



**Art in Chemistry**

**Chemistry in Art**

Second Edition

**Barbara R. Greenberg and Dianne Patterson**

# **Art in Chemistry; Chemistry in Art**



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*This book is dedicated to Anne, Emily, Vicki,  
Kimmy, Josh, and Betsy*



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# Preface

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Since 1998, when *Art in Chemistry; Chemistry in Art* was first published, I have conducted numerous workshops for students and teachers involving the implementation of the book's many activities and ideas about merging art with chemistry. During that time certain patterns emerged. Initially students and teachers were skeptical. How can art and chemistry be related? Why should we care about such a connection? As the workshops progressed, enlightenment occurred. Teachers realized that there was a logical connection between art and chemistry. They realized that spatially gifted students could express understandings of abstract chemistry concepts in works of art. Verbally and auditorally adept students could try their hand at this new form of expression. Students acknowledged that chemistry could be fun. A new happy atmosphere filled the rooms.

There was another unexpected outcome. Students used their imagination to explain chemistry concepts at a new level. This provided teachers with new insights into the minds of the students. The works of art that the students created told more than written answers to a standard test. Students and teachers explored concepts in a different way. Who knows? A student's imaginative art chemistry creation could lead to new insights into chemical bonding or atomic structure. Needless to say, art in chemistry workshops have been an unqualified success.

Albert Einstein said, "Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the earth." He saw and experienced the power of imagination. He did not mean that knowledge is unnecessary; it just does not have the scope of imagination. This is how I see it:

Knowledge stirs imagination.

Imagination needs knowledge as a springboard.

Knowledge is always available to enhance imagination.

Imagination is limitless.

I think that Albert Einstein would be very pleased to observe the effects of *Art in Chemistry; Chemistry in Art*, the commingling of art with chemistry, where knowledge stimulates imagination.

Barbara R. Greenberg



# Introduction

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The focus of *Art in Chemistry; Chemistry in Art* is to avoid subject matter isolation and help students grasp interconnections between disciplines. In life experiences, problem solving crosses several subject areas. Students need to stretch their imaginations and find new pathways to solve a multitude of problems they may face in life.

Let's examine this second edition of *Art in Chemistry; Chemistry in Art*. Just what is changed? A great deal! This new edition is enhanced with

- essential questions,
- challenge activities,
- new and revised activities,
- additional explanatory material,
- answers to the activity and demonstration questions at the end of each chapter, and
- more safety warnings.

All of these additions add excitement, new knowledge, and ease of use for students and teachers alike. Let's find out more about these new items.

*Essential questions* are questions that students should be asking. They may not have definite answers but are designed to be thought provoking and interest stimulating. Essential questions appear in every chapter of this new edition. They can be used to introduce chapter topics or for in-depth research projects. The questions can lead to entire class investigations or individual student projects. Examples of essential questions are:

- Why is the sky blue?
- When two paint colors are mixed, why does a third color result?
- Why do some isotopes decay spontaneously, while others are very stable?

For a further discussion of essential questions, see *Understanding by Design* by Grant Wiggins and Jay McTighe.

*Challenge activities* provide unique ways to understand and enrich chemistry and art concepts presented in the book. They can be games, model making, symbol investigations, and other group classroom activities or individual projects. Examples of challenge activities are

- inventing a board game (Players spin for atoms and trade them to make molecules.);
- creating original symbols for molecules (like Egyptian hieroglyphics);
- forming human unsaturated, saturated, and supersaturated solutions; and
- using digital photos to explain equilibrium.

New activities include the following:

- Activity 1.1 Atomic Modeling and Color
- Activity 8.1 Making a Pinhole Camera
- Activity 9.1 Qualitative Chemistry and the Detection of Art Forgeries

In Activity 1.1 an atomic model kit is constructed, then used in other activities. Atom colors are related to atomic physical and chemical properties. In Activity 8.1 a pinhole camera is constructed and used to photograph model chemical equations. In Activity 9.1 a qualitative system for identifying mystery ions in solution is performed and related to detecting these ions in an art forgery.

Other activities have been revised. In Activity 1.8, Create Your Own Atom, students create a two-dimensional drawing of an atomic theory. In addition, classmates have to guess the theory and critique the drawings as works of art. In Activity 4.4, Construction of a Three-dimensional Periodic Table, students are referred to mobile making for their periodic table construction. Many activities have changes that clarify the activity and add additional approaches to achieving the activity objectives.

Additional explanatory material is added throughout the book. Some of the material explains further and simplifies concepts under discussion, while other material adds new information. In Chapter 2 paint pigments and binders are discussed. New information on surprising origins of ancient paint pigments and binders is added. In Chapter 3 supports for paints are described, and information is added about supports used in 50 B.C. that are still used today. In Chapter 6, in which jewelry making and the study of metals and electrochemistry are combined, an electromotive series is added to enhance cell voltage calculations.

The answers to the activity and demonstration questions placed at the end of each chapter are complete and often add new information that further explains the answers provided. This information can be used by the teacher and student alike to stimulate further questions and discussions.

Safety instructions have been enlarged and added, and materials considered hazardous have been eliminated. Chapter 10 provides detailed information about possible health hazards and methods to eliminate these hazards.

Two important questions remain: Who should use this book? and How should this book be used?

This new edition has been written for students. It can be used as a textbook for college students as well as grades 7–12 and can be modified for grades 5 and 6. It has material for full courses in general chemistry and introductory art. Ideally an art teacher and a chemistry teacher will team teach these subjects using *Art in Chemistry*; *Chemistry in Art* as their textbook. For grades 5 and 6, quantitative calculations can be eliminated and descriptive chemistry can be taught. The art material as presented will fit into this approach.

Alternatively, the book can be used as a resource for a combined approach to art and chemistry or for each subject taught separately. Art and chemistry teachers can confer and teach some combined activities. Some schools have used *Art in Chemistry; Chemistry in Art* as a source of enrichment material for gifted students. This new edition has more explanations and information to help teachers with most of the art and chemistry topics presented.

Combining art with chemistry provides some amazing outcomes. When students express their knowledge of chemistry concepts through art projects, they reveal their understanding and vision of the concepts. This is a form of assessment that can be achieved in no other way. Originally art was combined with chemistry to promote interest, creativity, and relevancy in chemistry and art and to stimulate students to think outside the box. It was never expected that expression of chemistry concepts through art experiences would reveal the inner thoughts of the student artist.

Finally, it should be remembered that *Art in Chemistry; Chemistry in Art* does not contain a chapter on chemistry and then a chapter on art. It fully integrates the two subjects; a merger of two disciplines results in one relevant curriculum. In this case, the whole is infinitely greater than its parts.



# Colors Do Matter

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## *How Do We See Color?*



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: Why is the sky blue?**

## INTRODUCTION

### Artists and Chemists; Friends or Foes?

Does an artist need a chemist? Does a chemist need an artist? Do they have anything in common? Both artists and chemists make careful observations. Then a chemist forms a hypothesis; tests the hypothesis using a control and a test subject, taking care to have only one variable; and draws a conclusion based on test data results. The chemist then makes interpretations that may lead to new hypotheses and new controlled experiments. The artist makes interpretations also, but these usually come directly from observations. Artists may try many interpretations of observations until a satisfying work is created. The chemist needs the artist's creativity when making interpretations of the experimental data. The artist needs the chemist to test and formulate new and useful materials. The work of the artist and the work of the chemist are interdependent. They need each other.

### Why Is the Sky Blue?

Have you ever wondered, "Why is the sky blue? There is no simple answer to this difficult question. To understand why the sky is blue, it is necessary to understand the nature and properties of matter and electromagnetic radiation and see the connections among matter, electromagnetic radiation, and color. We look to both art and chemistry for enlightenment

#### What is electromagnetic radiation?

- Most of it is invisible. We see only a small amount, called visible light.
- It travels through space in waves at a speed of  $2.998 \times 10^8$  meters/second, the "speed of light."

In the study of chemistry, the properties and composition of matter are investigated, along with the nature of electromagnetic radiation and how it affects matter. Electromagnetic radiation is radiant energy that exhibits wave properties and travels at the speed of light (when in a vacuum).

### What are the parts of an atom?

- The three primary components of atoms are protons, neutrons, and electrons. The following chart summarizes the physical properties of these subatomic particles:

Particle	Mass/grams	Charge
Electron	$9.109389 \times 10^{-28}$	-1
Neutron	$1.674929 \times 10^{-24}$	none
Proton	$1.672623 \times 10^{-24}$	+1

- Protons and neutrons are found in an atomic nucleus. Electrons are found in space outside the atomic nucleus.
- Atoms are unbelievably small. The radius of a typical atom is about  $6 \times 10^{-8}$  cm.
- If we counted how many milliliters of water are found in the Atlantic Ocean, we would find three times that number of atoms in only one ml of water.
- The atomic nucleus, which contains protons and neutrons, is extremely dense. A piece of atomic nucleus about the size of a pencil eraser would have a mass of 250 million tons!!

**Essential Question: How can we know so much about objects we cannot see?**

### What is the law of definite proportions?

- A molecule is the smallest unit of a compound that retains the chemical properties of that compound.
- A compound is two or more types of atoms chemically combined in definite proportions.
- When water,  $H_2O$ , is formed, two atoms of hydrogen always combine chemically with one atom of oxygen at a mass ratio of one gram of hydrogen to eight grams of oxygen. Since there are two atoms of hydrogen and one atom of oxygen in every water molecule, the mass ratio of one hydrogen atom to one oxygen atom is 1:16, which corresponds to the relative weight of oxygen as compared to hydrogen.
- In 1799 Joseph Proust (1754–1826), a French chemist, observed that specific compounds always contained the same elements in the same ratio by mass. This came to be known as the law of definite proportions. The law of definite proportions provided a means for determining relative weights for numerous atoms and verified John Dalton's theory that elements are made up of atoms. Dalton (1766–1844) was an English teacher, chemist, and physicist. He used modern scientific methodology to develop long-lasting atomic theories.

Matter is made of particles. Some particles are atoms that contain subatomic particles, called electrons, protons, and neutrons; other particles are molecules that are made up of atoms.

### **What is electron configuration?**

- In a modern view of the atom, the positions of electrons outside an atomic nucleus can only be described in probability areas.
- These probability areas are designated as shells or principle energy levels ( $n$ ). The shells depict a most probable distance from the nucleus for an electron to be located.
- This probable placement of electrons in probability areas outside the atomic nucleus is called the electron configuration of the atom.

### **What is a chemical element?**

- The number of protons in the atomic nucleus of a particular element is fixed, but the number of neutrons is not. Atoms of an element that contain the same number of protons but a different number of neutrons are called *isotopes*.
- In a sample of the element carbon, 98.89% of the atoms have six protons and six neutrons in the nucleus. However, 1.10% have six protons and seven neutrons in the nucleus, and an even smaller percentage have eight neutrons in the nucleus. These atoms are isotopes of carbon.
- This difference in the number of neutrons does not affect the chemical properties of an element, which are determined by atomic electron number and configuration.

If all the atoms in a particular substance have the same electron configuration (i.e., if they have the same number and arrangement of electrons), the substance is an element. An atom is the smallest particle of an element that can exist alone or in combination with particles of the same or a different element. Each atom of a particular element has the same number of protons in its nucleus. An element cannot be broken down by ordinary chemical means, such as burning, heating, or simply combining with other substances.

### **What is a molecule?**

- Atoms usually do not exist independently but rather bond together to form *molecules*.
- A molecule can consist of two atoms bonded together or a thousand atoms bonded together.
- No matter how many atoms are bonded together to form a molecule, the molecule behaves as one unit.

### **What is a compound?**

- When atoms of the same or different elements bond, they form molecules. A compound is a pure substance made up of molecules that are all the same. Each molecule is composed of two or more different elements.
- Certain compounds are colored; others are not. Why?

We can answer these questions when we understand the effect of electromagnetic radiation on matter.

### **What are the five elements of design?**

- It is not possible to consider one element of design without referring to another.
- Whether or not the subject matter is a Rodin sculpture or a water molecule, shape cannot be considered without considering line, for line is the outermost boundary of a shape.

In the study of chemistry, the atom is the basic structure of matter and protons, electrons, and neutrons are basic subatomic particles. In the study of art, design is the basis of an artistic arrangement, and color is one element of design. The design of a work of art includes not only color but also line, texture, light and dark contrast, and shape. However, color is the element of design that arouses the most appreciation and is the element to which we are most sensitive. Even one who is puzzled by “modern art” usually finds its color exciting and attractive. One may question the use of distortion of shape but will seldom object to the use of color and may like a work of art solely for its use of color.

**Essential Question: What is the source of color?**

## **MODELING**

A model helps us to understand concepts and ideas that are abstract. Since atoms and molecules are not directly observable, models are used to understand how atoms bond to form molecules and how molecules change during chemical reactions. In Activity 1.1, an atomic model kit is constructed. This kit will be used throughout your art-in-chemistry experience.

**ACTIVITY**

### **1.1**

## ***Atomic Modeling and Color***

### **Objectives**

1. Students will construct and use an atomic model kit.
2. Students will become familiar with common elements.
3. Students will understand color as a physical property of an element.
4. Students will consider the psychological effect of color.
5. Students will predict how atoms might combine to form molecules.

**Materials**

For each atomic model kit, 16 1-in. white Styrofoam™ balls; black, red, and green acrylic paint; paintbrush; about 20 toothpicks; toothpick holder; small box.

**Time**

55 minutes

**Procedure**

1. Place toothpicks in the Styrofoam balls.
2. Pick up each ball by the toothpick. Paint the balls as follows: three black, two red, and three green. Leave eight white. (A total of sixteen Styrofoam balls.)
3. After each ball is painted, stick the toothpick end in a toothpick holder so the ball can dry. (The holder can be a Styrofoam slab.) Drying should take about 15 minutes.
4. After the Styrofoam balls are dry, remove the toothpicks from them and place them in a small box, along with the toothpicks and eight white balls. The kit should have sixteen balls and about twenty toothpicks. This kit will be used in this and future *Art in Chemistry*; *Chemistry in Art* activities.

**Questions and Conclusions****Level One**

1. What is the actual color of the following elements: carbon, hydrogen, oxygen, and chlorine?
2. In your atomic model kit, carbon atoms are black, oxygen atoms are red, hydrogen atoms are white, and chlorine atoms are green. Explain why these colors were chosen. Think about the actual colors of the elements represented and the emotional effects of colors.
3. The chemical formula for a water molecule is  $\text{H}_2\text{O}$ . Using the atomic model kit, construct a model of a water molecule. Use toothpicks to hold the atoms together. Have your teacher check your model to see if it is correct.

**Level Two**

1. Color is a physical property of matter. Write a definition of *physical property*. (See pages 34–35.) Which elements in your kit are represented by their color?
2. Write a definition of *chemical property*. (See page 72.) Which elements in your kit are colored according to a chemical property? What is this chemical property?
3. How are the colors used to represent the atoms in your kit associated with an emotion?

- Using your atomic model kit, make a model of a methane molecule ( $\text{CH}_4$ ). Have your teacher check your model to see if it is correct. Explain why the methane molecule must be constructed in a specific way.
- 

### Challenge Activity

Invent a game called Chemical Change. It can be a board game or card game or both. Make your model kit atoms part of your game. Use color in a meaningful way; for example, to show a good or bad outcome, to call attention to specific instructions, or to make the game components more attractive. Be sure that your game involves specific chemical changes, such as hydrogen gas and oxygen gas combining to form water or sodium chloride decomposing to produce sodium metal and chlorine gas.

In a Chemical Change game, atoms can be earned to make molecules that are appropriately reacted to achieve a chemical change. Players with the majority of chemical changes win. Players can trade atoms in order to make correct molecules. You can add game details such as a game board on which players move atom pieces in order to win atoms. Be imaginative and creative. Play your game in class.

## THE NATURE OF COLOR

Color is one of the most expressive elements of design because its quality affects our emotions directly and immediately. For example, red signifies energy (among other things), and blue is often associated with wisdom. In China, red is attributed to the living and blue to the dead.

- Color is often considered the most universally understood element of design.
- Color is often associated with experiences common to humans throughout the world.
- People of all cultures associate green with nature and growth, which implies a sense of calmness and serenity.
- People associate blue with the emptiness of space or the look of still, deep water and sometimes feel sad; people speak of feeling blue.
- People associate red with fire and the sun, which exudes a feeling of excitement and sometimes anger.

Psychology is the study of animal behavior. The human animal exhibits complex behavior patterns. Is color a factor affecting human behavior?

**ACTIVITY**

## 1.2

### ***The Psychology of Color***

#### **Objectives**

1. Students will examine the emotional effects of color.
2. Students will interpret the meanings of particular colors from a personal point of view.
3. Students will use color effectively in a work of art having a chemistry theme.

#### **Materials**

Pencil; paper; colored markers; large colored cards (red, yellow, blue).

#### **Time**

30 minutes

#### **Procedure**

1. While the teacher holds up red, yellow, and blue cards one by one, you should list an emotion you associate with each color (e.g., happiness, anger, boredom, confusion, warmth, or surprise).
2. Explain why the color evokes that emotion. See if other students have the same color–emotion relationship. For example, does red always evoke anger?
3. Make a colored drawing. It can be a design or a scene. Use a chemistry theme in the drawing. The design can be a repeating pattern of chemistry equipment, such as repeating beakers and test tubes or a realistic drawing representing the discovery of fire. Have the drawing illustrate one emotion.

Discuss objective and nonobjective works of art. If a work is nonobjective, it should not contain recognizable objects. Designs are often nonobjective.

4. After the drawing is finished, write the emotion it expresses on the back.
5. Display the drawings on a wall.
6. The class should guess what emotion each drawing represents.
7. The artist should explain how the drawing illustrates certain emotions. Color should be part of the discussion.
8. Answer the question, “Does color affect animal or human behavior?”

**Do all animals see color?**

- The answer to this question is still up for debate.
- However, it is quite certain that cows and sheep are colorblind.
- It is thought that dogs and cats can distinguish blues and greens but lack the ability to pick out shades of red.

A colorless world would be a drab one. The fictional story *The Giver* by Lois Lowry describes an Orwellian society in which every member is assigned a specific, lifelong task. No one has a choice. All originality is lost. The world is colorless until one young man breaks out of the mold. As he rebels, objects take on a new appearance. He sees a *red* apple! As the young man begins to see more and more colored objects, there is no turning back to a colorless world.

With a sense of color, people can see more aspects of their world, in more detail. Without color, with only black and white and gray, the eye can see a mere dozen or so different tones. With color, the eye can see thousands of distinctions, which not only look different than one another but also convey different feelings and associations. Psychologically, gray is dull and negative. With color, warmth and coldness, excitement and stimulation, and countless other human expressions are conveyed.

**ACTIVITY****1.3*****Color versus Black and White***

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**Objectives**

1. Students will examine how color expresses emotion.
2. Students will use a black-and-white drawing and the same drawing in color to tell the story of a significant discovery in chemistry.

**Materials**

Pencil; paper; colored pencils or markers.

**Procedure**

1. Create a black-and-white picture that tells a story, then rework the same picture in color. The story should have a chemist theme; for example, the story of the alchemists' discovery of sulfur, mercury, or antimony; Robert Boyle's experiments concerning the properties of gases; or John Dalton's development of his atomic theory.

In the 1500s, prechemists, or alchemists, were using trial and error methods to examine matter. In addition to discovering sulfur, mercury, and antimony, alchemists were convinced that they could turn metals such as lead into gold. They tried to "seed" vats of boiling lead with gold coins. Needless to say, their unscientific experiments were dismal failures. Certain glassware flasks developed by the alchemists are still in use today.

Robert Boyle (1627–1691), an English scientist, noticed that gases can be compressed. He used J-shaped tubes to show that gas pressure and gas volume at a constant temperature and amount are inversely related. His experiments were performed with one variable, and his conclusions were drawn from experimental observations. He argued that theories should be the result of experimental observations, and therefore he considered is the founder of the modern scientific method.

■ *Note:*

John Dalton's atomic theory is discussed again before Activity 1.8 is performed. John Dalton concluded the following in 1808:

Matter is made up of very small particles called atoms.

All atoms of the same element are the same and differ from atoms in other elements.

In a chemical change, atoms are neither created or destroyed.

When atoms of two or more elements combine to form a compound, the relative number of atoms of each kind is constant.

2. Evaluate each of your pictures for emotional significance and storytelling effectiveness.
3. Watch the portion of *The Wizard of Oz* in which the film changes from black and white to color. Explain why you think the film was made in this manner. Discuss the use of black and white and color in other films you have seen (e.g., why do you think that *Schindler's List* was first filmed in black and white and later filmed in color?).
4. Discuss the subject of your picture. What is the chemistry significance of your subject matter?

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## LIGHT AS A SOURCE OF COLOR: THE ELECTROMAGNETIC SPECTRUM

### How are light and color related?

- Visible white light is a source of color. The color observed for an object is a function of the light source and the reflective and absorbing properties of the surface that the light strikes.
- If white light strikes a red apple, because white light contains all of the visible colors—red, orange, yellow, green, blue, indigo, and violet, all of the visible colors will be absorbed except for red, which will be reflected. Thus, the apple is red.

