation for an observation. It can be tested by further investigation or experimentation. Suppose your hypothesis is that the penny turned to actual gold during the procedure. To test that hypothesis, you can compare your gold-colored penny to actual gold to see if it has all the **properties,** or characteristics, of gold. You can check the penny's physical properties, such as color, hardness, weight, and the temperature at which it melts. You can also test its chemical properties, such as whether it changes when you pour acid on it or rusts over time.

CONSUMER CONNECTION

Why is gold so valuable? It retains its shine and resists change, even after hundreds of years. Gold is soft and easy to fashion into beautiful jewelry. It is a vital component in computers and cellular phones. Gold is also relatively rare.



StockByte/Fotosearch

Over the course of this unit, you will explore whether it is possible to turn copper or any other substance into gold. But unlike the alchemists, you will have the advantage of hundreds of years of chemistry knowledge to help you answer this question.

Chemistry at work—an iron train rusting

Chemistry: The Study of Matter and Change

Changes are constantly occurring all around you. Nails rust, colors fade, milk sours, and plants grow. You can mix ingredients and bake them in an oven to make cookies. You can bleach your hair to change its color, and you can freeze water to make ice cubes. Your body can transform cheeseburgers and burritos into muscle, fat, and bone. Chemists seek to understand changes such as these.

Chemistry is the study of what substances are made of, how they behave, and how they can be transformed. It is the study of matter and how matter changes. In this first unit, you will investigate matter and how it can be changed. You will learn to describe and explain what happens when matter is changed and you will begin to understand what changes are possible.

LESSON SUMMARY

What is chemistry?

KEY TERMS
hypothesis
property
chemistry

Chemistry is the study of the substances in the world around you. It is the study of matter and how matter can be changed. The modern study of chemistry emerged from the experimentation and effort of the alchemists. The alchemists invented useful tools and discovered many valuable laboratory techniques in their efforts to create gold out of ordinary substances.

Exercises

Reading Questions

1. How did the alchemists contribute to the modern study of chemistry?
2. What is chemistry?

Reason and Apply

3. PROJECT WWW Use the library or the Internet to research the development of alchemy in one of these regions: China, India, the Middle East, Greece, Spain, England, or Egypt. Write a two-paragraph essay on the history of alchemy for your chosen region. Be sure to list your sources.
4. PROJECT WWW Use the library or the Internet to research common uses for sodium hydroxide, which is also called *lye*.
5. Write down at least ten changes that you observe in the world around you. Which changes involve chemistry? Explain your reasoning.

What's the Matter?

Defining Matter

THINK ABOUT IT

People tend to value gold over other substances. You don't often see someone wearing aluminum jewelry or putting coal in a high-security bank vault. What is it about gold that makes it unique? Is it possible to create gold from another substance?

This lesson begins to explore the nature of matter as the first step toward proving whether you can or cannot create gold. After all, chemistry is the study of matter and its properties.

INDUSTRY CONNECTION

Gold has several special properties. It is shiny and it does not rust or tarnish. It is smooth, bendable, easy to dent, and even a small piece of gold is surprisingly heavy.

SAJJAD HUSSAIN/AFP/Getty Images

What is matter?

To answer this question, you will explore

- Defining Matter
- Is It Matter?
- Measuring Matter

EXPLORING THE TOPIC

Defining Matter

Matter is the word chemists use to refer to all the materials and objects in the world. Your desk, this book, and the paper and ink in the book all are matter. These are all things you can see or feel. However, your senses alone are not always enough to tell you if something is matter. For instance, you cannot see the virus that gave you a cold, but it is matter. Conversely, you can see shadows on the ground cast by the light from the sun, but they are not matter.

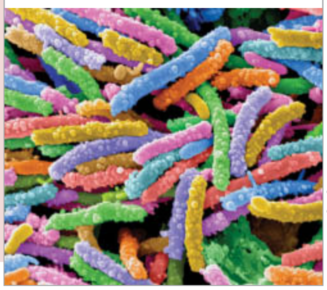
A gold ring, the ink in this book, and a virus each have *substance,* which means they are made out of material, or "stuff." The amount of substance, or material, in an object is called **mass.** Mass is a property of matter that can be measured. So, although the virus has very little substance, it still has mass.

Another property that a gold ring, the ink in this book, and a virus have in common is that they take up space, which means they have dimensions. The amount of space something takes up is called **volume** and is also a property of matter that can be measured.

So, matter is anything that has mass and volume. You can also say matter is anything that has substance and takes up space. This explains why a virus is matter but a shadow is not.

BIOLOGY CONNECTION

Viruses are so small that the length of a virus or other microorganism is measured in microns. A micron is equal to 0.001 millimeter. The viruses in this image have been magnified 10,000 times and colorized to make them easier to see.



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Is It Matter?

It is easy to see that solids and liquids have mass and volume. When water is poured into a container, you can see how much space it takes up. When