Color begins with and is derived from light, either natural or artificial. Where there is little light, there is little color; where the light is strong, the color is likely to be particularly intense. We notice at such times as dusk or dawn, when the light is weak, that it is difficult

to distinguish one color from another. Under bright, strong sunlight, such as in tropical climates, colors have more intensity.

### Where does all light come from?

- Initially, all light comes to us from the sun.
- Certain atoms and molecules store light energy and emit that light energy under certain conditions, such as during a chemical change. Burning is a common example of such a chemical change.
- Light from atoms also appears when excited atoms release energy.

### What is electromagnetic radiation?

- A form of energy that travels in waves is called *electromagnetic radiation*.
- The following relationship exists between the wave frequency,  $\nu$ , and wavelength,  $\lambda$ : frequency times wavelength = velocity. Velocity refers to the speed of electromagnetic radiation waves in a vacuum. It is a constant ( $2.998 \times 10^8$  m/s), sometimes called the speed of light,  $c$ .
- Using the following equation, when the frequency of a wave is known, the wave's wavelength can be calculated, and when a wavelength is known the frequency can be calculated:

$$\lambda = \frac{c}{\nu}$$

All light from the sun comes to us in the form of waves that transfer, or radiate, energy. Waves from the sun are disturbances that carry energy through space. All these waves travel at the same speed through a vacuum (the speed of light), but they differ in wavelength (the distance from crest to crest) and frequency (the number of waves that pass a point in a certain period of time). Some waves from the sun are not visible to the human eye. Together, these visible and invisible waves are called *electromagnetic radiation*. The three characteristics of waves discussed here are wavelength and frequency (defined above) and amplitude, half the distance from the crest of a wave to its trough. (See Figure 1.1.)

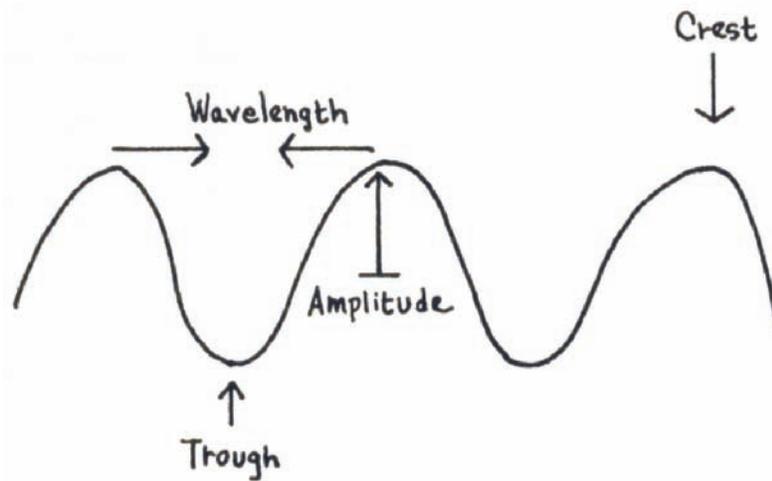


Figure 1.1. Wave Properties.

In the electromagnetic spectrum, the waves with the shortest wavelength and, correspondingly, the greatest energy and highest frequency, are called gamma rays. The waves with the longest wavelength, least energy, and lowest frequency are called radio waves. As shown in Figure 1.2, the visible range is very narrow compared to the entire range of electromagnetic radiation. We only see a narrow range of the vast amount of radiation that surrounds us. How would the world look if every wave of the electromagnetic spectrum became visible to our eyes? We would see colors beyond our wildest imagination. When we use a prism to separate sunlight, visible light, into its component wavelengths, we see the colors of the rainbow. This is a very small sample of what might appear if gamma rays, X-rays, microwaves, and radio waves were visible to our eyes.

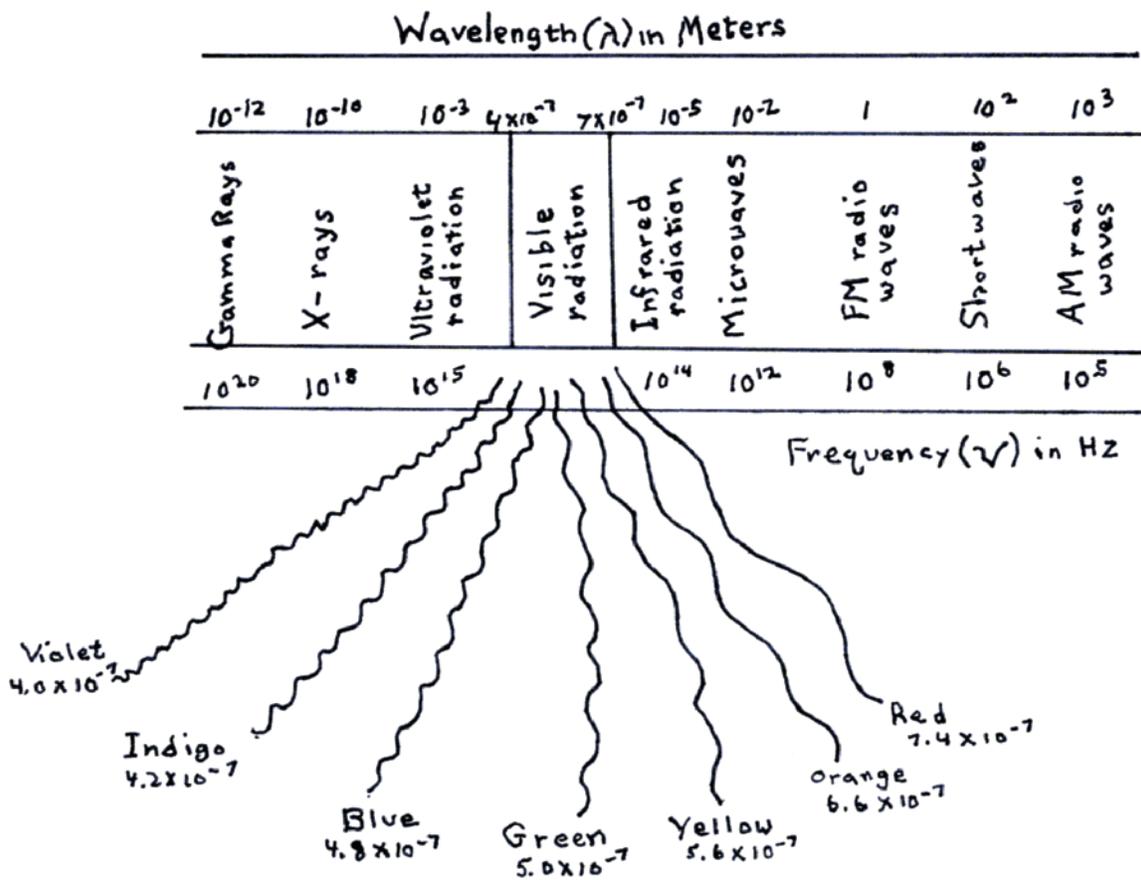


Figure 1.2. Electromagnetic Spectrum.

**Essential Question: What would happen in our everyday lives if we could see the entire electromagnetic spectrum?**

**ACTIVITY****1.4*****The Rainbow: A Chorus of Waves*****Objectives**

1. Students will define the waves in the electromagnetic spectrum in terms of their wavelengths and frequencies.
2. Students will make a diagram identifying the following characteristics of a wave: crest, trough, wavelength, and amplitude.
3. Students will use a prism to see the colors of the waves present in the visible range of the electromagnetic spectrum.
4. Students will make a poster of the electromagnetic spectrum.
5. Students will describe the relationships among wavelength, frequency, and energy of waves in the electromagnetic spectrum.
6. Students will describe and explain the differences between the spectrum created by white light (incandescent light) leaving a prism and the spectrum created by plant grow-light (fluorescent light) leaving a prism.

**Materials**

Figure 1.2; prism; incandescent light or sunlight; sheet of white paper; plant grow-light; colored pencils or markers; 1-x-5-ft. sheet of shelf paper.

**Time**

60 minutes

**Procedure**

1. Make a diagram of a wave and label the crest, trough, wavelength, and amplitude (see Figure 1.1). This diagram can be included on a separate space on the poster used to draw Figure 1.2 in step 2.
2. Working in groups of four to six, copy Figure 1.2 onto a 1-x-5-ft. sheet of shelf paper. As shown in Figure 1.2, add waves in the visible range of the spectrum, using the correct colors and relative wavelengths for each visible wave (the red wave should have the longest wavelength; the violet wave should have the shortest wavelength). Use colored pencils or markers to

represent the colors of the visible waves and to make the poster attractive. Save room on the poster to include the wavelengths observed in step 6.

Regarding the elements of design, your poster should emphasize color and line, not only two of the elements of design but also the main elements necessary to portray and describe the electromagnetic spectrum.

3. Hang the poster on the wall.
4. Allow incandescent light or sunlight to pass through a prism at an angle that projects a rainbow, sometimes referred to as a spectrum, onto a sheet of white paper.
5. Repeat step 4, using a plant grow-light.
6. Make colored drawings of the spectra produced from incandescent light or sunlight, and from a plant grow-light, using relative wavelengths. The drawings should be sized to fit on the poster of the electromagnetic spectrum.
7. Place the drawings on the poster. (Be sure that the color of the longest wavelength, red, is oriented beside the infrared wave group, and that the color of shortest wavelength, violet, is oriented beside the ultraviolet wave group.)

### **Questions and Conclusions**

#### **Level One**

1. Which waves in the electromagnetic spectrum carry the greatest energy? The lowest energy? (The common names for the wave groups indicate the amount of energy associated with a particular wave group.)
2. What color was the light that entered the prism? What colors of light left the prism? What waves are present in white light?
3. Compare the spectrum from the incandescent light or sunlight to the spectrum from the plant grow-light. Make a list of any differences and explain why they occur.

#### **Level Two**

1. As the energy of a wave increases, what happens to its frequency? To its wavelength?
  2. As the wavelength of a wave increases, what happens to its frequency?
  3. Speed is defined as distance traveled in a period of time. All waves in the electromagnetic spectrum travel in a vacuum at the same speed, the speed of light. What is this speed?
-

### Challenge Activity

Arrange a group of prisms to form a three-dimensional sculpture. (See elements of sculpture, p. 203.) Have the prisms interact with each other to refract and reflect light. Shine colored lights on the sculpture. Explain resulting light patterns and colors, including the term *wavelength* in your explanation. Remember that for light waves, the shorter the wavelength, the greater the angle of refraction.

You should see rainbow patterns from refracted and reflected visible light waves. Violet waves have the shortest wavelength and are refracted at the greatest angle, while red waves have the longest wavelength and are bent at the smallest angle. Therefore, rainbows always are red at the top and violet at the bottom.

In Activity 1.4, the component waves of white light having wavelengths in the range of  $7.4 \times 10^{-7}$  m (red) to  $4.0 \times 10^{-7}$  m (violet) are separated by a prism into individual wavelengths representing red, orange, yellow, green, blue, indigo, and violet. Because sunlight is made of all these waves, we would expect the sky to be white. The question “Why is the sky blue?” remains.

## ACTIVITY

### 1.5

### Color and Energy

#### ■ Warning!

Bunsen burners should be used by experienced students under teacher supervision! (This activity can be performed as a demonstration.)

#### Objectives

1. Students will learn how to calculate the frequency of a wave when its wavelength is known, and its wavelength when its frequency is known.
2. Students will relate wave energy to frequency and wavelength.
3. Students will experimentally examine the difference in the temperature of a blue flame compared to a yellow flame, then examine the psychological effects of these colors.

#### Materials

Two Bunsen burners; matches.

#### Time

10 minutes

**Procedure**

1. Light two Bunsen burners, adjusting the air inlets so one flame is yellow and the other is blue.
2. Simultaneously place a match into each flame.
3. Note the time it takes for the matches to light and record your observations. (The match in the blue flame will light more quickly than the match in the cooler, yellow flame.)

**Questions and Conclusions****Level One**

1. Use Figure 1.2 to find the wavelength and frequency of blue and yellow waves:

	<b>Wavelength</b>	<b>Frequency</b>
Blue	$4.8 \times 10^{-7}$ m	$6.2 \times 10^{14}$ Hz
Yellow	$5.6 \times 10^{-7}$ m	$5.4 \times 10^{14}$ Hz

The unit for frequency, or cycles per second, is the hertz;  $1 \text{ Hz} = \text{s}^{-1}$ .

2. Compare yellow and blue waves for each of their three wave characteristics: wavelength, frequency, and energy.
3. Compare the energy of blue and yellow waves to the sense of temperature evoked by these colors. Was your sense of temperature confirmed in Activity 1.5?

**Level Two**

1. Calculate the frequency of blue and yellow waves by dividing the speed of light ( $2.9979 \times 10^8$  m/sec) by each wavelength in meters, and compare these answers to the values given in Figure 1.2.
2. Explain how to calculate the frequency of a wave when the wavelength is known and how to calculate the wavelength of a wave when the frequency is known. (Frequency and wavelength are inversely related.)

**Does the color of a substance indicate the energy associated with that substance?**

- The color of a substance does not indicate the energy associated with the substance.
- Pigment particles, often molecules, determine the color of a substance by absorbing certain light waves and reflecting others.
- In a red apple, all visible wavelengths are absorbed by pigment molecules except red waves, which are reflected. The red color of an apple does not indicate the amount of energy stored in the apple.

### Challenge Activity

Fill three small test tubes half full with water. Place a thermometer calibrated to  $0.1^\circ$  in each test tube. Record each temperature to  $0.1^\circ$ . Using identical penlight flashlights, shine a violet light into one test tube and a red light into another test tube. Let them stand for half an hour and then record the temperatures in all three test tubes. Continue to record temperatures for four hours at half-hour intervals. Explain your results. Why was one test tube prepared with water and a thermometer but no flashlight?

Violet and red filters on the flashlights will result in violet and red light. Since violet waves have shorter wavelengths, higher frequency, and higher energy than the red waves, the water receiving the violet light will reach a higher temperature than the water receiving the red light. The third test tube is a control. It should remain at a constant temperature. This shows that temperature changes in the other two test tubes are due to added light waves.

From Activity 1.5, it can be seen that blue waves carry more energy than yellow waves (a blue flame is hotter than a yellow flame). Yet we often think of blue as being cool and yellow as being warm: Blue jeans are cool; the sun is warm. There is little relationship between the energy of visible waves and the psychological significance of their colors.

## THE PSYCHOLOGICAL SIGNIFICANCE OF COLOR

### What is color conditioning?

- The emotions we experience when certain colors are observed is a result of our range of experiences with those colors.
- This range of experiences evoking emotions is called color conditioning.

Each color has its particular traditional significance. Partly because of its direct emotional effect upon us and partly because of its associations with various experiences, each has acquired a symbolic significance. Color conditioning through the centuries has had a strong influence on our lives. Usually, each color has both positive and negative connotations. For example, we use expressions such as “black-hearted,” “green with envy,” and “red-hot.” Many of our associations with colors are a result of the manner in which we have been taught to think of them since we were children. Consider the following color combinations: orange and black; red and green. Do Halloween and Christmas come to mind? On what holiday do we see red? We hope to see red on Valentine’s Day. It would be hard for us to send an orange-and-yellow valentine or decorate our houses in red and green for Halloween. How many people do you know who think pink is for boys and blue is for girls?

### Color: Get the Meaning

**White.** White stands for purity and light, innocence and spiritual joy, as in “whiter than snow.” Negatively, white is sterile, blank, and ghostly.

**Black.** Black represents the absence of light. It often stands for the power of darkness. It has a strong, solid feeling about it. Objects made of black often appear smaller than the same object made of white. Black is usually associated with mourning and is symbolic of evil, death, and despair.

**Yellow.** Yellow is the lightest color after white. It usually suggests light. It is also associated with gold and suggests power and wealth. It is a symbol of happiness or cheerfulness. In China, it is the imperial color. Negatively, yellow suggests cowardice (“to have a yellow streak”), sickness, and decay.

**Red.** Red is the most vibrant color, which is why the eye is drawn to it. Traditionally, it stands for love, energy, strength, and courage. Red means “stop” all over the world (except in China, where green means “stop” and red means “go”). Red also means danger (“red alert”), cruelty, and sin.

**Blue.** Blue is a favorite color of many people, as evidenced by the prominence of blue in clothing. Blue suggests truth and loyalty (“true blue”). In China, blue is attributed to the dead, signifying divine eternity and immortality. It is a cool, relaxing color. It is also associated with wisdom, reliability, and justice. Negatively, blue suggests melancholy and sadness (“feeling blue”).

**Violet (Purple).** Violet is the royal color, suggesting wealth and power, passion and luxury. The Phoenicians obtained a purple dye from oysters that was reserved for royalty because of its rarity. Negatively, violet indicates mourning and sadness, but a sadness not as deep as that indicated by black.

**Green.** “Having a green thumb” is a familiar phrase. The word *green* brings to mind growth, life, and continuation. It is a quiet color, often suggesting restfulness. It also symbolizes a tender, unripe state or lack of experience. Green also suggests jealousy.

**Orange.** Orange suggests glory, heat, a sense of plenty, and happiness, and has few negative associations. Because the eye is attracted to it, it has visibility and is especially useful in identifying important areas.

## ACTIVITY

### 1.6 *Color Psychology I*

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#### Objectives

1. Students will observe the effects of color on individuals in specific situations.
2. Students will apply the principles of good composition and the creative process to an original work.

#### Materials

Paper; pencils (Level One); colored pencils, markers, or paints and paintbrushes (Levels Two and Three Only).

**Time**

15 minutes (Level One); 50 minutes (Level Two); 30 minutes (Level Three)

**Procedure****Level One**

1. Make a list of specific chemistry-related situations in which color plays a psychologically expressive role. For example, chemical changes often involve fire production, where one envisions a bright red scene.

**Level Two**

1. Draw and then color an original composition based on a holiday celebrated with nontraditional colors. Or, draw and then color a scene or a single object using atypical or unexpected colors (e.g., a green hamburger in a blue bun or a forest of blue and pink trees). Include a chemical change in each composition; for example, a Fourth of July fireworks display or the forest of pink and blue trees on fire.

**Level Three**

1. Interpret, in picture form, a phrase using a specific color (e.g., “green with envy,” “yellow streak,” or “true blue”) and include a chemistry theme in the picture. For example, a picture “green with envy” could include the discovery of a rare, radioactive element that glows enough to turn the faces of onlookers “green with envy.”
  2. At this point, a brief discussion of how to arrange a work of art would be appropriate.
- 

See the next section for a discussion of the principles of good composition. These principles include a strong center of interest, a predetermined direction for the movements of a viewer’s eye, a balance of parts, and interesting use of positive and negative space. They provide some basic common denominators to visual expression. However, there are unlimited possibilities for a meaningful arrangement of these common denominators. The more unique the arrangement, the more powerful the work of art.

Organizational components of art include dominance, proportion, balance, variety and harmony, repetition and movement, and selectivity.

**Dominance.** An artist uses dominance techniques to hold a viewer’s attention. To achieve dominance, an artist can accent a part of an image with color, line, shape, value, or texture contrast. Another way to achieve dominance is to have one object in sharper focus than its surroundings.

**Proportion.** Included in proportion is the visual agreement of relative parts, such as a head size compared to a body size or furniture size compared to room size, and also agreeable relationships of intangible features such as the intensity of a blue color as compared to yellow in a sunset painting. In addition, it is often stated that odd

numbers of visual components should be used in an artwork rather than an even number of components. The Japanese art of flower arranging, ikebana, requires that three flowers, not two or four, be used in an arrangement.

**Balance.** An artist uses balance to achieve a visual equilibrium and harmony. Balance can be symmetrical when one side of an artwork is the mirror image of the other side. Often one side of an image varies from the other side, but a similarity is still felt and there is a sense of balance. (This is known as asymmetrical balance.) In Winslow Homer's painting *Snap the Whip*, a central figure is surrounded by three figures on the right and four figures on the left, one falling to the ground. Even though the number of figures is not equal, the figures are similar in shape and movement and the work has a sense of balance.

**Variety and Harmony.** Harmony, a pleasing combination of shapes, is enhanced when variety is introduced. In Ben Jones's *Black Face and Arm Unit*, a wall-mounted sculpture of several arms below associated masklike faces, there is harmony in the repetitive arm and face units and also variety in the face expressions, the arm and mask decorative motifs, and the direction in which the arms are bent.

**Repetition and Movement.** When visual elements repeat, we find a movement and energy associated with that repetition. In Andy Warhol's *200 Campbell Soup Cans*, the repeating cans seem to vibrate and move with unending energy.

**Selectivity.** Economy implies a sense of brevity. It is necessary that an artist know what is and what is not essential to accomplish his or her purpose. Kasimir Malevich painted *White on White*, a white square painted on a white square ground, the two squares having almost no value contrast. He felt these squares alone would create a certain tension in the viewer

It can be seen from this discussion that there are many factors to consider when an artist arranges a work of art.

## THE PRINCIPLES OF GOOD COMPOSITION

When planning a work of art, good composition is important. An interesting, orderly arrangement of line, texture, light-and-dark contrast, shape, and color (the elements of design) will help create an interesting work of art. The elements of design and the principles of composition are addressed in greater depth in Chapter 7; for now, a brief introduction to good composition is appropriate.

**Do both two- and three-dimensional artworks require the same elements of design to achieve a good composition?**

- Yes. Considering all the elements of design, in a two-dimensional work, color can play a major role, while in a three-dimensional work of art shape is of primary importance.

### All the Pieces Are in Place

We have all had a chance to assemble a jigsaw puzzle. After emptying the puzzle box, we have a jumble of odd-shaped pieces that we must assemble into a meaningful whole.

Good composition is much the same: The pieces of this puzzle are the elements of design—line, texture, light-and-dark contrast, shape, and color. Any composition, whether two- or three-dimensional, should use the elements of design to achieve the following:

1. A strong center of interest or focal point

This is the point or spot that first attracts the viewer's attention, which can be achieved by a variety of means:

- a. A light center of interest against darker areas, or vice versa
- b. A bright or intense (full strength) color as the center of interest against duller areas, or vice versa
- c. A group of small objects against a background of larger shapes, or vice versa
- d. A complex or detailed area set against areas of less complexity

This contrast of focal point against the remainder of the composition is known as the effect of dominance and subordination.

2. Movement of the eye through the composition

Once the center of interest has been established, the rest of the composition should be arranged so that the eye of the viewer will move in a predetermined direction through it. This movement should follow a direction, such as around, back and forth, up and down, or diagonally, which can be indicated by various means:

- a. Repetition of a single color in different amounts
- b. A line or lines
- c. A shape or shapes
- d. Repetition of a texture, line, or shape in various sizes

3. Balance of parts

The focal point need not be placed at the center of the picture. Frequently the focal point is moved off-center to create an interesting effect. In a good composition, the balance of all parts is important. There are two types of balance: formal (or symmetrical) and informal (or asymmetrical). In symmetrical balance, the subject is centered and other elements are placed on either side of an imaginary center line to achieve a balanced presentation. In asymmetrical balance, objects of one type or size on one side of a center line are visually balanced by objects of a different type or size on the opposite side of the line.

4. Interesting negative and positive space

This is addressed in greater detail in Chapter 5; for now, it is sufficient to say that the artist should be aware of not only the shapes and sizes of the subject matter but also the negative space, or remaining space in the background. Too much negative space can overpower the subject matter, detracting from it rather than complementing it.

5. Unity and harmony

Finally, the composition should possess unity and harmony if all the elements of design—line, texture, light-and-dark contrast, shape, and color—fit together successfully. Regarding art, *unity* does not necessarily mean “sameness.” Therefore, within unity variety of size, shape, and color are important to a successful composition. The puzzle is then complete!

**Examples of Good Composition**

**Focal Point**

*Woman Weighing Gold*, Jan Vermeer, 1664  
*The White Girl*, James Abbott McNeill Whistler, 1862  
*Fighting Forms*, Franz Marc, 1914  
*A Ballet Seen from an Opera Box*, Edgar Degas, 1885

**Movement**

*The Starry Night*, Vincent van Gogh, 1889  
*Dutch Interior II*, Joan Miro, 1928  
*Three Dancers*, Pablo Picasso, 1925  
*The Assumption of the Virgin*, Peter Paul Rubens, 1626

**Balance: Symmetrical**

*Portrait of a Man in a Tall Hat*, Rembrandt van Rijn, 1662  
*The Sisters*, Berthe Morisot, 1869  
*Vase of Chrysanthemums*, Claude Monet, 1880  
*Beasts of the Sea*, Henri Matisse, 1950

**Balance: Asymmetrical**

*Four Dancers*, Edgar Degas, 1899  
*Breezing Up*, Winslow Homer, 1876  
*Persistence of Memory*, Salvador Dali, 1931  
*The Starry Night*, Vincent van Gogh, 1889

**Interesting Negative and Positive Space**

*Equatorial Jungle*, Henri Rousseau, 1909  
*Portrait of an Elderly Lady*, Mary Cassatt, 1887  
*Woman with Red Hair*, Amedeo Modigliani, 1917  
*A Young Girl Reading*, Jean Honore Fragonard, 1776

**COMMERCIAL USE OF COLOR**

**Name some products recognizable by colored symbols.**

- Coca Cola is recognized by a white wave on a red background.
- McDonald’s is recognized by golden arches.
- Pepsi Cola is recognized by a red, white, and blue ball.

- Certain frozen vegetables are recognized by a jolly green giant.
- It should be noted that some parking garages have color names for floors so drivers can remember where they parked their cars.

People connect more immediately with color than with words or pictures. This is clearly evident in street signs and traffic signals: Red means “stop,” green means “go,” and yellow means “caution.” Some colors symbolize meanings more clearly than others; some combinations are more easily seen than others. The best and most easily seen combination is black on yellow, followed by green on white, then red on white. The least effective combination is red on green. Strongly contrasting color combinations are used on automobile license plates, road signs, billboards, packaged goods in grocery stores, book and magazine covers, and myriad other objects for clarity, visibility, and attractiveness. The pigment primary colors (red, yellow, blue) and the secondary colors (orange, green, violet) in full strength, plus black or white, are most often used because these combinations are the easiest to identify. In the world of advertising, companies use color to imprint a product in the memory of the consumer (a combination of red and yellow is often associated with McDonald’s; a combination of red and white is often associated with Coca-Cola).

The following list includes artists who have used color in an unusual way to evoke emotions and imprint an image in the viewer’s memory:

Franz Marc, *Blue Horse*, 1911

Henri Matisse, *Green Stripe (Madame Matisse)*, 1905

Marc Chagall, *The Green Violinist*, 1918

Andy Warhol, *Marilyn Monroe Series*, 1970s

Pablo Picasso, any painting from his blue period, 1901–1904

**ACTIVITY****1.7****Color Psychology II**

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**Objectives**

1. Students will analyze the effectiveness of color in conveying a specific emotion.
2. Students will explore the role of color in advertising.
3. Students will apply the principles of good composition and the creative process to an original work.
4. Alternatively, students will explain chemical concepts involved in advertising slogans.

**Materials**

Paper; colored pencils; markers; or paints and paintbrushes.

**Time**

50 minutes

**Procedure****Level One**

1. Make a list of specific emotions and the colors that evoke them, including situations in which the colors play a significant role. For example, in a battle scene, red blood evokes anger, fear, and lightheadedness. In a parade, a red, white, and blue American flag evokes a feeling of patriotism and pride.

**Level Two**

1. Prepare an advertisement using color to evoke an emotion. For example, a travel advertisement might use blue and green to represent relaxation, or an advertisement for children's clothes might emphasize red, yellow, and blue, the pigment primaries, to represent youth and activity. Apply the principles of good composition to your advertisements.

**Level Three**

1. Alternatively, prepare a list of advertising slogans based on chemical concepts, such as "Use Fluoride Toothpaste for Strong Teeth" or "Alpha Hydroxy Skin Cream Removes Wrinkles." Draw advertisements using color to evoke emotion, as discussed above, but also explain the chemical concepts involved in the slogans. Apply the principles of good composition to your advertisements.
- 

The fluorine in fluoride toothpaste is in the form of a fluorine compound. One such compound is sodium monofluoride phosphate. The fluorine in the sodium monofluoride phosphate bonds with calcium in tooth enamel and forms a calcium fluoride layer that acts as a bacterial barrier.

Alpha hydroxy acid is an organic acid with mild abrasive properties. However, it is difficult to believe that any skin cream removes wrinkles.

## THE CONNECTION BETWEEN LIGHT AND COLOR

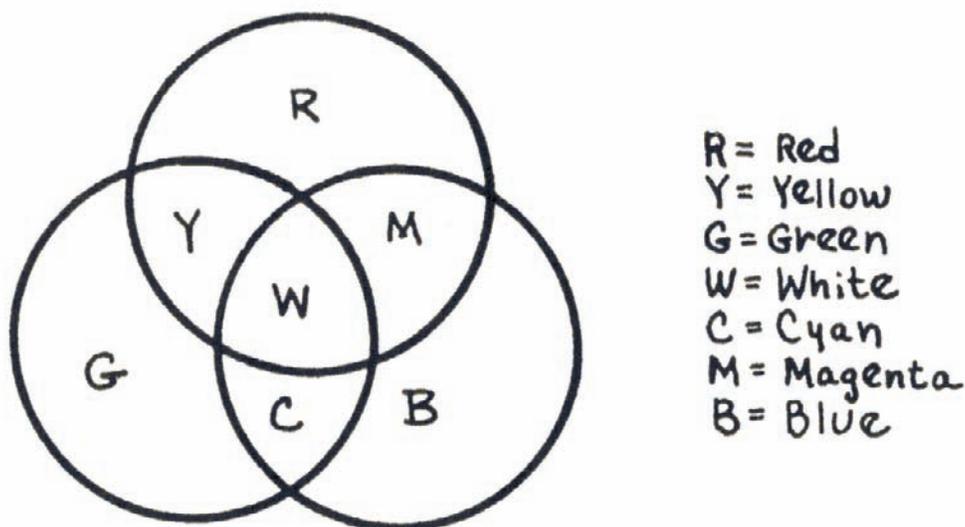
### Light Primaries

**What are the primary colors of light?**

- The primary colors of light are red, green, and blue.
- A television monitor screen is coated with dots composed of chemicals that emit red, green, and blue light when excited by electrical energy. Colored light combinations are added or stacked to produce other than primary colors. This is called an additive system.
- When red, green, and blue light is mixed, white light results.
- When all light is absent, we "see" black.

**Essential Question: Why is it rare to see a green star?**

To see color, light must enter the eye through the iris and focus on the retina, which contains rods for seeing at night, when there are few light waves, and cones to detect color during the day when more light waves are present. Some cones absorb mostly red and some yellow waves; other cones absorb mostly green and some yellow waves; and a third variety of cones absorb mostly blue and some violet waves. Red, green, and blue are the primary colors of light, which when mixed in various proportions produce all other colors. When the three primary colors are mixed in equal proportions, white light is produced. When equal portions of red and green light are mixed, yellow light will be observed. If equal portions of blue and red light are mixed, magenta light results, and blue and green light produce cyan. Try it. (See Figure 1.3.)



**Figure 1.3. Mixing Primary Colors of Light.**

Now we can reconsider the question, “Why is the sky blue?” We know that the sun brings us light that contains all the colors of the rainbow, or visible spectrum, not just blue. If all waves are reaching our eyes, the sky should be white. We need still more information to explain why the sky is blue.

### **Atoms and “Neon” Signs: An Array of Colored Light**

#### **What produces the colored light in electrified gas tube signs?**

- Neon, argon, and krypton, often used in electrified gas tube signs, are colorless noble gases. The nobility do not mix with other classes, so elements that do not combine with other elements (i.e., are nonreactive) are called “noble.” They like to remain uncombined and alone. When these noble gas atoms are bombarded with electricity, electrons, the atoms become “excited.” Some of the atomic electrons

move to probability areas farther from their nuclei, where the electrons are unstable. These unstable electron drop back to their original positions and emit the energy that they absorbed. This energy corresponds to some waves in the visible spectrum.

- Most neon atom electrons emit red energy waves. Argon atom electrons emit blue energy waves. Helium atom electrons emit yellowish-white energy waves.
- New York City's Times Square and Las Vegas, Nevada, have something in common: high electric bills! At night, both places glow with colored lights, many of which are electrified gas-tube signs that light up the sky. Obviously this is not light sent from the sun. To understand the source of the spectacularly colored signs of Times Square and Las Vegas, we must examine the structure of atoms.

## Atomic Theory: A Historical Perspective

### How did Greek philosophers explain the composition of matter?

- Democritus reasoned that one could cut a piece of lead into smaller and smaller pieces until one reached pieces the size of an atom. After that, one could no longer divide the lead piece.
- Today we recognize hundreds of subatomic particles. Included are the elementary particles: electrons, protons, and neutrons. Electrons are members of a group called leptons. In this group are two heavier cousins of the electron, the muon and the tau. Another lepton is the enigmatic neutrino, the antisocial cousin that hardly reacts with any other type of matter. Protons and neutrons belong to a second group called baryons. Recently it has been suggested that baryons are made up of even more elementary particles called quarks. (Is this starting to resemble Dr. Seuss's *Cat in the Hat*?) A third group of subatomic particles are named mesons. Most amazingly, when binding forces holding protons and neutrons together were investigated, it was found that protons and neutrons are not separate entities. They change into each other by rapidly passing between themselves meson particles called pions.

In 400 B.C., the Greeks explained that all matter was made of fire, earth, water, and air. A Greek philosopher, Democritus (460–370 B.C.), reasoned that matter was made of small, indivisible particles called *atomos*. Though the Greeks did not use experiments to test their ideas, the following scientists did, basing their atomic theories on experimental data:

John Dalton (1766–1844) stated that each element was made of tiny, indivisible particles called atoms, and that the atoms of one element were different from the atoms of another element.

J. J. Thomson (1856–1940), an English physicist, proposed a “plum pudding” model of the atom, in which the atom was a diffuse cloud of positive charge (the pudding); negatively charged electrons (the raisins) were embedded randomly in the cloud.

Ernest Rutherford (1871–1937) said that the atom was mostly empty space. He proposed a nuclear atom with a dense, positively charged center, the nucleus, and negatively charged electrons moving around the nucleus, at a relatively great distance from it.

Neils Bohr (1885–1962) proposed an orbital model of the nuclear atom in which electrons in an atom moved around the nucleus, just as planets move around the sun.

Erwin Schrodinger (1887–1961) and others considered the wave properties of electrons and proposed that electrons were not orbiting around the nucleus in an atom but were in electron-cloud probability areas outside the atomic nucleus. These probability areas were designated as energy levels.

### What is the modern concept of an atom?

- The modern concept of the atom corresponds to Schrodinger's model.
- This model includes wave mechanics, in which the electron in a hydrogen atom is described as a wave.

Today we recognize the atom as having negatively charged electrons outside the nucleus and positively charged protons and uncharged neutrons inside the nucleus. The mass of an electron is about one 2,000th the mass of a proton or neutron, a neutron being slightly heavier than a proton.

## ACTIVITY

### 1.8

## Create Your Own Atom

#### Objectives

1. Students will demonstrate an understanding of the five basic atomic theories—the Dalton atom, the Thomson atom, the Rutherford atom, the Bohr atom, and the Schrodinger electron cloud model—and illustrate this understanding in a two-dimensional work of art.
2. Students will describe the parts of an atom and their properties.
3. Students will use principles of good composition to achieve a strong focal point when illustrating their conception of an atom.

#### Materials

Colored pencils; paper.

#### Time

45 minutes

#### Procedure: All Levels

1. The five basic atomic theories are discussed: those of Dalton, Thomson, Rutherford, Bohr, and Schrodinger. You should have a mental picture of an atom as described in each atomic theory.
2. Good composition is discussed, including color, center of interest, positive and negative space, balance, proportion, repetition, and movement.
3. The teacher should assign an atomic theory to each of you. You should write the name of your atomic theory on the back of your paper.

4. Make a drawing of an atom or atoms based on the atomic theory assigned to you by your teacher. The drawing can be nonobjective, such as a repetitive design, or objective, in which a story is told using recognizable subject matter. Use principles of good composition to achieve a strong focal point, and use colors that convey the emotions you want your drawings to evoke. The drawings should contain detailed visual information about atomic structure (including depiction of subatomic particles), and you should feel free to let your imagination run wild (e.g., a drawing of “The Atom That Ate New York” would be interesting).
5. The completed drawings should be hung on a wall.
6. The entire class should guess what theory each drawing represents. Then each drawing should be critiqued as a work of art. Does the artwork display good elements of design?

### Questions and Conclusions

#### Level One

1. Explain the relationship of your drawing to the particular atomic structure of your atom, as well as your choice of design elements, particularly color.
2. Why did it take scientists so long to discover the structure of an atom?

#### Level Two

1. Explain your depiction of subatomic particles, pointing them out while discussing the theory on which the drawing is based.
2. How can electrons and protons reside in different parts of the same atom, since oppositely charged particles attract each other?
3. How can an atomic nucleus contain a large number of protons, when particles with the same charge repel each other?
4. How is a pointillist painting like an atomic theory?

### Challenge Activity

Examine the life of Leonardo Da Vinci (1452–1519), who was an engineer, architect, inventor, scientist, mathematician, musician, and artist. If Leonardo had proposed an atomic theory, in light of his many talents, how do you think he would have described an atom?

You should find contributions made by Leonardo da Vinci in his areas of expertise. As an engineer, Leonardo imagined the world as a giant machine set in motion by spiritual forces and controlled by a superior intelligence that has arranged everything by mathematical laws. He designed a variety of clocks with complex gear mechanisms. His atoms might behave like gears meshed to correctly move clock hands.

## Atoms and “Neon” Signs: What’s the Connection?

Not all electrified, tubular glass signs—“neon” signs—contain neon gas. Neon is just one of several gaseous elements used in sign creation. Helium gas, argon gas, mercury vapor, and sodium vapor are also used to make brightly colored signs. Electrified gas tubes are also used to make works of art.

Each of these gases glows in a characteristic color, which never changes. When no electrical energy is present, all these elements are colorless in the gas phase. When electricity is added, these elements release energy with wavelengths in the visible range of the electromagnetic spectrum.

Neon Gas	Red
Mercury Vapor	Purple-Blue
Helium Gas	Violet
Sodium Vapor	Orange
Argon Gas	Violet

When atoms of these elements are bombarded with electricity and some of this electrical energy is absorbed, we say that the atoms become “excited.” These atoms are having a party, and they turn color with excitement! Actually, the electrons outside the nucleus of the atom are affected. The excited electrons move to specific energy levels of greater energy farther from the nucleus, where the electrons contain more energy. Before the electrical energy is added, we say the electrons are in the “ground” state, having no fun. When the electrons move to higher energy levels, their configuration becomes very unstable. They fall back to lower energy levels closer to the atomic nucleus and release packages of energy, previously absorbed, in the form of light waves. For each of these elements, the light waves released from its electrons when electricity is added are always from the same range of wavelengths. For gaseous neon atoms, the energy released is mostly in the range of red wavelengths; therefore, neon signs appear red. Now let us see how we can separate and detect these red wavelength waves and other visible waves.

### ■ **Warning!**

**Demonstrator and students should wear goggles!**

**DEMONSTRATION**

## 1.1

### ***Light from Excited Atoms***

#### **Objectives**

1. Students will explain how energy is emitted from atoms when the atoms are stimulated by an electrical charge.
2. Students will explain the electron cloud model of the atom and the significance of energy levels for electrons.
3. Students will calculate the energy emitted or absorbed when electron transitions occur.

4. Students will explain why an atom's spectral lines are called the "fingerprints" of the atom.
5. Students will make a drawing using spectral lines and color to convey an emotion.

### Materials

Spectroscopes; gas discharge tubes, one filled with hydrogen, one with neon, and one with argon; a source of high-voltage direct current; colored pencils or paints and paintbrushes; paper; spectral line charts for hydrogen, neon, and argon.

### Time

15–30 minutes

### Procedure

1. The teacher will send high-voltage direct current through each gas discharge tube.
2. View each electrified gas discharge tube through a spectroscope.
3. Draw and color or paint the lines observed through the spectroscope, including observed spacing between lines. These lines are called *spectral lines*; each element produces a particular pattern of spectral lines, which can be used to identify the element. The spectral lines represent specific waves of energy released when electrons in atoms fall back to lower energy levels.
4. Make a drawing using spectral lines as the theme. Remember that line is an element of design. *Line* can be defined as a visible path of a moving point. A line can be straight or curved. The kind of line created often depends on what tool is used to make the line. Also, colors having desired emotional significance should be used in the drawing.

### Questions and Conclusions

#### Level One

1. Find charts showing spectral lines of several elements (try chemistry books). You should draw and color the spectral lines of three elements.
2. Compare and contrast the spectral lines of the three elements and explain why elements have different spectral lines.
3. The ground state for electrons in an atom is when they are as close to the atomic nucleus as possible and have not moved to higher energy levels, farther from the nucleus. When electrons absorb energy and move away from the atomic nucleus, they are in the excited state. In which state—ground or excited—does an electron have more energy?

#### Level Two

1. Examine the spectral lines for hydrogen and determine the following:

- a. The energy of a mole ( $6.02 \times 10^{23}$ ) of hydrogen atom electrons at the second and third energy levels. Use this equation:

$$E = -\frac{1312}{n^2} \text{ kJ / mole}$$

( $n$  is a quantum number that has a positive integer value corresponding to an electron's energy level. In these calculations,  $n = 2$  and  $n = 3$ . 1312 kJ is the amount of energy needed to remove a mole of hydrogen atom electrons at the ground state,  $n = 1$ , completely away from the atoms.)

$$E_2 = -\frac{1312}{2^2} \text{ kJ / mole} \quad E_3 = -\frac{1312}{3^2} \text{ kJ / mole}$$

Answers:

$$E_2 = \frac{-1312}{4} \text{ kJ / mole} = -328.0 \text{ kJ / mole}$$

$$E_3 = \frac{-1312}{9} \text{ kJ / mole} = -145.8 \text{ kJ / mole}$$

- b. Calculate the wavelength of the energy released when a mole of hydrogen atom electrons drop from the third energy level to the second energy level. Use the following equation:

$$\text{wavelength} = \frac{1.196 \times 10^5}{E_3 - E_2} \text{ kJ / nm}$$

Answer: 656.4 nm or  $6.6 \times 10^{-7}$  m, an orange wave in the visible spectrum.

- c. Determine whether the wavelength calculated places the energy emitted from an electron drop from the third energy level to the second energy level in the visible spectrum. If the wavelength corresponds to energy in the visible spectrum, students should identify the color associated with the wavelength and check to see if the hydrogen atom has a spectral line of that color. You can refer to Figure 1.2 (p. 11) to verify the color that corresponds to the calculated wavelength.

### Challenge Activity

Write a science fiction story about an atom that has electrons in an excited state and at the ground state. This story should have ups and downs, highs and lows. Use color psychology to describe the atom's emotional state as the story progresses.

**What is a spectroscope?**

A spectroscope is an instrument used to disperse a beam of electromagnetic radiation into its component waves. Many spectroscopes have diffraction gratings that separate the waves, which are beamed to a mirror and reflected back to the eye of an observer. Each wave appears as a separate colored line.

**DEMONSTRATION****1.2*****More Excitement in Atoms:  
A Fireworks Display*****■ Warning!**

**This demonstration should be preformed by a teacher behind a protective shield!**

**Objectives**

1. Students will write simple equations for the chemical changes observed in this activity.
2. Students will explain how energy is released in a chemical change and research the types of electromagnetic radiation that can be released.
3. Students will explain how colorless compounds produce colored light in a chemical change.

**Materials**

$\text{Sr}(\text{NO}_3)_2$  (strontium nitrate) or  $\text{SrCO}_3$  (strontium carbonate);  $\text{CH}_3\text{OH}$  (methyl alcohol); magnesium metal strip, tongs, emery cloth, one Petri dish; distilled water; matches; Bunsen burner, 10 ml graduated cylinder; centigram balance.

**Time**

30 minutes

**Procedure: All Levels**

1. Under a hood, the teacher should dissolve about 5 g of either  $\text{Sr}(\text{NO}_3)_2$  or  $\text{SrCO}_3$  in a Petri dish using a small amount of distilled water and then add 10 ml  $\text{CH}_3\text{OH}$  (methyl alcohol) to the solution. Ignite the solution; a bright-red fireworks display will ensue: Electrons falling back to the ground state emit energy with wavelengths of about  $6.5 \times 10^{-7}$  m, in the red-orange range.
2. Under a hood, the teacher should clean a magnesium metal strip that is 1 to 2 in. in length and, using tongs, hold the magnesium metal strip in the hottest part of a Bunsen burner flame. The strip will ignite!

**■ Warning!**

**Students should shield their eyes.**

**■ Note:**

In this demonstration, chemical changes occur. With the addition of heat, reactants change into products. New substances are formed with new physical properties. Chemistry is the study of chemical change.

**Questions and Conclusions****Level One**

1. Explain how colors appear when some chemicals are ignited. Include electrons in the ground state and electrons in the excited state in your explanations.
2. Consider the colors observed during the demonstration and record your emotional response to the colors.
3. What wavelengths of light were emitted when the magnesium strip burned? (Remember, the magnesium strip produced a brilliant white light when it burned.)
4. Define *chemical change* and explain why the reactions in this demonstration resulted in chemical changes.

**Level Two**

1. Research the chemicals used in this demonstration and determine what chemical products were produced. Find equations that express the chemical changes that occurred in the demonstration. (Answers:  $2\text{Sr}(\text{NO}_3)_2(\text{s}) \rightarrow 2\text{SrO}(\text{s}) + 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$ ;  $\text{SrCO}_3(\text{s}) \rightarrow \text{SrO}(\text{s}) + \text{CO}_2(\text{g})$ ;  $2\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{MgO}(\text{s})$ )
2. Research whether or not all chemical changes result in a release of energy.
3. Research the following question: If energy is released in a chemical change, is it always energy in the visible range of the electromagnetic spectrum? If you find the answer to be no, provide examples of the types of electromagnetic radiation that can be released in a chemical change.
4. Compare the colors of the original compounds to the colors of the energy released during this demonstration and explain how colorless compounds produced colored light.

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Considering our understanding of excited atoms, we can now propose a theory about why the sky is blue: Perhaps atoms in the earth's atmosphere are absorbing blue wavelengths of light from the sun's electromagnetic radiation, and these atoms are releasing blue light waves when their electrons fall back to the ground state. However, oxygen ( $\text{O}_2$ ), about 20% of the earth's atmosphere, absorbs radiation with wavelengths between  $1.0 \times 10^{-7}$  m and  $2.4 \times 10^{-7}$  m, waves of much shorter wavelengths than blue light waves, which

are  $4.8 \times 10^{-7}$  m. (Figure 1.2 shows that blue light waves are  $5.6 \times 10^{-7}$  m in length.) Also, nitrogen ( $N_2$ ), about 79% of the earth's atmosphere, absorbs wavelengths of less than  $1.0 \times 10^{-7}$  m in length. It is not likely that excited atoms of the atmospheric gases release blue waves of light. We must still ask, "Why is the sky blue?" (Scientists believe that the northern lights are the result of sun storm radiation producing a variety of excited atoms and, thus, the colorful displays in the northern night skies during periods of sun storms.)

## THE CONNECTION BETWEEN PIGMENT COLORS AND LIGHT COLORS

We have discussed light wavelength stimulation of retina cones, which the brain translates into color, but there is more to understand when examining the nature of color. Most pigments, whether they are made of atoms or molecules (two or more atoms bonded together), selectively absorb, transmit, or reflect certain wavelengths of light. Basic pigment colors are magenta (red), yellow, and cyan (blue), usually referred to as red, yellow, and blue. They are identified as primary pigments because no other colors can be mixed to produce these colors. A primary pigment's color depends on the color of light it reflects. The following chart summarizes the colors absorbed and reflected by the primary pigments:

Primary Pigment	Color Absorbed	Colors Reflected
Red	Green	Red-Orange, Violet
Yellow	Blue	Red-Orange, Green
Blue	Red, Red-orange	Green, Violet

### ACTIVITY

## 1.9

### Mixing Primary Pigments

#### Objectives

1. Students will learn the proper procedure for mixing secondary colors from primary pigments.
2. Students will observe the results of mixing two primary colors.

#### Materials

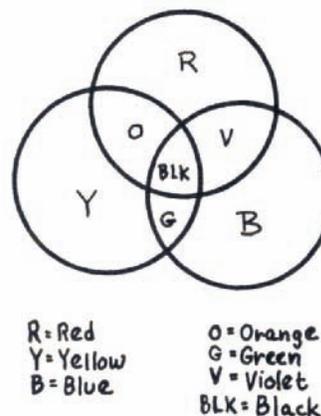
Red, yellow, and blue poster paints; paintbrushes; paper; mixing trays; paper towels; water containers.

#### Time

30 minutes

**Procedure (see Figure 1.4)**

1. Mix the following pigments in equal proportions:
  - a. Red and yellow: The result will be orange or red-orange. (This is because red pigment absorbs green waves and yellow pigment absorbs blue [violet], leaving red-orange waves for us to observe.)
  - b. Red and blue: The result will be violet. (This is because red pigment absorbs green waves and blue pigment absorbs red and red-orange waves, leaving violet for us to observe.)
  - c. Yellow and blue: The result will be green. (This is because yellow pigment absorbs blue waves and blue pigment absorbs red and red-orange waves, leaving green for us to observe.)
  - d. Yellow, red, and blue: The result should be black but will probably be a muddy color. (This is because all waves are absorbed, leaving no waves for us to observe.)

**Figure 1.4.****Questions and Conclusions**

1. What accounts for the difference when mixing light and mixing pigments? For example, if we mix red and green light we see yellow. If we mix red and green pigments, do we see red-orange or violet?
2. Why do you think the mixture of all three pigment primaries is a muddy color instead of black?

## COLOR SYSTEMS AND COLOR WHEELS: A RIDE THROUGH COLOR

Color wheels take us on a sensational, visual ride. These wheels are color systems used to display colors in a systematic fashion and to illustrate a property of color called hue. Value and intensity, two other properties of color, are sometimes also illustrated in these color systems.

### Color: A Historical Perspective

#### **Define extensive physical property.**

- A physical property of a substance is a property that can be observed and measured without altering the composition of the substance.

- An extensive physical property changes with amount. Mass and volume are extensive physical properties.

**Define intensive physical property.**

- An intensive physical property does not change with amount.
- Density, melting and boiling temperatures, and color are intensive physical properties.

Many systems of color have been developed over time. Early theories about the nature of color existed in many countries of the ancient world. An interest in color was expressed by the Babylonians as early as 1900 B.C. Most early theories assumed that color was one of the properties of matter, such as density or mass. These theories were correct in identifying some physical properties of matter. Color and density are intensive physical properties. They remain constant regardless of amount. Mass, on the other hand, is an extensive physical property of matter. It changes with amount.

**Explain Sir Isaac Newton’s color theory.**

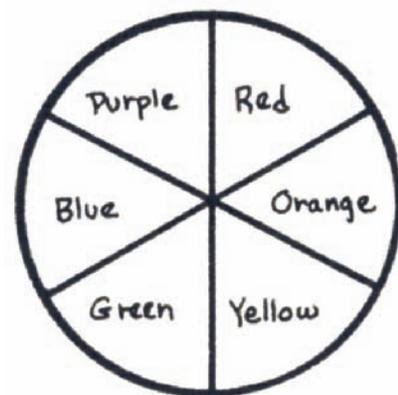
Sir Isaac Newton not only compared the seven colors of the visible spectrum to the seven major notes of the musical scale but also did experiments with light and discovered that the human mind’s perception of color requires only three colors: red, green, and blue. White light is a mixture of these three colors.

During the seventeenth century, Sir Isaac Newton (1642–1727), an English scientist, discovered the visible spectrum by projecting a beam of sunlight through a glass prism, separating the sun’s electromagnetic radiation of visible wavelengths into the colors seen in a rainbow. Newton chose seven basic colors—red, orange, yellow, green, blue, indigo, and violet—and compared them to the seven major notes of the musical scale. He was looking for regularity: repeating patterns to explain natural phenomena. Since the time of Newton, many scientists and artists have developed color theories.

**What were the primary colors in Moses Harris’s color circle?**

- The primary colors were red, yellow, and blue.

Just about a century after Newton, about 1766, Moses Harris (1731–1785), an English engraver and authority on insects, published the first known example of a color circle in full hue. This circle had primaries in red, yellow, and blue, and secondaries in orange, green, and purple (or violet). Harris began a tradition for color order that is favored in art and color education today. (See Figure 1.5.)

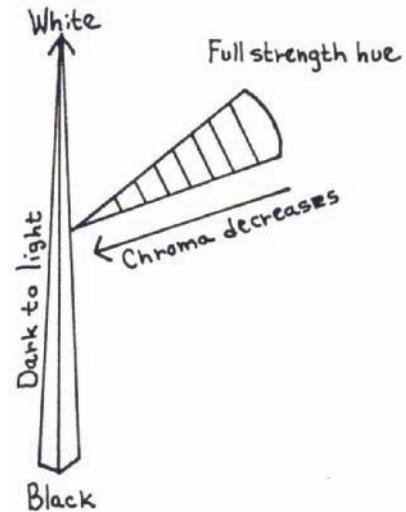


**Figure 1.5. Harris Color Wheel.**

### Why is the Munsell color system so outstanding?

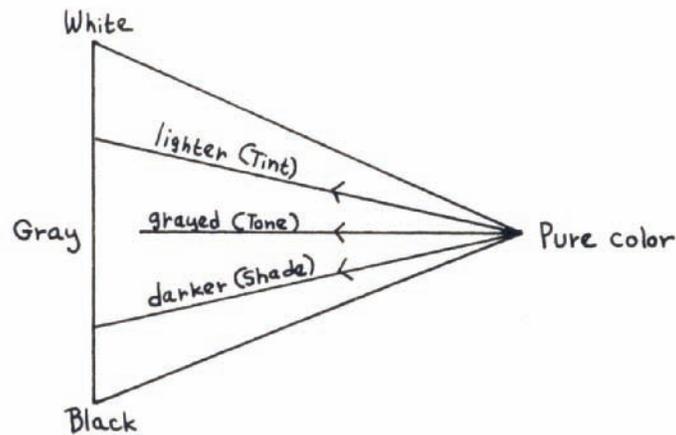
- The Munsell system provided a model for easily identifying a color.
- Each location on the model is given a numerical letter corresponding to its location.
- This makes identifying a particular hue having a certain value and intensity an easy job.
- Munsell established a standard nomenclature for colors.

The greatest American color theorist was Albert H. Munsell (1858–1918). About 1900 he designed and invented a color circle and color solid that has today become one of the most outstanding color order systems in existence. Munsell chose five basic colors—red, yellow, green, blue, and purple—and five intermediate colors—yellow-red (orange), green-yellow, blue-green, purple-blue, and red-purple. He described color in terms of hue (a simple color value for lightness and darkness) and chroma (for color purity, intensity, or saturation). Today the Munsell system is widely used as a standard for color identification and is so recognized in the fields of science and industry. (See Figure 1.6.)



**Figure 1.6. Segment of the Munsell System.**

Another great modern theorist was Wilhelm Ostwald (1853–1932) of Germany, a Nobel Prize winner in chemistry. Ostwald developed the process for converting ammonia and oxygen to nitric acid. His color system, devised about 1915, had four primaries—red, yellow, sea-green, and blue—and four secondaries—orange, purple, turquoise, and leaf-green. Ostwald accepted a triangular order of color, with pure color at one angle, white at a second angle, and black at a third angle, intermixtures being within the triangle. Today this system is commonly used by artists, designers, and stylists to achieve interesting color effects. (See Figure 1.7.)

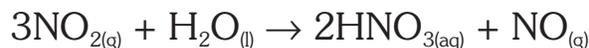
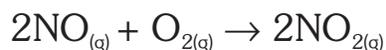
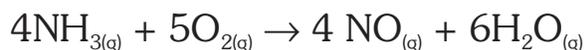


**Figure 1.7. Segment of the Ostwald System.**

### How was Wilhelm Ostwald both a chemist and an artist?

Wilhelm Ostwald not only devised a color system, as described above, but also developed a process for making nitric acid. About 15.4 billion lbs. (7 billion kg) of nitric acid are produced in the United States each year.

The following equations describe the process:



The first step requires a platinum containing catalyst.

About 96% of the ammonia ( $\text{NH}_3$ ) is converted to nitrogen dioxide ( $\text{NO}_2$ ), which is absorbed into water to form nitric acid ( $\text{HNO}_3$ ).

The color wheel that we will be studying uses the colors as they appear in the rainbow, bent into a circle and connected together with the color red-violet. The color wheel consists of 12 main divisions, or sections. Three categories of color are represented in the hues of the wheel, and all appear in full strength; a fourth category, neutrals, is not part of the color wheel. To review information about color (following the discussion below), Handout 1.1 may be distributed.

**Primary Colors.** Red, yellow, and blue are called primary because no combination of other colors will produce any of these colors. All the remaining colors are produced from the three primary colors.

**Secondary Colors.** Orange, green, and violet (or purple) are second in importance. Each is made by combining two primary colors in equal amounts.

**Intermediate Colors.** There are six intermediate colors, each made by combining adjoining primary and secondary colors in equal amounts. The intermediate colors are red-orange, red-violet, blue-violet, blue-green, yellow-green, and yellow-orange.

**Neutrals.** Black, white, and gray are the three neutrals or noncolors, which are not part of the color wheel. A neutral, when used beside a color, intensifies the color. Black and white, if not used properly, can dominate a composition. We “see” black when no electromagnetic radiation reaches our eyes; we see white when all the wavelengths in the electromagnetic spectrum reach our eyes.



## Handout 1.1

**Color**

Name: \_\_\_\_\_

A prism is used to separate white light waves into separate wavelength bands that we call the colors of the rainbow. The flat band of colors formed in this way is called the spectrum.

These colors, in the same order as in a rainbow, can be bent into a circle. In the circular form, they are called a \_\_\_\_\_.

If you know the arrangement of the colors and their places on the \_\_\_\_\_, you will be able to mix and identify colors more easily.

There are 12 colors on the color wheel that we are using (see Figure 1.8). They are divided into three groups:

**Primary Colors.** Three colors: Red, yellow, and blue.

**Secondary Colors.** Three colors: Orange, green, and violet (or purple). Each secondary color is a mixture of equal amounts of the two primary colors on either side of it on the color wheel:

red + blue = \_\_\_\_\_

blue + yellow = \_\_\_\_\_

yellow + red = \_\_\_\_\_

**Intermediate Colors.** Third in importance are the six remaining colors on the color wheel, which are combinations of equal amounts of the colors on either side of them on the wheel:

red-orange = \_\_\_\_\_ + \_\_\_\_\_

red-violet = \_\_\_\_\_ + \_\_\_\_\_

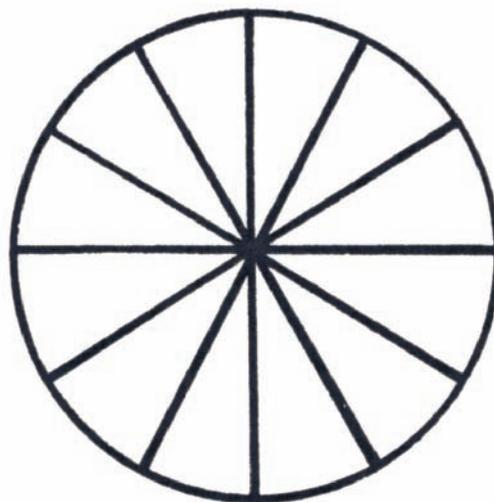
blue-violet = \_\_\_\_\_ + \_\_\_\_\_

blue-green = \_\_\_\_\_ + \_\_\_\_\_

yellow-green = \_\_\_\_\_ + \_\_\_\_\_

yellow-orange = \_\_\_\_\_ + \_\_\_\_\_

The name of the primary color always appears first. There could be many more than 12 divisions on the color wheel, but we will only use 12.

**Figure 1.8.**

**ACTIVITY**

## 1.10

### ***Creating a Color Wheel***

#### **Objectives**

1. Students will learn the proper procedure for mixing secondary and intermediate colors.
2. Students will learn the proper sequence of colors as they appear on the color wheel.

#### **Level One: Creating a Simple Color Wheel**

#### **Materials**

Rulers; compasses; pencils; red, yellow, and blue poster paints; small paintbrushes; white paper suitable for paint; water containers; paper towels; black markers.

#### **Time**

100 minutes

#### **Procedure**

1. Use a compass to draw a circle with a radius of 4 in.
2. Divide the circle into four equal parts.
3. Divide each of the four parts into three equal parts.
4. Paint in the primary colors as indicated on Handout 1.1.
5. Paint in the secondary and intermediate colors by mixing appropriate primary and secondary colors.
6. When it is dry, accent the circle and its divisions by outlining with a black marker.

#### **Level Two: Creating a More Elaborate Color Wheel**

#### **Materials**

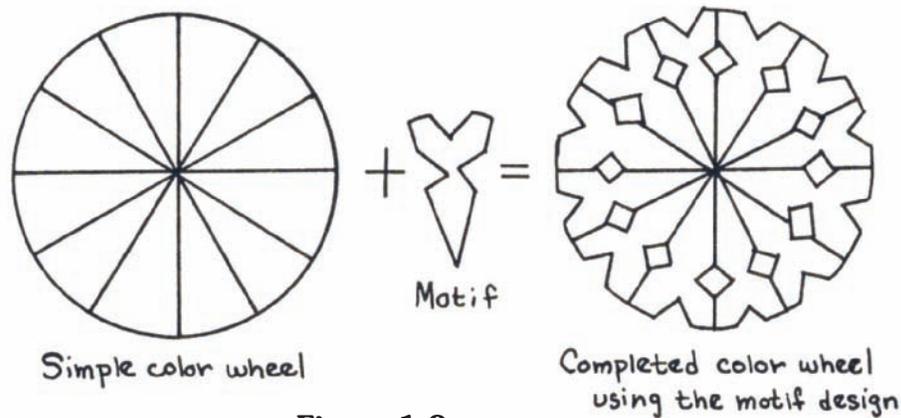
Same as Level One, with the addition of heavy paper for making a pattern, a second sheet of paper for mounting the color wheel, and glue or rubber cement.

#### **Time**

200 minutes

**Procedure (see Figure 1.9)**

1. Follow steps 1 through 5 for Level One.
2. When the color wheel is complete, design a motif or pattern of your own choice (see Figure 1.9 for an example) on the heavy paper. The motif should be large enough to cover the majority of a single pie-shaped section of the color wheel.
3. Trace the motif onto each of the 12 sections of the color wheel; cut out the shapes and arrange them on the second sheet of paper in the same order, creating a color wheel of original design. Outline each section with marker.
4. Glue the sections into place.

**Figure 1.9.****Level Three: Creating a Color Design****Materials**

Same as Level One, with the addition of 12-x-12-in. white, heavy paper suitable for painting.

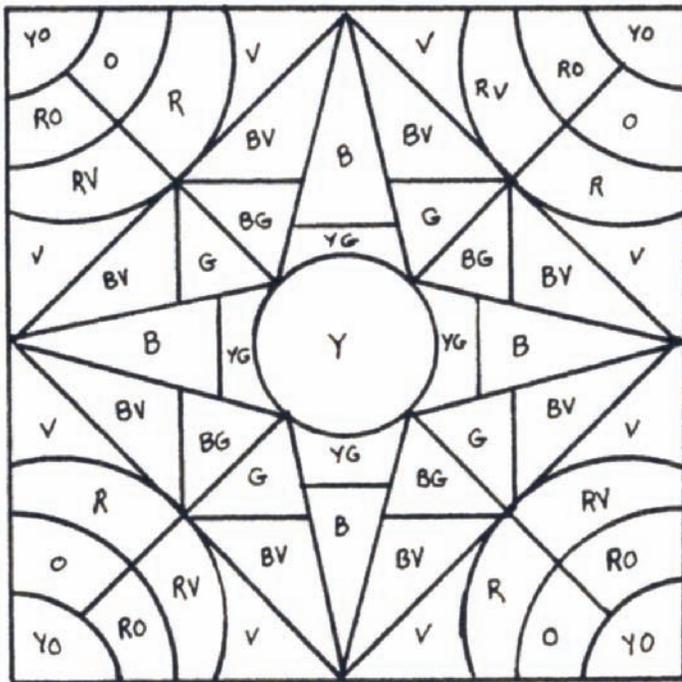
**Time**

200 minutes

**Procedure**

1. On a sheet of heavy white 12-x-12-in. paper, create an original, nonobjective, symmetrical design of geometric shapes. The composition should have a minimum of 12 different shapes radiating outward from the center point. (See Figure 1.10 for an example.)
2. Begin by painting the center shape one of the primary colors.
3. Proceed by painting the next set of shapes, outward from the center, in the next color of the color wheel, an intermediate color. NOTE: No two shapes sharing a common side should be painted the same color.
4. Paint the next set of shapes in the appropriate secondary color.

5. Paint the next set of shapes in the appropriate intermediate color.
6. Repeat steps 2–5, moving outward from the center and adding colors following the order of the color wheel, until all 12 of the colors have been used (e.g., begin with the primary red, paint the next set red-orange, the next set orange, the next set yellow-orange, the next set the primary yellow, etc.). If all 12 colors have been used and shapes still remain unpainted, repeat the order of colors until all shapes are painted.



Key  
 Y= Yellow  
 YG= Yellow-green  
 G= Green  
 BG= Blue-green  
 B= Blue  
 BV= Blue-violet  
 V= Violet  
 RV= Red-violet  
 R= Red  
 RO= Red-orange  
 O= Orange  
 YO= Yellow-orange

Figure 1.10.

## The Warm and Cool of Color

The colors of the color wheel can be divided into two groups: warm colors (red-violet, red, red-orange, orange, yellow-orange, and yellow) and cool colors (yellow-green, green, blue-green, blue, blue-violet, and violet). Warm and cool colors are used by artists to create a mood or atmosphere in their artwork. Warm colors create a feeling of joy and happiness and have a festive atmosphere about them. Cool colors are restful, cold, subdued, and quiet.

**ACTIVITY**

**1.11**

***Warm and Cool Colors***

**Objectives**

1. Students will understand how warm or cool colors aid in portraying a specific subject (all levels).
2. Students will apply the creative process and principles of good composition to an original work of art (Levels Two and Three).

**Level One: Warm and Cool Colors I**

**Materials**

Magazines and scissors.

**Time**

50 minutes

**Procedure**

1. Look through magazines and cut out examples of pictures in warm colors and pictures in cool colors.
2. Discuss how the pictures make you feel.
3. Find advertising pictures that relate to chemistry, for example, fluoride toothpaste ads, pH balanced shampoo ads, vitamin supplement ads. In the advertising pictures, discuss the use of warm and cool colors to convey a message to a buyer.

**Level Two: Warm and Cool Colors II**

**Materials**

Magazines; glue; scissors; paper on which to glue the compositions.

**Time**

150 minutes

**Procedure**

1. Choose a descriptive theme (e.g., words such as *excitement*, *peaceful*, *busy*, and *sad* are possible themes). Each student should choose a different theme.
2. Find a variety of pictures in magazines to express your theme, cut them out, and arrange them into a composition, making effective use of warm and cool colors and the elements of design to best describe the theme.

3. Find advertising pictures that relate to chemistry, for example, fluoride toothpaste ads, pH balanced shampoo ads, vitamin supplement ads. Identify a field of chemistry associated with each advertisement.

### Level Three: Warm and Cool Colors III

#### Materials

Poster paints; paintbrushes; colored markers or colored pencils; 12-x-18-in. paper suitable for the chosen medium; list of descriptive words.

#### Time

200 minutes

#### Procedure

1. Choose a word from the list made in Activity 1.2 and create a composition on 12-x-18-in. paper interpreting the word in either warm or cool colors, using the elements of design. The picture can be realistic or nonobjective.
2. Find advertising pictures that relate to chemistry, for example, fluoride toothpaste ads, pH balanced shampoo ads, vitamin supplement ads. Explain the chemical concept associated with each advertisement.

---

## THE THREE PROPERTIES OF COLOR

### Name and explain the three properties of color.

*Hue* is the response of the human brain to the quality and quantity of a wavelength. Each wavelength represents a different hue. In the absence of visible light, there is no color or hue. Some artists use many colors to express an idea. Their paintings are polychromatic. An example of a polychromatic painting is Marc Chagall's *I and the Village*. Other paintings are monochromatic, consisting of only one color. Lamar Dodd's *Pawley's Island at Night* is painted only in blue and is therefore a monochromatic painting.

*Value* is the response of the human brain to the quantity of a certain wavelength reaching the retina. When a black pigment is added to a hue, some of the light that was reflected from the hue is absorbed. The hue appears darker. When a white pigment is added to a hue, more light is reflected from the hue and it appears lighter.

*Intensity* is the response of the human brain to color purity. The purist colors are said to have the highest intensity. A colored laser light has high intensity. All of the light waves reaching the retina are of the same wavelength.

**Hue.** Hue refers to the quality of a color that we indicate by its name, such as red, orange, green, and blue. To change the hue of a color, it must be mixed with another hue (e.g., to change yellow to yellow-green some blue must be added).

**Value.** Value refers to the lightness or darkness of a color. This lightness or darkness depends on the amount of white or black added to the hue. To make a hue lighter, white is added. To make a hue darker, black is added. Adding black or white to a hue does not change the hue to a different hue; this only lightens or darkens it.

**Intensity (or Chroma).** Intensity, or chroma, refers to the color strength or saturation of a hue. A pure color as it appears on the color wheel is the strongest or most intense. The intensity of a color can be lessened by the addition of gray to the color, which dulls the color. A second way to lessen the intensity of a color is to add the hue that appears directly opposite on the color wheel. This opposite color is referred to as its *complement*.

### Challenge Activity

Pick an artist from the list below. Explain how the work listed for that artist illustrates the color properties represented in that artwork. For example, how specifically does Piet Mondrian's *Tableau II* illustrate the use of primary colors at full intensity?

■ *Note:*

You can find examples of the artworks listed below at a library or on the Internet.

The following is a list of significant modern artists and the properties of color represented in each artist's work:

Piet Mondrian	Primary colors, full intensity, neutrals <i>Tableau II</i> , 1921–1925
Stuart Davis	Primary and secondary colors, full intensity <i>Rapt At Rappaport's</i> , 1952
Fernand Leger	Primary and secondary colors, full intensity <i>The Great Parade</i> , 1954
Pablo Picasso	Low intensity, neutrals <i>Woman Ironing</i> , 1904
Juan Gris	Low intensity, neutrals <i>La Place Ravignan, Still Life in Front of an Open Window</i> , 1915
James Abbott McNeill Whistler	Low intensity, neutrals <i>Chelsea Wharf: Grey and Silver</i> , 1875
Hans Hoffman	Full intensity <i>The Gate</i> , 1960
Roy Lichtenstein	Full intensity, neutrals <i>Artist's Studio</i> , 1974
Auguste Renoir	Light and dark values <i>Le Moulin de la Galette</i> , 1879
Vincent van Gogh	Full intensity <i>The Night Cafe</i> , 1888
Mark Rothko	Full and low intensity <i>Orange Yellow Orange</i> , 1969
Victor Vasarely	Light and dark values <i>Vona-KSZ</i> , 1968
Ellsworth Kelly	Full intensity <i>Blue Green Yellow Orange Red</i> , 1966

**ACTIVITY****1.12*****Solution Preparation and Pigment  
Primary Hues*****Objectives**

1. Students will explain the mole concept and use this concept to prepare chemical solutions of particular molarities.
2. Students will use colored chemical solutions to determine the outcome of mixing particular colors of pigments.

**Materials**

CuSO<sub>4</sub> (copper sulfate); K<sub>2</sub>CrO<sub>4</sub> (potassium chromate); distilled water; periodic table; three small test tubes for each pair of students; red food color; three small flashlights; red, green, and blue transparency paper or filters; white paper; centigram balance.

**Time**

30 minutes

**Procedure: All Levels**

1. Prepare three flashlights by covering the lens of one flashlight with red transparency paper, the lens of another with green transparency paper, and the lens of the third with blue transparency paper. Red, green, and blue filters may be used instead of transparency paper.
2. You can help prepare 0.1 M CuSO<sub>4</sub> and 0.1M K<sub>2</sub>CrO<sub>4</sub> solutions using the following combinations: 15.9 g CuSO<sub>4</sub>/liter H<sub>2</sub>O and 19.4 g K<sub>2</sub>CrO<sub>4</sub>/liter H<sub>2</sub>O.

During this procedure, your teacher will introduce the mole concept. Use a periodic table to find the relative masses of all the elements in the molecule CuSO<sub>4</sub> and K<sub>2</sub>CrO<sub>4</sub>, respectively: Cu (copper), S (sulfur) and O (oxygen); and K (potassium), Cr (chromium), O (oxygen). The relative mass in grams for any element contains the same number of atoms. This number of atoms,  $6.02 \times 10^{23}$ , is called a mole. In the preparation of any 0.1 M solution, 0.1 mole of molecules is needed. A 0.1 M solution, by definition, contains 0.1 mole of a substance dissolved in 1.0 liter of a solvent.

To find the mass of one mole of a molecule, add the relative masses of the elements contained in the molecule. This is called the relative mass of a molecule. The number of molecules in one relative mass of a molecule is  $6.02 \times 10^{23}$ .

### Table of Relative Masses (AMU)

Cu, 63.5   S, 32.1   O, 16.0   K, 39.1   Cr, 52.0

Note that the subscripts in a molecular formula represent the number of atoms in a molecule. Since a molecule of  $\text{CuSO}_4$  has four oxygen atoms, the relative mass of oxygen must be multiplied by four and added to the relative mass of one copper atom and one sulfur atom to find the relative mass of a mole of  $\text{CuSO}_4$ , copper sulfate molecules. Two atoms of potassium, four atoms of oxygen, and one atom of chromium must be accounted for in potassium chromate,  $\text{K}_2\text{CrO}_4$ . Students should calculate the mass of one mole of each of the molecules needed, convert each to 0.1 mole (multiply by 0.1) and check their answers, which should be 15.9 g for  $\text{CuSO}_4$  and 19.4 g for  $\text{K}_2\text{CrO}_4$ .

3. The  $\text{CuSO}_4$  solution will be blue and the  $\text{K}_2\text{CrO}_4$  will be yellow. Have students place a sample of each solution into a small test tube. In addition, fill one small test tube half full of distilled water and add red food color to attain a bright red solution. Next, place a sheet of white paper behind each test tube, then focus a beam of light through each solution, as follows: red light through the blue solution ( $\text{CuSO}_4$ ), blue light through the  $\text{K}_2\text{CrO}_4$  solution, and green light through the red solution.
4. Students should observe the white paper. In all three cases, students will see no transmission of color through the solutions because blue  $\text{CuSO}_4$  solution absorbs red light waves, the yellow  $\text{K}_2\text{CrO}_4$  solution absorbs blue light waves, and the red solution absorbs green light waves.

### Questions and Conclusions

#### Level One

1. List the primary colors of pigments (red, yellow, and blue), the color of light wave each absorbs (respectively, green, blue, and red), and the colors of light waves each reflects (respectively, red-orange and violet; red-orange and green; and green and violet).
2. Explain what a mole is in terms of the number involved.
3. Explain what a mole is in terms of the relative weight of an element.
4. How many atoms are present in one mole of any element? In one relative weight of any element? How do these two numbers compare?
5. How many particles are in a mole of anything; a mole of stars, a mole of apples, a mole of paper clips?

#### Level Two

1. Explain why some pigments are black and some are white. Include absorption and reflection of colored light waves in your explanation.

2. Calculate the number of moles in 100.00 grams of sulfur, carbon, and iron. The relative masses of sulfur, carbon, and iron are 32.07, 12.01, and 55.85, respectively.
  3. Explain why a chemist needs to use a mole as a unit when dealing with chemical change.
- 

### **What particles can determine the color of substances?**

- Pigment molecules or atoms can determine the color of a substance. These molecules or atoms absorb and reflect certain visible waves of energy. The waves that are reflected enter our eyes and interact with our retinas, and we see color.
- Each molecule and atom has its own wavelength-absorbing and -reflecting properties.

Activity 1.12 shows the relationship between pigment hue and the wave absorption and reflection properties of the pigment molecule. We will use this activity as a basis for learning about molecules, compounds, and ions, some of the particles that determine the colors of substances.

## **The Periodic Table: Elements, Molecules, Compounds, and Ions**

### **What is an element?**

- An element is a substance that cannot be divided into simpler substances by ordinary chemical means.
- An element is the simplest type of a pure substance.

### **What is an isotope?**

- An isotope is an atom of an element that has the same number of protons as another atom of that element but a different number of neutrons. When the percent abundance of the isotopes in a sample of an element are known, the average atomic mass of the element can be calculated.
- In a sample of boron, 19.91% of the atoms have an isotopic mass (amu) of 10.0129 and 80.09% have an isotopic mass of 11.0093. The average atomic mass of boron is calculated as follows:

$$\text{Average atomic mass} = (.8009 \times 11.0093) + (.1991 \times 10.0129) = 8.817 + 1.994 = 10.81$$

- Isotope abundance can be determined by using a mass spectrometer.

### **What is a molecule?**

- A molecule is a particle made up of atoms bonded together by covalent bonding.

**What is a compound?**

- A compound contains two or more different atoms chemically bonded in fixed proportions.

**What is an ion?**

- An ion is an atom or group of atoms that no longer are neutral but have a negative or positive charge because electrons are gained or lost .

**What is the periodic table?**

- The periodic table is an arrangement of the elements in ascending order of their atomic numbers.
- In addition, the elements are arranged in a unique pattern so most vertical columns of elements, groups or families, have similar electron configurations and therefore similar chemical properties.
- Most elements in the same group also exhibit similar physical properties.
- A horizontal row is called a *period*. As one travels from left to right across a period certain trends occur. In general, atomic radius decreases from left to right (disregarding the noble gases). Metallic properties also decrease from left to right.

Elements are substances that are made of the same kind of atoms, except for isotopes of an element, which have a different number of neutrons. Molecules are made of two or more atoms bonded together. Compounds are made of two or more different atoms bonded together. Ions are charged particles, mainly charged atoms or groups of atoms. All of these particles can transmit, absorb, and reflect light and appear colored. If we intend to work with colored pigments, we should understand the language that the chemist uses to describe the particles contained in these pigments. Also, we need a method of organizing these particles. The periodic table is used to organize the elements. For the non-nuclear chemist, the atoms that come from the elements are the fundamental building blocks of all the other particles, including molecules, compounds, and ions. The periodic table organizes the elements into a meaningful pattern.

**ACTIVITY****1.13*****Elements and the Periodic Table***

---

**Objectives**

1. Students will identify the families found on the periodic table.
2. Students will examine the color of various elements and look for regularities in the placement of these elements on the periodic table.
3. Students will relate the physical and chemical properties of the elements to their placement on the periodic table.

4. Students will find a relationship between the color of a free element and the color of a compound containing the same element.
5. Students will become familiar with compounds that provide pigments for paint products.

### Materials

Periodic table; colored pencils; 5 ml samples of 0.1 M  $\text{Cu}(\text{NO}_3)_2$ ,  $\text{Fe}(\text{NO}_3)_3$ ,  $\text{Co}(\text{NO}_3)_2$ ,  $\text{Ni}(\text{NO}_3)_2$  and  $\text{Zn}(\text{NO}_3)_2$ ; small samples of bromine, iodine, sulfur, carbon, copper, iron, cobalt, nickel, zinc, magnesium and calcium; and 0.1M 5 ml samples of sodium chloride,  $\text{NaCl}$ , and potassium chloride,  $\text{KCl}$ ; magnesium nitrate,  $\text{Mg}(\text{NO}_3)_2$ , and calcium nitrate,  $\text{Ca}(\text{NO}_3)_2$ .

### Time

30 minutes

### Procedure

1. The teacher should show students samples of solutions of copper nitrate,  $\text{Cu}(\text{NO}_3)_2$ , iron nitrate,  $\text{Fe}(\text{NO}_3)_3$ , cobalt nitrate,  $\text{Co}(\text{NO}_3)_2$ , nickel nitrate,  $\text{Ni}(\text{NO}_3)_2$  and zinc nitrate,  $\text{Zn}(\text{NO}_3)_2$ . List the solution name and formula and color. Name the metal element in each compound.
2. The teacher should show students samples of copper, iron, cobalt, nickel, and zinc. List the symbol and color for each metal.
3. The teacher should show students samples of solutions of  $\text{Mg}(\text{NO}_3)_2$  and calcium nitrate,  $\text{Ca}(\text{NO}_3)_2$ . List the solution name and formula and color. Name the metal element in each compound.
4. The teacher should show students sample of solutions of sodium chloride,  $\text{NaCl}$ , and potassium chloride,  $\text{KCl}$ . List the solution name and formula and color. Name the metal element in each compound.
5. The teacher should show students samples of sulfur, carbon, bromine and iodine. Write the formula and color for each of these elements.
6. Find each element listed above on your periodic table and circle the element. Decide if there is a regularity or pattern in the element's color and position on the periodic table.
7. Find, label by name and outline the following families on your periodic table: alkali metals, alkaline earth metals, transition metals, halogens, and inert gases. Draw a dark line to show the separation between metals and nonmetals. Also, draw lines to enclose the metalloids. Colored pencils can be used to distinguish between the families.

## Questions and Conclusions

### Level One

1. Elements observed in this activity (copper, iron, cobalt, nickel, zinc, sodium, magnesium, calcium, bromine, and iodine) belong in the following families: alkali metals, alkaline earth metals, transition metals and halogens. Place each element in its proper family. Is there any relationship between the element's family and the element's color?
2. Some elements, when they combine with other elements, tend to form colored compounds. These elements occur in what family?
3. Research the common physical and chemical properties for each family (a vertical column) in the periodic table. The families to consider are alkali metals, alkaline earth metals, inert gases, halogens, and transition metals.
4. Why do you think the table is called a *periodic* table?
5. Make a list of all the elements in the periodic table that are colored, recording the colors. Do elements in the same family tend to have the same color?

### Level Two

1. When certain transition metals combine with nitrate,  $\text{NO}_3^{1-}$ , they form colored compounds. Does the color come from the transition metal or from the nitrate ion? Explain your answer.
2. Explain the arrangement of the periodic table, including why repeating rows of eight elements and eighteen elements appear on the table.
3. Relate the electron configuration of elements to the arrangement of the elements in the periodic table. Examine the outermost electrons for members of each group A family and see if a pattern develops in the outermost electron configuration for members of the same family.
4. Propose a theory to explain why many transition metal elements form colored compounds, while most alkali metal and alkaline earth metal elements form colorless compounds.

## Challenge Activity

Hieroglyphs are pictures of recognizable objects used to tell a story. Egyptians used hieroglyphs from about 3000 B.C. until the time of the Roman Empire. Compare chemical symbols to hieroglyphs. How are they the same, and how are they different? Rewrite the following equations using hieroglyphs that you create: Hydrogen gas plus oxygen gas produce water; copper plus oxygen gas produce copper oxide. Which gives more information, a chemical symbol equation or a hieroglyphic equation? Why? Find artworks that include hieroglyphics. Explain how the hieroglyphs themselves are part of the artwork.

Some elements have symbols with Latin or Greek origins. The Latin word *plumbus* gives lead its symbol, Pb. *Plumbus* means lead or heavy. The word *oxygen* comes from the French word *oxygene* and is derived from the Greek words *oxy* and *genes*, meaning acid forming. (It was believed that all acids contained oxygen.) Other elements are named for their place of discovery or for the discoverer. Berkelium, Bk, is named after Berkeley, California, where it was discovered. Fermium, Fm, is named after Enrico Fermi, a physicist who made atoms radioactive with slowed-down neutrons.

Chemical symbols are used to describe atomic and molecular structures and how they appear in chemical changes. A chemical equation describes a chemical change. The chemical symbols in the equation show the atomic structures of the reactants and products. Hieroglyphs are merely pictures and do not show atomic and molecular structure.

A hieroglyphic equation depicting hydrogen and oxygen producing water could be a balloon containing hydrogen and a person breathing oxygen, yielding a waterfall. This equation would not convey specific information useful to a chemist. However, it might be an unusual two-dimensional modern work of art.

## Ions

### Define ion.

- An atom or group of atoms that gains or loses one or more electrons to acquire a net electrical charge is an ion.
- The charge of a monatomic ion is found by subtracting the number of electrons from the number of protons.
- If an ion has more electrons than protons, the ion has a negative charge. If the ion has more protons than electrons, the ion has a positive charge.

### How is an ion formed?

- When electrons are transferred in a chemical change, ions are formed.
- Metals tend to form positive ions, and nonmetals tend to form negative ions.
- Some compounds are composed entirely of ions. These compounds are called *salts*. The ions in most ionic compounds can be separated by melting or dissolving them in water. When melted or dissolved in water, ionic compounds are good conductors of electricity. Most ionic compounds have high melting points and tend to be brittle.

When particular substances are dissolved in water to make a solution, the solution is colored. This is apparent from Activity 1.1. The particles imparting the color are called ions, which are charged particles, mainly charged atoms or charged groups of atoms. We have considered neutral atoms, which have no overall charge because the number of protons (positively charged particles in the atomic nucleus) is equal to the number of electrons (negatively charged particles) outside the atomic nucleus. (*Note:* Neutrons, uncharged particles, are also in the atomic nucleus.) When some compounds are placed in

water, the compounds break apart, electrons are transferred from one atom to another, and ions are formed. *Voilà!* Charged particles are floating around in the solution. If atoms lose electrons, the ions formed are positively charged (the atoms have more protons than electrons); if the atoms gain electrons, the ions formed are negatively charged. Ions are symbolized with the element symbol and the ion charge. The compounds used in the previous activities are ionized in the following way:  $\text{CuSO}_4 \rightarrow \text{Cu}^{2+} + \text{SO}_4^{2-}$ ;  $\text{Zn}(\text{NO}_3)_2 \rightarrow \text{Zn}^{2+} + 2\text{NO}_3^{1-}$ ;  $\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-$ .

■ *Note:*

A chemical equation is a shorthand way for a chemist to show a chemical change. On the previous page, to show ion formation, chemical equations are used. In the equations, reactants are on the left and products are on the right. The arrow separating reactants and products means “yields.” A chemical equation is balanced so that reactant atoms and product atoms are the same and equal in number, conforming to the law of conservation of matter. In an ionic equation, charge is also balanced.

### What family of elements usually forms colored ions?

- Transition metals usually form colored ions.

Now we can identify the source of color in the solutions. Experiments show that copper ions ( $\text{Cu}^{2+}$ ) are blue, nickel ions ( $\text{Ni}^{2+}$ ) are green, and cobalt ions ( $\text{Co}^{2+}$ ) are a pale red. Some color-producing ions are combinations of transition metals and nonmetals. Examples are  $\text{Fe}(\text{SCN})_2^+$  (red) and  $\text{CrO}_4^{2-}$  (yellow). You should note that the elements in the ions producing the colors in these solutions are the transition metals. Upon further examination, you would find that most of the colored ions in solutions contain transition metal elements or are transition metal ions.

Understanding ions can lead us to a new theory to explain why the sky is blue: Perhaps the sun provides the correct wavelength of energy to ionize atmospheric particles producing blue ions. However, there is no evidence that oxygen ( $\text{O}_2$ ) and nitrogen ( $\text{N}_2$ ) molecules in our atmosphere are ionized by the sun.

## Value

### Define *value*.

- Value is relative lightness or darkness of a hue or of black or white.
- Values are easy to see in black-and-white works, where shades of gray are used to define shapes and distinguish one form from another.
- The amount of light that strikes the retina determines how light or dark an object appears.
- The amount of light perceived as reflected from a surface is determined by the nature of the light source (fluorescent or natural), the nature of the reflecting surface (smooth or rough), the distance of the light source from the reflecting surface, and the angle of reflected light.

### **How is the value of a hue changed?**

- The value of a hue is changed when the amount of light reflected from the hue is changed. This amount of light reflected can be altered by adding black or white pigment to a hue.

### **Define solution.**

- A solution is a homogenous mixture of solute and solvent particles. The solute particles are evenly dispersed in the solvent.
- The following combinations can result in solution formation. Solids can dissolve in liquids, such as salt in water. Liquids can dissolve in liquids, such as alcohol in water. Solids can dissolve in solids, such as copper in silver. These solutions are called *alloys*.

### **How is the concentration of a solution expressed?**

- The concentration of a solution can be expressed in mass percent, as described below.
- It can also be expressed in moles/liter. This is called molarity and is abbreviated M. A 1 M solution has one mole of solute dissolved in 1 L of solution. The molarity of a potassium chloride solution that has a volume of 500 ml and contains 149.2g of KCl is calculated as follows:  $500\text{ml} \times 1\text{ L}/1000\text{ml} = .500\text{L}$ .  $149.2\text{g} \times 1\text{ mole}/74.55\text{g} = 2.001\text{ mole}$ .  $2.001\text{ mole}/.500\text{L} = 4.00\text{M}$ .

An artist changes the value of a hue of pigment by adding black or white pigment, so that the hue becomes darker or lighter. Black pigment absorbs all wavelengths of visible light; when added to a hue of pigment, it reduces the number of light waves of the hue that reach the retina, thus making the hue appear darker. White pigment reflects all wavelengths of visible light waves; it increases the concentration of all wavelengths that reach the retina, which the brain interprets as white light, and makes a hue appear lighter.

Another way to change the value of a hue of pigment is to change the concentration of the hue particles in a particular pigment solution.

In chemistry, solutions are prepared so that a specific concentration of particles, the solute, is added to a specific volume of solvent. When a uniform mixture of solute and solvent results, a solution is formed. The concentration of a solution is expressed as the ratio of solute to solution, solution being solute plus solvent. In the next demonstration, we examine a change in value through dilution using mass percent as a means of expressing concentration of the solution. In mass percent, the ratio of grams of solute to grams of solution, multiplied by 100, is used to calculate the mass percent of the solution.

**DEMONSTRATION**

## 1.3

### ***Copper Sulfate Dilution, Mass Percent, and Color Value***

#### **Objectives**

1. Students will define *solution* and explain how to express the concentration of a solution using mass percent.
2. Students will describe the concept of color value change.

#### **Materials**

10.0 g  $\text{CuSO}_4$  (copper sulfate); distilled water; 100 ml graduated cylinder; 10 ml graduated cylinder; 0.1 gram balance; eight 250 ml beakers.

■ *Note:*

Each specific mass-percent solution prepared in this demonstration should be saved for Activity 1.14.

#### **Time**

45 minutes

#### **Procedure**

1. The teacher should dissolve 10.0 g of  $\text{CuSO}_4$  in 90.0 g of distilled water,  $\text{H}_2\text{O}$  (1.0 ml  $\text{H}_2\text{O}$  = 1.0 g). This results in a 10% solution of  $\text{CuSO}_4$ . Calculate the mass percent of this solution (mass of solute in grams, 10.0, divided by mass of solution in grams,  $10.0/100.0 = .100$ , multiplied by 100 to find percent) to verify that it is a 10% solution. Observe the color.

■ *Note:*

For the purposes of this demonstration, assume that 1.0 ml of solution has a mass of 1.0 g.

2. The teacher should add 10.0 g (10.0 ml) of the 10% solution of  $\text{CuSO}_4$  to 90.0 g (90.0 ml) of distilled water. This is a 1% solution. Observe the change in color.
3. The teacher should add 10.0 g (10.0 ml) of the 1% solution of  $\text{CuSO}_4$  to 90.0 g (90.0 ml) of distilled water. This is a 0.1% solution. Observe the change in color.
4. The teacher should repeat this process until a colorless solution is achieved. (A total of eight solutions will be prepared. All of the solutions prepared should be saved for Activity 1.14.)

5. Calculate the mass percent of the colorless solution.

### Questions and Conclusions

#### Level One

1. Define *solution* and name the parts of a solution. Where do solutions appear in a classification of matter?
2. Define *mass percent*. If 20.0 g of sodium chloride (NaCl) are added to 180.0 g of H<sub>2</sub>O, what is the mass percent of the solution?

#### Level Two

1. In this demonstration, color value was changed by dilution. How else can color value be changed?
2. Use the concept of light wave reflection to explain why color value changes when a solution is diluted.
3. Are any blue solute particles present when the solution appears colorless?

■ *Note:*

The value of a hue changes as a solution is diluted because, in a constant volume, the number of colored particles (ions) is reduced. There are fewer ions to reflect colored light waves. In this demonstration, the number of blue-green copper ions (Cu<sup>2+</sup>) is reduced.

## ACTIVITY

### 1.14 Color Value

#### Objectives

1. Students will create changes in value by adding white or black to a specific hue (all levels).
2. Students will observe the changes that occur when various amounts of black and white are added to a specific hue (all levels).
3. Students will apply the creative process and the principles of good composition to an original work of art (Levels Two and Three).

- Students will assemble a value cube, creating a design that continues from one surface of the cube to another (Level Three).

### Level One: A Chart for One Hue

#### Materials

Solutions from Demonstration 1.3; pencil; ruler; turquoise, black, and white poster paints; paintbrushes; white paper suitable for painting; mixing trays; water containers.

#### Time

50 minutes

#### Procedure: All Levels

■ *Note:*

Use the solutions from Demonstration 1.3 as a guide to representing values of one hue using pigment.

- Mix paints to achieve hues close to the hues of the eight solutions of  $\text{CuSO}_4$ , copper sulfate, from Demonstration 1.3. Use this hue to prepare a value chart.
- Draw a series of seven 2-x-2-in. squares, arranged vertically on a sheet of white paper.
- Paint the full-strength hue in the center square, then add a small amount of white paint to the original hue (until the color resembles the next lightest hue of solution) and paint the mixture in the square above the original hue.
- Continue to add white paint and paint the squares above the previous square with the new, lighter mixtures.
- Repeat steps 3–4, with the following exceptions:
  - Substitute black paint for white paint.
  - Paint the squares below the full-strength hue.
- Compare the hue values on their chart with the hue values of the solutions. Explain that, for the solutions, the hue changed as the number of color-producing ions ( $\text{Cu}^{2+}$ ) in a specific volume decreased. In preparing hue values in this activity, as black or white was added, the number of  $\text{Cu}^{2+}$  ions in the paint also decreased in a specific volume. However, the added white particles reflect all wavelengths to the eye, along with reflected blue wavelengths from the  $\text{Cu}^{2+}$  ions. We see blue with white: The value is lighter. When the black paint is added, all wavelengths striking the black particles are

absorbed, but the  $\text{Cu}^{2+}$  ions still reflect blue-green wavelengths, which appear to be more highly concentrated—darker—in the absence of other interfering wavelengths.

### Level Two: A Picture of Great Value

#### Materials

Pencil; ruler; a full-strength color of poster paint (from the color wheel); black-and-white poster paints; paintbrushes; 9-x-12-in. white paper suitable for painting; mixing trays; water containers.

#### Time

100 minutes

#### Procedure

1. Print your first name in block letters diagonally across a 9-x-12-in. sheet of paper (see Figure 1.11).
2. Outline your name in pencil with consecutive lines about  $\frac{1}{2}$  in. apart, outward from the name to the edge of the page.
3. Paint all the letters of the name in one full-strength hue of the color wheel.
4. Continue by painting consecutive bands with increasingly lighter values of the original hue, by adding white paint, until the edge of the paper is reached. Or, in the case of a naturally light hue such as yellow, follow the same procedure, except use increasingly darker values of the original hue, by adding black paint.

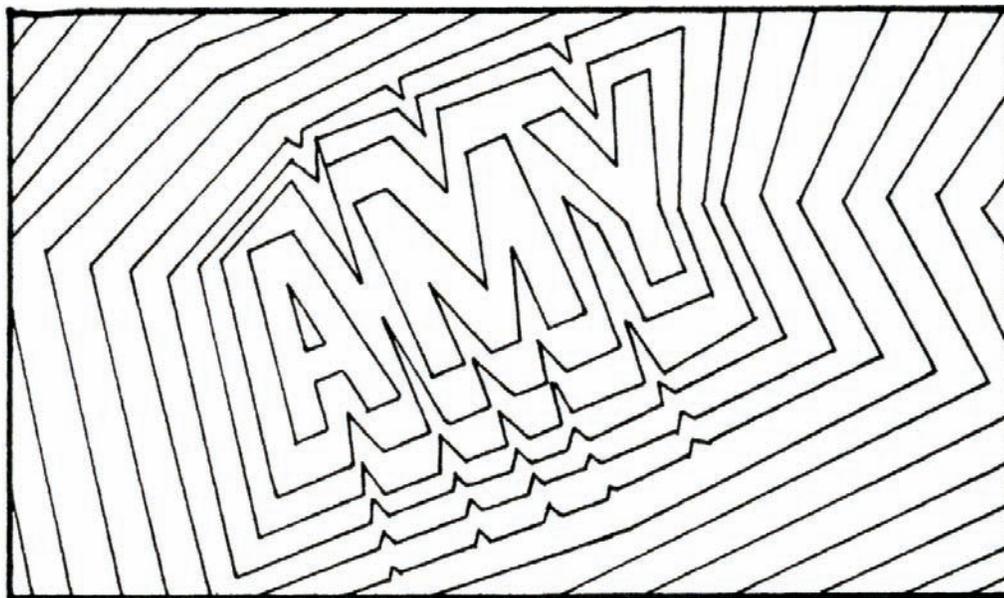


Figure 1.11.

### Level Three: Three-Dimensional Value Cube

#### Materials

Handouts 1.2 and 1.3 (pages 60–61); pencil; ruler; 20-x-22-in. white posterboard; scissors; glue or rubber cement, full-strength color of poster paint (from the color wheel); black-and-white poster paints; small paintbrushes; mixing trays; water containers; black markers.

#### Time

250 minutes

#### Procedure

1. Distribute Handouts 1.2 and 1.3.
2. Draw a cube on white posterboard according to the directions provided.
3. Paint your cubes showing a variety of light and dark values, according to the instructions provided.

## Intensity (or Chroma)

### Define *intensity*.

- Intensity refers to the purity of a color.
- A red laser light would have maximum intensity, since all of the wavelengths in the red light are the same.
- The red color is a pure color.

### How does an artist change the intensity of a color?

- Intensity is changed by mixing a color with its complementary color or making the color more gray.

### Explain two ways that a chemist expresses the concentration of a solution.

- Molarity (M) is the most common way of expressing solution concentration. It is defined as moles of solute dissolved in liters of solution.
- Molality (m) is another way to express solution concentration. It is defined as the number of moles of solute dissolved in each kilogram of solvent.
- Still another way to express solution concentration is mole fraction, which is moles of solute or moles of solvent dissolved in total moles of solution. The mole fraction has no units since moles appear in the numerator and denominator and thus cancel out.
- Molarity is calculated as follows: What is the molarity of a solution containing 50.0 grams of NaCl dissolved in 500.0 ml water? Changing grams to moles,  $50.0\text{g} \times \frac{1\text{ mole}}{58.5\text{g}} = .855\text{ moles}$ . To find molariy,  $.855\text{moles}/.500\text{ L} = 1.71\text{ M}$ .

- Molality is calculated as follows: If 200 g of sucrose ( $C_{12}H_{22}O_{11}$ ) are dissolved in 600.g of water, what is the molality of the solution?  $200 \text{ g} \times 1 \text{ mole}/342.3\text{g} = .584 \text{ mole sucrose}$ .  $.584 \text{ mole}/.600 \text{ kg} = .973\text{m}$ .
- Mole fraction is calculated as follows: What is the mole fraction of carbon dioxide, ( $CO_2$ ), in a mixture of 67.4 g of carbon dioxide in 587 g oxygen ( $O_2$ )?  $67.4 \text{ g} \times 1 \text{ mole}/44.0 \text{ g} = 1.53 \text{ mole carbon dioxide}$ .  $587 \text{ g} \times 1 \text{ mole}/32.0 \text{ g} = 18.4 \text{ moles oxygen}$ . Moles of solution = 1.53 moles carbon dioxide + 18.4 moles oxygen = 19.9 moles of solution. The mole fraction of carbon dioxide is 1.53 divided by 19.9 = .0769. The mole fraction of oxygen must be .925 since the mole fraction of the solute and the mole fraction of the solvent equal one.

Intensity, or chroma, refers to the saturation of a color. A color is saturated when it reaches its maximum intensity. An artist lessens the intensity of a color by adding gray to dull it or by adding the complementary color on the color wheel. The artist is changing the concentration of colored particles in a solution. A chemist knows that a solution is saturated when no more solute can dissolve in a particular volume of a solvent. The chemist expresses solution concentration in a quantitative way. One way for a chemist to express the concentration of a saturated solution is grams of solute per 100 ml of solution. Another way to express the concentration is in moles of solute per liter of solution. In a colored saturated solution, the color is at maximum intensity. If the solution is not saturated, the color is less intense because there are fewer colored particles to bring to the eye the wavelengths that are colored.

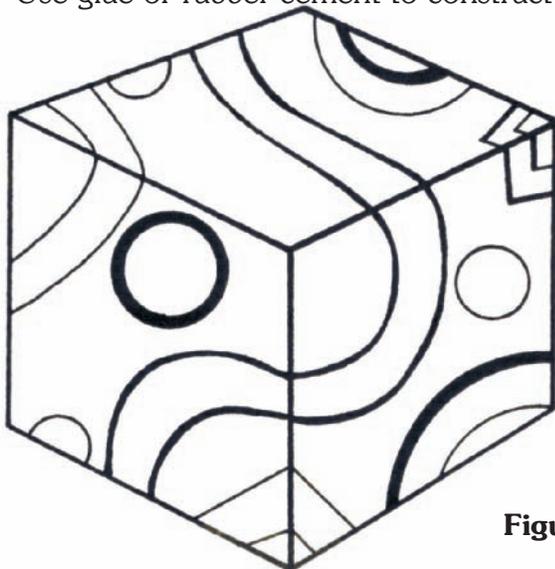


## Handout 1.2

**Three-Dimensional Value Cube**

Name: \_\_\_\_\_

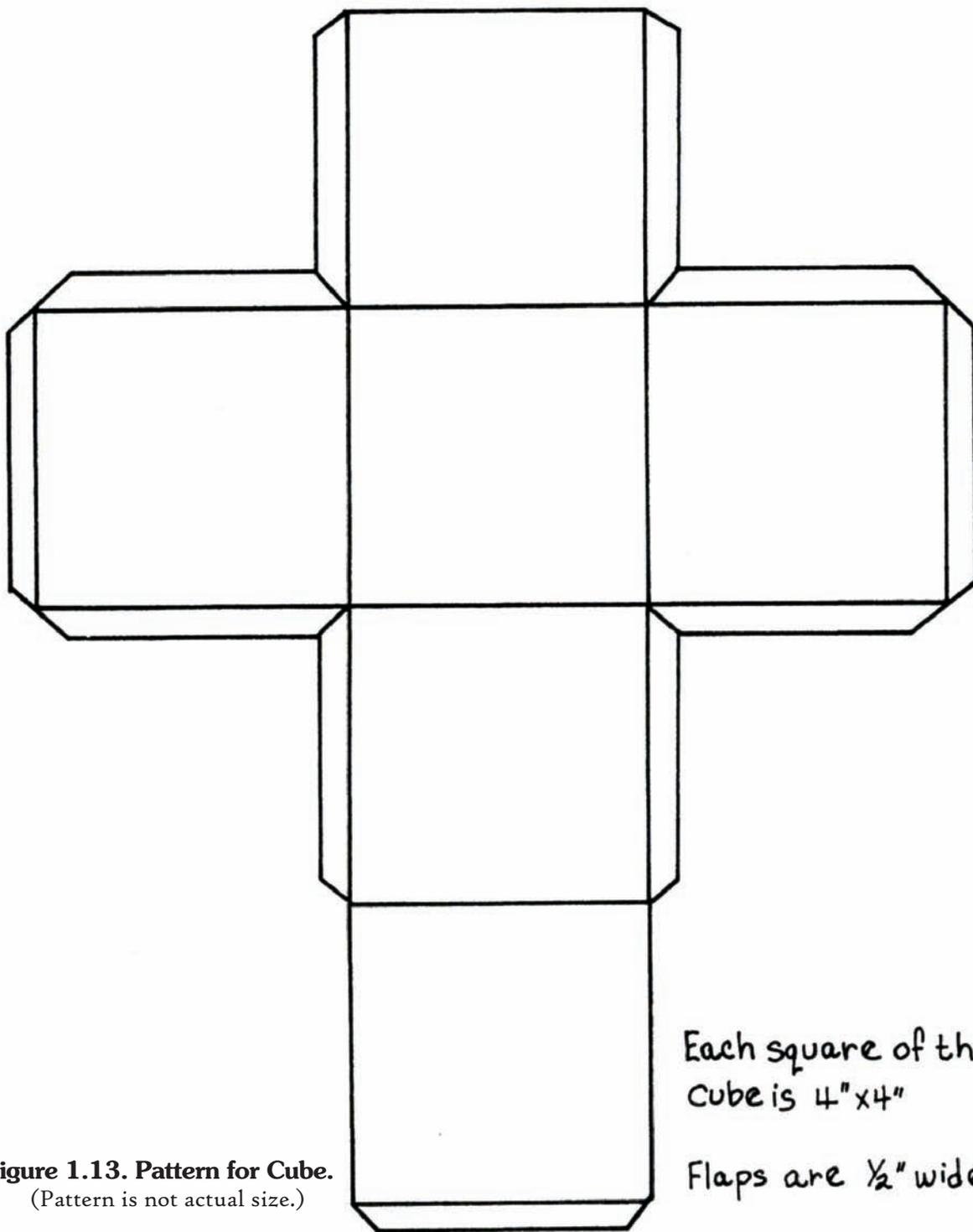
1. Construct a cube by following the pattern provided (Handout 1.3). Use a piece of white posterboard. (Pattern does not appear actual size.) With pencil, draw the sections and flaps as shown.
2. Using scissors, cut out the cube and score all lines with the blade of the scissors. Score the cube on the outside surface.
3. Using a pencil, create a continuous design that moves from one surface of the cube to another (see Figure 1.12). The design may be objective (pictures of objects) or nonobjective (interesting, imaginative lines and shapes). It is important that the design extend over the edges of the cube, from one surface to another.
4. When the design is complete, test it to make sure it is a continuous design by folding the cube into its three-dimensional shape. Do not glue: It is easier to paint flat and glue last.
5. Choose one of the 12 colors of the color wheel and paint the entire surface of the cube using the full-strength hue and a variety of lighter and darker values of the hue.
6. When the cube is painted, enhance the design, if desired, by outlining it using a black marker.
7. Use glue or rubber cement to construct the cube.

**Figure 1.12. Value Cube.**



Handout 1.3

## Pattern for a Three-Dimensional Value Cube



Each square of the  
cube is 4" x 4"

Flaps are  $\frac{1}{2}$ " wide

**Figure 1.13. Pattern for Cube.**  
(Pattern is not actual size.)

**DEMONSTRATION**

## 1.4

### ***Color Intensity in a Saturated Solution and in a Pigmented Hue***

#### **Objectives**

1. Students will observe the preparation of a colored solution in various concentrations.
2. Students will calculate the concentration of a saturated solution.
3. Students will compare the change in color intensity of the solution to the change in color intensity of a pigment hue by the addition of its complementary color.

#### **Materials**

CuSO<sub>4</sub> (copper sulfate); distilled water (H<sub>2</sub>O); 0.1 g balance; 150 ml beaker; 100 ml graduated cylinder; glass stirring rod; pencil; ruler; blue, gray, red, and green poster paints; paintbrushes; white paper suitable for painting; mixing trays; water containers; small test tubes; blue- and gray-colored pencils.

#### **Time**

20 minutes

#### **Procedure: All Levels**

1. The teacher should fill a 150 ml beaker with 100.0 ml of distilled water, then add increments of 5 g of CuSO<sub>4</sub> to the distilled water until no more CuSO<sub>4</sub> will dissolve. The solution is saturated at this point. Record the grams of CuSO<sub>4</sub> added and use blue and gray pencils to make a sketch of the solution color after each addition of CuSO<sub>4</sub>, showing color intensity. About 5 ml of each solution should be saved in a small test tube.
2. Paint the colors of the solution, from the most intense to least intense, using a chart having seven 2-x-2-in. squares arranged vertically in a column. The most intense color should be at the top, the least intense at the bottom. Turquoise will be at the top. Small amounts of gray paint are added to the turquoise in increasing amounts to decrease the intensity. At the bottom, the square will be gray. (See intensity or chroma, page 58.)

■ *Note:*

At 25°C (77°F), there are 20.0 g of CuSO<sub>4</sub> in 100 ml of H<sub>2</sub>O in a saturated solution.

3. Calculate the concentration of the saturated solution in grams solute per 100 ml solvent and in moles of solute per liter of solution. In order to calculate moles/liter (M), known as molarity of a solution, it is necessary to change

grams of  $\text{CuSO}_4$  to moles. If 5.0 g of  $\text{CuSO}_4$  are used, the calculation for moles of  $\text{CuSO}_4$  is 5.0 divided by 159.6 (the mass of one mole of  $\text{CuSO}_4$  molecules), which equals 0.031 mole. If this is dissolved in water to make 100.0 ml of solution, the solution is 0.31 M.

- Repeat step 2, using poster paints of complementary (opposite) colors from the color wheel, such as red and green. Red should be in the top square; green should be in the bottom square. A decrease in intensity, from red to green, is shown by mixing a bit of green in the red and painting this in the next square below. More green is added to the red as subsequent squares are painted.
- Compare the change in intensity of the turquoise hue to the change in intensity of the red hue.

### Questions and Conclusions

#### Level One

- Define *saturated solution*.
- If a colored solution is saturated, can the intensity of the color be increased by adding more solute to the solution? Explain your answer.

#### Level Two

- How can an observer determine whether or not a solution is saturated?
- Explain why the addition of a complementary color will decrease the intensity of the original color.
- Describe another way to decrease the intensity of a color.

### Challenge Activity

When a solution is diluted, it is useful to know the resulting concentration of the diluted solution in moles per liter, molarity (M). When a solution is diluted, the moles of solute remain constant. Therefore, the volume (V) in liters times the concentration (M) of the original solution (o) equals the volume (V) times the concentration (M) of the final solution (f). In equation form,  $M_o V_o = M_f V_f$ . Take 10.0 ml of a 0.10 M copper sulfate solution. Add 2.0 ml of water to the original solution and calculate the molarity of this new solution. Continue to add 2.0 ml of water to each subsequent solution until no color is visible. Calculate the molarity of the final solution. Explain how colored particles can be present in a colorless solution.

Using the above equation,  $(0.10)(10.0) = M_f(12.0)$ .  $M_f = 0.083\text{M}$ . This is the molarity, M, of the solution after the first dilution. Molarity should be calculated after each dilution. When no color is visible, the blue reflecting copper sulfate molecules are so spread out that they cannot reflect a concentration of blue waves dense enough for an eye to “see” the blue color.

**ACTIVITY**

## **1.15**

### ***Intensity Painting (or Chroma Painting)***

#### **Objectives**

1. Students will create changes in intensity, or chroma, by adding various amounts of a complementary color to the original hue (all levels).
2. Students will apply the creative process and the principles of good composition to an original three-dimensional work of art (Level Three).
3. Students will assemble a “pyramid intensity critter” (Level Three).
4. Students will use creative thinking to arrive at an imaginative solution to the problem of choosing a subject (Level Three).

#### **Level One: Intensity Chart I**

#### **Materials**

Pencil; ruler; poster paints (complementary colors from the color wheel); paintbrushes; paper suitable for painting; mixing trays; water containers.

#### **Time**

50 minutes

#### **Procedure**

1. Draw a series of seven 2-x-2-in. squares, arranged vertically on a sheet of white paper.
2. Choose two complementary (opposite) colors from the color wheel, such as red and green. Paint one color in the top square and the other color in the bottom square.
3. Show a decrease in intensity by mixing a bit of the color for the bottom square into a larger amount of the color for the top square and painting this mixture in the square below the top square.
4. Continue decreasing the intensity for the remaining squares, each time adding more of the color for the bottom square.

#### **Level Two: Intensity Chart II**

#### **Materials**

Same as Level One, but using 6-x-18-in. paper suitable for painting.

**Time**

75 minutes

**Procedure**

1. Create a series of seven shapes in a line lengthwise across a sheet of 6-x-18-in. paper. The same shape should be repeated, but its size should be increased from left to right.
2. Choose two complementary colors from the color wheel. Paint the smallest shape with one color and the largest shape with the other color.
3. Decrease the intensity from left to right: Add a small amount of the color for the largest shape to the color for the smallest shape and paint the next largest shape. Continue with this procedure until all the shapes are painted.
4. Describe the change in intensity from the smallest shape to the largest shape.

**Level Three: Making a Pyramid Intensity Critter**

**Materials**

Handouts 1.4 and 1.5 (pages 66–67); pencil; ruler; white posterboard; poster paints (in complementary colors from the color wheel); paintbrushes; mixing trays; water containers; heavy scrap paper and small pieces of cardboard or posterboard; scissors; glue or rubber cement.

**Time**

250 minutes

**Procedure**

1. Distribute Handouts 1.4 and 1.5.
  2. Construct a pyramid intensity critter by following the directions (Handout 1.4) and pattern (Handout 1.5) provided.
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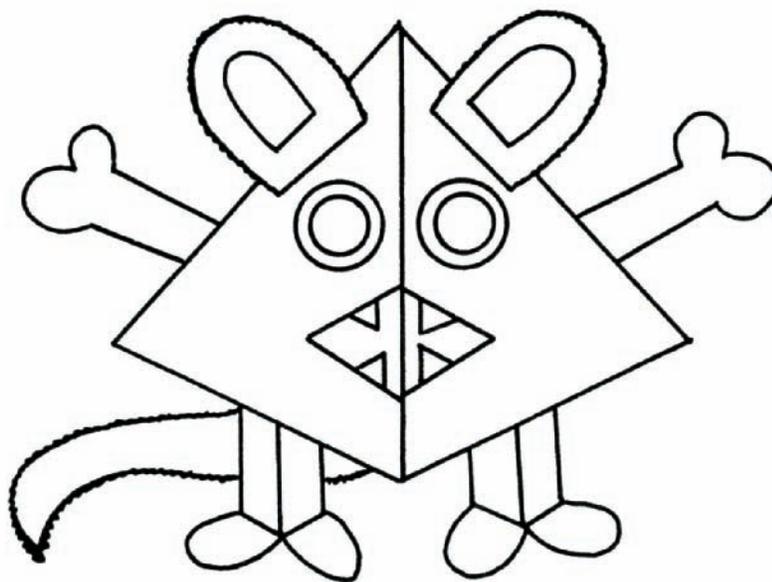


## Handout 1.4

**Pyramid Intensity Critter**

Name: \_\_\_\_\_

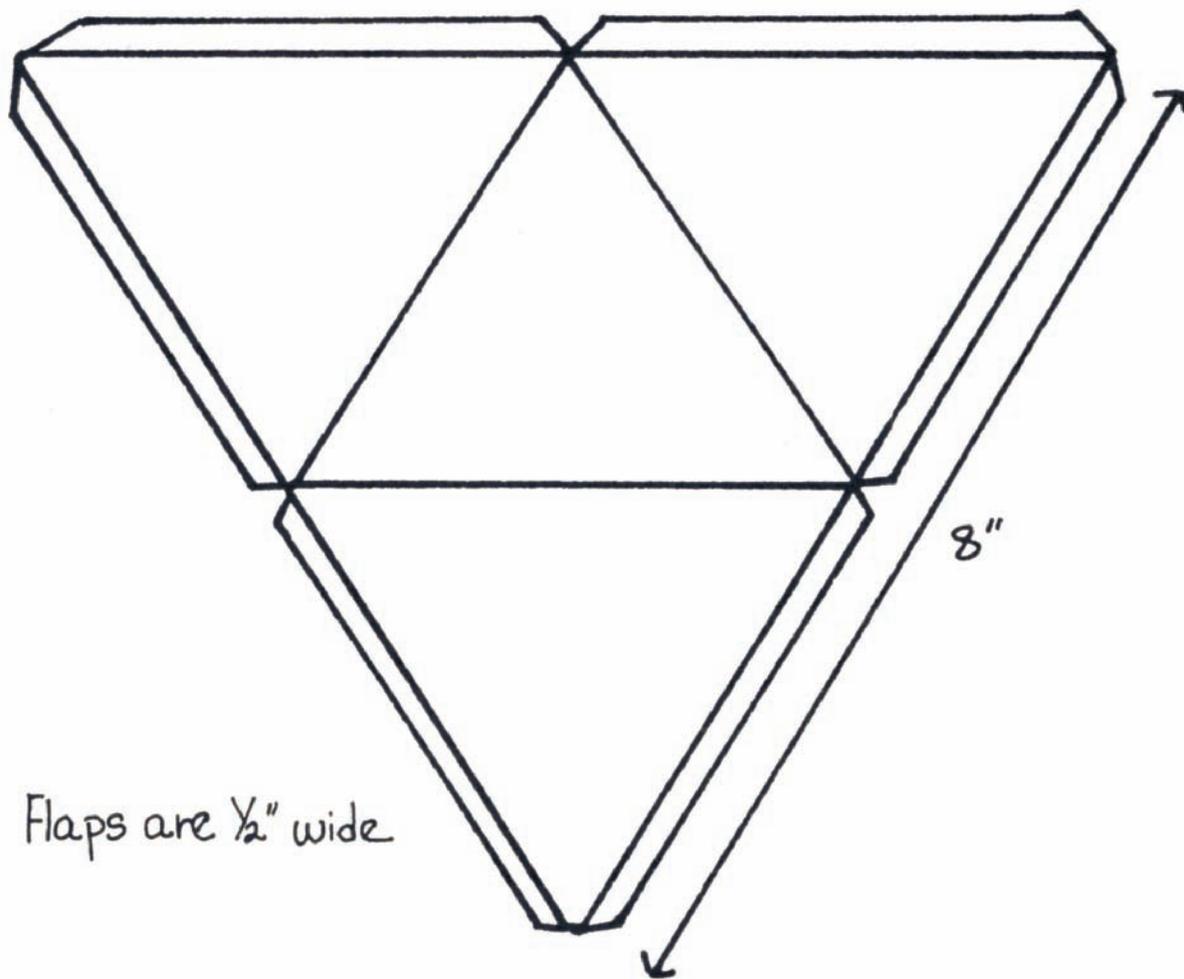
1. Following the pattern provided (Handout 1.5), draw the pattern onto a piece of white posterboard. (Pattern does not appear actual size.) Using pencil, draw the sections and flaps.
2. Cut out the pyramid and score all lines with the blade of the scissors. Score the pyramid on the outside surface.
3. Assemble the pyramid using glue or rubber cement.
4. Design an imaginary creature or animal. Use the pyramid as the body of the creature, attaching arms, legs, wings, horns, teeth, and so on, made from small pieces of cardboard or posterboard. The creature need not stand on its own; it might be made for hanging.
5. When the design is complete, choose two complementary (opposite) colors from the color wheel, such as red and green. Limit the colors used in painting the creature to different intensities of these colors. Dull each of the two original colors by mixing some of the second color. The two original colors may also be used in full strength. If using only two colors is too limiting, include the use of the neutrals—black, white, and gray—for more variety. Remember, this is not a realistic creature, so the colors may be a little weird! (See Figure 1.14.)

**Figure 1.14. Pyramid Intensity Critter.**



Handout 1.5

## Pattern for the Body of a Pyramid Intensity Critter



**Figure 1.15.**  
(Pattern is not actual size.)

## Intensity in Art; Intensity in Chemistry

### How does an artist change the intensity of a hue?

- An artist changes the intensity of a hue by adding some complementary color or adding some black or white paint.

### What is a complementary color?

- Complementary colors are colors that are opposite each other on a color wheel.

### How does a chemist use color intensity?

- A chemist uses color intensity to determine the concentration of a solution.
- Also, a chemist can use color intensity to monitor the progress of a chemical change. As reactants change to products, color changes occur.
- For the following reaction,  $2\text{NO}_{2(g)} \rightleftharpoons \text{N}_2\text{O}_{4(g)}$ , as pressure on these gases is increased the equilibrium shifts to the right, decreasing the number of brown  $\text{NO}_2$  molecules and increasing the number of colorless  $\text{N}_2\text{O}_4$  molecules. The chemist can observe the rate of this reaction by observing the change in intensity of the brown color as the reaction proceeds.

### Define *dilute solution* and *concentrated solution*.

- A dilute solution is one with a low ratio of solute to solvent particles, and a concentrated solution is one with a high ratio of solute to solvent particles.

An artist changes the intensity of a hue by adding various amounts of the complementary color. When the complementary color is added, some of the wavelengths of light reflected by the original hue are absorbed by the complementary color particles. Less light of the original hue reaches the eye, so the color is less intense. A chemist looks at the intensity of color in a solution to determine whether the solution is concentrated or diluted. The ratio of solute particles to solvent particles determines the concentration of a solution. In a concentrated solution, in which the color is intense, the ratio of solute to solvent is high; in a dilute solution, the ratio of solute to solvent is low. In other words, the intensity of the color in a solution is determined by the number of color-producing solute particles in a given volume. The more color-producing particles, the more intense the color.

## COLOR RELATIVITY: ALL THINGS ARE RELATIVE

### According to Albert Einstein, how is matter relative to speed and time?

- As the speed of an object increases, time slows down and mass increases.

### What is color relativity?

- Combinations of colors placed next to each other can change the way we perceive these colors.
- If two complementary colors are placed next to each other, both of them will seem more brilliant.
- Red strawberries and red tomatoes are often placed in green containers. This makes the red seem redder and the green seem greener.

Since the time of Albert Einstein, we have been aware of the relative nature of time, speed and matter. Now we will consider the relative nature of color. Colors can best be discussed in relationship to one another. A particular color may appear one way against a black background and another way against a yellow background. The following activities and demonstration give students an opportunity to experiment with various color relationships to see the effects of a particular color against various backgrounds, or fields.

**ACTIVITY**

## **1.16**

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### ***Color Relativity***

#### **Objectives**

1. Students will become familiar with the works of professional artists who use color relativity in their work.
2. Students will create examples of color relativity.
3. Students will observe the relationship of one color to another and how color relationships affect a chosen color.

#### **Materials**

A variety of colors of paper (all 12 colors of the color wheel, plus white, black, and gray); pencil; ruler; scissors; glue or rubber cement; typing paper or other paper suitable for mounting samples.

#### **Time**

150 minutes

#### **Procedure**

1. Review the following definitions:
  - Hue.** The name given to a specific color, such as red, blue, blue-green, and yellow.
  - Value.** The lightness or darkness of a specific color. To lighten a color, white is added. To darken a color, black is added.
  - Chroma.** The intensity (brightness or dullness) of a specific color.
  - Complements (or Complementary Colors).** Colors that are direct opposites of each other on the color wheel, such as green and red.
  - Warm and Cool Colors.** Warm colors are red-violet, red, red-orange, orange, yellow-orange, and yellow. Cool colors are yellow-green, green, blue-green, blue, and blue-violet.
2. The teacher should show students reproductions of works of contemporary nonobjective artists who work with color relationships, such as Josef Albers,

Mark Rothko, Ad Reinhardt, Barnett Newman, Kenneth Noland, and Ellsworth Kelly.

3. Choose a specific hue and cut a sheet of paper of that hue into seven 2-x-2-in. squares.
  4. Experiment with relationships between the hue chosen and other colors. In the following steps, try to change the appearance of the hue by placing it against backgrounds of various other colors available. Each sample should be compared to the sample on the white background.
    - a. Place a square of the chosen hue on a 4-x-4-in. white background (all backgrounds should be of this size).
    - b. Place a square of the chosen hue on a black background. Does the square of the chosen hue appear larger or smaller than it does against a white background? Does it appear lighter or darker than it does against the white background?
    - c. Place a square of the chosen hue against a gray background. How does the gray background affect it? Does it look larger or smaller, lighter or darker?
    - d. Place a square of the chosen hue against a background that affects its value (i.e., makes it look lighter or darker).
    - e. Place a square of the chosen color against a background that affects its intensity, or chroma (i.e., makes it look brighter, gives it a vibrating effect, or makes it duller). What relationship on the color wheel exists between the subject color and the background color chosen?
    - f. Place a square of the chosen hue against a background that makes it look warmer.
    - g. Place a square of the chosen color against a background that makes it appear cooler.
  5. Use glue or rubber cement to attach the squares of the chosen hue to the background squares and then attach each sample to a sheet of typing paper. Label each sample, indicating which properties and relationships of color the sample illustrates.
  6. Compare your results and discuss them with the rest of the class.
-

**ACTIVITY****1.17****Color Relativity: Physical Properties and Physical Change****Objectives**

1. Students will define and distinguish the difference between physical change and physical property.
2. Students will interpret how color relativity affects perception of an individual color.

**Materials**

Carbon powder; sulfur powder;  $\text{CuSO}_4$  (copper sulfate); spatula; red, yellow, blue, black, and white poster paints; paintbrushes; paper for poster paints; small evaporating dish; paper.

**Time**

50 minutes

**Procedure****■ Note:**

Matter is something that takes up space and has mass. Physical properties are used to describe matter. Some physical properties of matter are shape, size, amount, density, distribution, and color. A physical change is a change in a physical property without a change in the actual substance.

1. Make a list of the physical properties of carbon and sulfur powder. The following discussion will aid you in making your list.
2. Combine a spatula of carbon powder with a spatula of sulfur powder. A physical change will occur. There is a change in the sulfur and carbon distribution and an apparent color change, but the sulfur and carbon remain. No new substance is formed.
3. Repeat steps 1–2 using sulfur powder and  $\text{CuSO}_4$ .

**Questions and Conclusions****Level One**

1. How does the yellow sulfur affect the brightness of the black carbon? Why are some letters on road signs black on a yellow background?
2. How does the yellow sulfur affect the brightness of the blue-green  $\text{CuSO}_4$ ? Is it a good idea for a road sign to use blue-green letters on a yellow background? Why?

**Level Two**

1. Experiment with various color combinations by painting signs in two colors. What combinations make the sign letters look brighter? What combinations make the sign letters look duller?
2. List some physical properties of your signs.
3. Make a list of your physical properties (e.g., hair color, height, eye color, etc.).
4. State an example of how you could make a physical change in your appearance.

**DEMONSTRATION**

## 1.5

### ***Color Relativity: Chemical Properties and Chemical Change***

**■ Warning!**

Magnesium burns to produce intense heat and light!

**Objectives**

1. Students will define and distinguish the difference between chemical property and chemical change.
2. Students will illustrate color relativity by producing a chemical change.
3. Students will write a balanced chemical equation and explain the meaning of the equation symbols.

**Materials**

1-in. magnesium strip; tongs; Bunsen burner; matches; black paper; white paper.

**Time**

15 minutes

**Procedure****■ Note:**

A chemical property of matter describes how a substance behaves during a chemical change. A chemical change occurs when a substance changes into a new substance or substances.

1. The teacher should hold the magnesium strip with tongs in the hottest part of the flame of a Bunsen burner (directly above the inner cone) until the magnesium burns.

2. The teacher should place a sheet of white paper behind the burning magnesium and have students observe the brightness of the magnesium flame.
3. The teacher should place a sheet of black paper behind the burning magnesium and have students observe the brightness of the magnesium flame.

■ **Warning!**

Students should not look directly at the burning magnesium.

### Questions and Conclusions

#### Level One

1. Define *chemical property*.
2. Define *chemical change*.
3. Describe one common chemical change that occurs in the home and one common chemical change that occurs outside the home.
4. State a chemical property of magnesium.
5. Write a word equation for the burning of magnesium. Do most metals burn?
6. Which background enhanced the brightness of the burning magnesium? Propose a theory to explain this result.

#### Level Two

1. Did a chemical change occur when magnesium burns in this demonstration? Examine the product. Are its properties different than those of the reactants? (Magnesium and oxygen are reactants; magnesium oxide is the product.)
2. A chemical equation has reactants on the left side and products on the right side. The reactants and products are separated by a “yields” sign ( $\rightarrow$ ). Numbers called coefficients are placed in front of the reactant and product symbols; these numbers balance the equation. What is being balanced in a chemical equation? Incorporate the law of conservation of matter into your answer.
3. Write a balanced symbol equation to show the chemical change observed.
4. Some additional information that can be conveyed in a balanced chemical equation: (s) = solid, (g) = gas, (aq) = aqueous, and (l) = liquid. The following equation shows the proper use of these symbols:  $S_{(s)} + 6HNO_{3(aq)} \rightarrow H_2SO_{4(aq)} + 6NO_{2(g)} + 2H_2O_{(l)}$ . It should be noted that [aq] means aqueous solution and [l] means in the liquid phase of a pure substance. Use phase-indicating symbols in your balanced equation in no. 3 above.

## COLOR FATIGUE

### What is color fatigue?

- *Color fatigue, or afterimage*, is a retina and brain phenomenon in which intense continued observation of a certain visible wavelength will result in brain interpretation of the complementary color when the viewer looks at a white paper.
- If a viewer stares at a flag with green-and-black stripes and black stars on an orange background for about 30 seconds and then quickly looks at a white paper or white wall, our red, white, and blue flag will appear. Chemical changes in retina molecules make this happen.

Our eyes adapt themselves to a change of color. The adaptation takes several steps, but we are usually not aware of them. We can observe the change if we stare at a colored area for about 30 seconds and then stare at a white surface. The color we see will be roughly the complementary color (the opposite color on the color wheel) of the color stared at. The size of the afterimage depends on the distance from the eye to the white surface: If closer to the white surface than to the original color, the afterimage will be smaller; if farther from the original color, the afterimage will be larger. It should be understood that color fatigue is a function of color relativity.

### ACTIVITY

## 1.18

### *Color Fatigue*

#### Objectives

1. Students will understand the principles of color fatigue by viewing examples (all levels).
2. Students will create an example of color fatigue using complementary colors (Level Two).

#### Level One: The Flag

#### Materials

Picture of the American flag colored in green, black, and orange (the complements of red, white, and blue); white paper.

#### Time

10 minutes

#### Procedure

1. The teacher should show the students a picture of the American flag colored in green, black, and orange. Have the students stare at the image and then

look away to a blank sheet of white paper (or close their eyes) to see the afterimage in complementary colors.

### **Level Two: Do It Yourself Fatigue**

#### **Materials**

Bits of colored construction paper, white paper, glue, scissors.

#### **Time**

30 minutes

#### **Procedure**

1. Create an example of color fatigue by substituting complementary colors for the actual colors of objects you choose (e.g., a green strawberry with a red stem).
2. Cut out the shapes and glue them to the white paper.
3. Stare at the image and then look away to a blank sheet of white paper or close your eyes to see the afterimage in the true colors.

### **Challenge Activity**

A child on the planet Uranus would ask the question, “Why is the sky green?” A child on Jupiter would ask the question, “Why is the sky reddish brown?” How would you answer these questions? Relate your answer to the chemical composition of the atmospheres of these planets.

Jupiter and Uranus are outer planets composed mainly of gases. Jupiter’s atmosphere contains reddish-brown clouds of ammonia. Uranus has an atmosphere made up mainly of hydrogen and helium with clouds of water vapor. This combination looks greenish to an outside observer. In addition, Mars has an atmosphere that is 95% carbon dioxide, and Venus has a permanent cloud cover of sulfur dioxide that appears pale yellow to an observer. Mercury has no permanent atmosphere. Saturn has 1 km thick dust and ice rings that orbit the planet. The eight planets in our solar system are diverse, each having different chemical compositions within and surrounding the planets. Out Earth is by far the friendliest planet for human existence.

## WHY IS THE SKY BLUE? FINALLY, AN ANSWER

Can we expect the sky to appear blue because of color relativity? It is not likely; color relativity requires that two hues be superimposed. In a cloudless sky, we are looking at one hue, blue. Do we see a blue sky because of color fatigue? If so, we would see the blue sky only after staring at an orange object. This does not happen. Previously, we ruled out excited atoms and ion formation as sources of blue in the sky.

To answer our question, we must reexamine color and light. We know that all wavelengths of electromagnetic radiation in the visible range are transmitted from the sun and enter the earth's atmosphere, where they encounter oxygen (O<sub>2</sub>) and nitrogen (N<sub>2</sub>) molecules. Almost all the wavelengths, except those seen as blue, travel straight through the atmospheric molecules and atoms and proceed to the earth's surface. However, the blue wavelengths become sidetracked. They are of such wavelengths that they bounce off the earth's atmospheric molecules, primarily oxygen (O<sub>2</sub>) and nitrogen (N<sub>2</sub>) molecules, and scatter across the entire sky. Everywhere we look, blue waves are present. They enter our eyes and strike the cones in our retinas, which relay a message to the brain: The sky is blue!

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## ANSWERS TO ACTIVITY AND DEMONSTRATION QUESTIONS AND CONCLUSIONS

### Activity 1.1 Atomic Modeling and Color

#### Level One

1. The color of an element sometimes depends on how the atoms of the element bond together. When the atoms of an element can bond in more than one way, we call the resulting forms of the element *allotropic forms*.

Carbon atoms can bond to form planes of atoms arranged in a hexagon pattern linked together by weak dispersion forces so that the hexagon layers are easily sloughed off. This form is called *graphite*. It is gray in color. In another allotropic form, four carbon atoms link together with a central carbon atom to form a tetrahedral pattern that results in a clear, colorless diamond allotropic form of carbon.

Oxygen has two allotropic forms;  $O_2$ , the oxygen that we breath and is necessary for life, and  $O_3$ , ozone, which is harmful to breath but is beneficial when blocking damaging ultraviolet rays from the sun. Both forms are colorless.

Hydrogen is also a colorless gas.

Chlorine is a yellow-green gas that is very reactive. Both ozone and chlorine are used to kill bacteria and generally sanitize public areas such as swimming pools and hospital rooms.

2. Black is sometimes the appearance of carbon in its graphite allotropic form.

Oxygen is a chemically reactive element and supports burning. Red indicates this reactivity.

Hydrogen is a colorless gas, so white is use.

Chlorine is yellow-green, so green is used.

3. In a water molecule, the two hydrogen atoms bond to the oxygen atom at an angle of 109.5 degrees to form a bent-shaped molecule. This is because the bonding occurs with oxygen atom electrons in p orbitals.

The angle is greater than 90 degrees because the positively charged hydrogen atoms repel each other slightly. If the bonding occurred in s orbitals rather than in p orbitals, the water molecule would be linear. A linear molecule would not solidify in the same manner as a bent molecule.

Bent water molecules solidify in a hexagonal pattern with hydrogen bonds between molecules. This gives water a higher than expected freezing point and ice a lower than expected density.

Without its bent-shaped molecule, water might be a gas at room temperature and ice might sink in water leaving our world uninhabitable.

### **Level Two**

1. A physical property is one that identifies an object. In addition to color, density, mass, and shape are physical properties. Carbon and chlorine are represented by their color.
2. A chemical property is one that describes the reactivity of a substance. Oxygen atoms are colored red to indicate oxygen molecule support of burning. Carbon atoms are black to indicate less spontaneous chemical reactivity.
3. Red indicates excitement and burning can be an exciting event. Black indicates sadness, and carbon is what is left when living objects die.
4. In methane, one carbon atom bonds with four hydrogen atoms. The bonding occurs in  $sp^3$  orbitals so the angles between the hydrogen atoms are all 109.5 degrees and the resulting shape is tetrahedral.

### **Activity 1.2 The Psychology of Color**

8. Color certainly enhances life experiences. In the animal kingdom, male birds present extravagant color displays to attract a mate. A male peacock struts in front of a female with a highly colored, iridescent tail feather display. In the Galapagos Islands, male frigate birds blow up to balloonlike proportions their neck-located skin sacs with bright red display feathers in order to attract a mate. Without color, these feather displays would have little meaning. Birds have excellent color vision. Students can investigate the chemical source of color vision.

In the human species, it is often the female who uses color to attract a male. Females use colored makeup to enhance their appearance. Makeup without color would hardly achieve a desired lively, attractive appearance.

### **Activity 1.4 The Rainbow: A Chorus of Waves**

### **Level One**

1. The waves with the shortest wavelengths and, therefore, the highest frequencies carry the greatest energy. Some of the highest energy waves are gamma rays, X-rays and ultraviolet waves. The waves with the longest wavelengths and the lowest frequencies carry the least amount of energy. Some of the lowest energy waves are radio waves, microwaves, and infrared waves.
2. White light entered the prism, and red, orange, yellow, green, blue, indigo, and violet waves—all of the waves that comprise white light—left the prism. The prism slowed down and bent the waves of white light as they entered the prism. This is called *refraction*. The shorter the wavelength, the greater the angle of refraction. Violet waves are bent the most, and red waves are bent the least. In a rainbow, violet appears at the top and red at the bottom.

3. The plant grow-light contains more violet, indigo, and blue waves and may not contain yellow, red and orange waves. Plants need shorter wavelength waves of energy for photosynthesis to take place.

### **Level Two**

1. As wave energy increases, the wave's wavelength decreases and the wave's frequency increases.
2. As a wave's wavelength increases, the wave's frequency decreases. Since all waves in the electromagnetic spectrum travel at the same speed, wavelength and frequency are inversely related, and frequency and energy are directly related.
3. The speed of light is  $2.998 \times 10^8$  m/s.

## **Activity 1.5 Color and Energy**

### **Level One**

1. The unit for frequency is usually written as  $s^{-1}$ , meaning 1 per second, 1/s. This is called hertz, abbreviated Hz.
2. Yellow waves have lower energy, longer wavelengths, and lower frequencies than blue waves.
3. Yellow waves have less energy than blue waves. However, yellow, the color of the sun, is usually associated with warmth and blue, the color of the sky, is usually associated with cooler temperatures.

### **Level Two**

1. 
$$v = \frac{c}{\lambda}$$

For blue waves:

$$v = \frac{2.9979 \times 10^8 \text{ m/sec}}{4.8 \times 10^{-7} \text{ m}} = 6.2 \times 10^{14} \text{ Hz}$$

For yellow waves:

$$v = \frac{2.9979 \times 10^8 \text{ m/sec}}{5.6 \times 10^{-7} \text{ m}} = 5.4 \times 10^{14} \text{ Hz}$$

These values are the same as the values given in Figure 1.2 (p. 11).

2. This equation is used: frequency,  $v$ , equals the speed of light,  $c$ , divided by wavelength,  $\lambda$ .

## Activity 1.6 Color Psychology I

### Level One

1. For example, a picture form of “green with envy” could include the discovery of a rare, radioactive element that glows enough to turn the faces of onlookers “green with envy.”

## Activity 1.8 Create Your Own Atom

### Level One

2. Knowledge concerning the structure of the atom is still evolving. Atoms are very small. In 12 g of carbon, there are  $6.0221367 \times 10^{23}$  atoms. This number is so large that if we distributed  $6.0221367 \times 10^{23}$  pennies to every man, woman, and child in the United States, each person would have  $2.4 \times 10^{19}$  dollars! Today we have sophisticated instruments to probe atoms. In particle accelerators, atomic particles collide to produce new and unusual particles that are detected in a cloud chamber. Scanning tunneling microscopy and atomic force microscopy are used to probe the surface of solids where individual atoms can be imaged.

### Level Two

2. The nucleus of an atom is about 100,000 times smaller than the atom. Positively charged protons in the small dense nucleus are far from electrons outside the nucleus. It can be theorized that since an attractive force between oppositely charged particles diminishes with distance, electrons are not attracted to protons in the atomic nucleus.
3. A strong nuclear force carried by particles called gluons binds together protons and neutrons in an atomic nucleus. When an atom is split, energy from the atomic nucleus is released. The amount of energy released is predicted by the equation,  $e = mc^2$ .
4. In a pointillist painting, small dots of color collectively form an image. Colors are juxtaposed so there is a mix of colors in the eye of the viewer rather than on a canvas. In John Dalton’s atomic theory, atoms are viewed as solid, indivisible spheres. The dots in a pointillism painting are reminiscent of the solid spheres described in Dalton’s atomic theory.

## Demonstration 1.1 Light from Excited Atoms

### Level One

2. Elements have different spectral lines because atoms of different elements have different electron configurations. Excited electrons in different element electron configurations fall to more stable energy levels, emitting different amounts of energy in the form of light waves. Each light wave represents a different color in the visible spectrum.

- An electron has more energy in an excited state than at the ground state. An electron stays at its lowest energy level until it is disturbed. When an electron moves to a higher energy level, energy is absorbed.

### Level Two

- The problem is solved as follows:  
 $145.8 \text{ kJ/mole} - (-328.0 \text{ kJ/mole}) = 182.2 \text{ kJ/mole}$   
Wavelength =  $1.196 \times 10^5 \text{ kJ/nm} \div 182.2 \text{ kJ/mole} = 656.4 \text{ nm/mole}$   
or  $6.6 \times 10^{-7} \text{ m/mole}$ .
  - $656.4 \text{ nm}$  or  $6.6 \times 10^{-7} \text{ m}$  represents an orange wave in the visible spectrum.

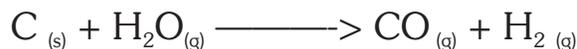
## Demonstration 1.2 More Excitement in Atoms: A Fireworks Display

### Level One

- When strontium compounds are ignited, strontium atom electrons absorb specific quantities of energy and move from a ground state to a higher energy level. At the higher energy level, these electrons are unstable and fall back to their ground state. Upon doing so, they emit the energy that they absorbed. If this energy is in the visible wavelength range, we see color. Since the magnesium strip emitted white light, all wavelengths of visible light were emitted.
- In a chemical change, one or more substances (reactants) are transformed into one or more different substances (products). In this demonstration, strontium nitrate is converted into strontium oxide, and magnesium metal (a shiny, malleable metal) is converted into magnesium oxide (a gray white powder).

### Level Two

- When energy is released in a chemical change, the reaction is called an *exothermic* reaction. Often the energy released is in the form of heat and light. Energy can be absorbed in a chemical change. These reactions are called *endothermic* reactions. An endothermic reaction occurs when carbon is combined with steam to form carbon monoxide and hydrogen,



This chemical change is often called the coal gas reaction. The hydrogen gas produced from steam reacting with coal is a clean-burning fuel. However, the energy released when the hydrogen gas is burned (113 kJ/mole) is equal to the amount of energy needed for the reaction to take place.

3. The energy released in a chemical change is not always visible. Often heat energy transmitted through infrared waves is released. In addition, ultraviolet waves are often released when a chemical change takes place.
4. The strontium reactant compounds are white powders. The magnesium strip is a shiny gray metal. When the strontium and magnesium atoms in these reactants absorb energy, their electrons attain an excited state but are unstable and revert back to a lower energy level, releasing energy to produce colors in the observable wavelengths.

### **Activity 1.9 Mixing Primary Pigments**

1. When light waves are mixed, none of the waves is absorbed. The waves enter the eye and stimulate the cones in the retina. We see white light. When pigments are combined, each pigment molecule or atom absorbs certain light wavelengths and reflects others. When all three pigment primaries are combined, all light wavelengths are absorbed and no waves reach the retina, so that no color message is sent to the brain: We “see” black.
2. Precisely equal amounts of pure pigment primary colors must be mixed to achieve a true black.

### **Activity 1.12 Solution Preparation and Pigment Primary Hues**

#### **Level One**

2. A mole is  $6.0221367 \times 10^{23}$  particles or objects. It is an amount of a substance that has a mass in grams numerically equal to the formula mass or relative weight of a substance.
3. There are  $6.0221367 \times 10^{23}$  atoms present in one mole of any element.
4. There are  $6.0221367 \times 10^{23}$  atoms present in one relative weight of any element. These numbers are the same.
5. There are  $6.0221367 \times 10^{23}$  particles in a mole of stars, apples, or paper clips.

#### **Level Two**

1. Black pigments are composed of particles that absorb all wavelengths of visible light. White pigments are composed of particles that reflect all wavelengths of visible light.
2. The calculations are as follows:  
 $100.00\text{g} \div 32.07 \text{ g/mole} = 3.118 \text{ moles}$   
 $100.00\text{g} \div 12.01 \text{ g/mole} = 8.33 \text{ moles}$   
 $100.00\text{g} \div 55.85 \text{ g/mole} = 1.790 \text{ moles}$
3. When atoms combine to form molecules, they bond in a definite number ratio. For example, when potassium sulfide,  $\text{K}_2\text{S}$ , is formed, two atoms of

potassium bond to one atom of sulfur to form one potassium sulfide molecule. Knowing the mole concept, a chemist can use the relative mass of sulfur and the relative mass of potassium to combine the exact amounts needed to form a desired mass of potassium sulfide. Two relative masses of potassium, 78.2 g, combine with one relative mass of sulfur, 32.1 g, to form 110.2 g of potassium sulfide. The mass ratio of 78.2 to 32.1 will provide a two-to-one ratio of the atoms. The mole concept tells the chemist how many atoms are in a certain mass of a substance.

### **Activity 1.13 Elements and the Periodic Table**

#### **Level One**

1. Copper, iron, cobalt, nickel, and zinc are transition metals. Sodium is an alkali metal. Magnesium and calcium are alkaline earth metals. Bromine and iodine are halogens. Most transition metals are gray shiny metals. An exception is copper which is a brown shiny, metal. Sodium and the other alkali metals are gray shiny metals. Magnesium, calcium, and the other alkaline earth metals are gray and shiny. The halogens range from light green fluorine to yellow-green chlorine, from orange bromine to purple iodine.
2. Transition metal family elements often form colored compounds. Many of these colored compounds are used as pigments in paints. Chromium oxide is a green pigment. Lead chromate is a yellow pigment.
3. *Common physical properties:* Alkali metals are soft, shiny, gray metals. Alkaline earth metals are shiny, gray malleable metals. Most transition metals are also shiny, malleable and gray. Gold with a density of 19.3 g/ml is second only to iridium (22.65 g/ml) and osmium (22.61 g/ml). Most transition metals are ductile and good conductors of electricity and heat. Halogens are non metals-poor conductors of electricity and heat. At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine is a solid. The inert or noble gases are colorless, odorless gases at room temperature.

*Common chemical properties:* The alkali metals are so chemically reactive that they are never found free in nature. Sodium and potassium react explosively with water to produce hydrogen gas. The alkaline earth metals are not quite as reactive as the alkali metals. The alkali metals react with water but not explosively. The transition metals are generally the least reactive of all the metals. However, when they combine with other elements, they form a large variety of colored compounds. Chromium oxide is green, titanium oxide and zinc oxide are white, manganese oxide is purple, and iron oxide is ochre.

4. The periodic table is arranged so that members of a family show repeating chemical and physical properties. Also, as one progresses from left to right across a row, repeating trends in atomic volume, ionization energy, and electronegativity are observed. When something is periodic, it is repeating.
5. Copper is brown. Gold is a pale yellow. Sulfur is yellow. Chlorine is yellow green. Fluorine light green. Bromine is orange. Iodine is purple. Carbon as

graphite is black. Phosphorus in one allotropic form is red and in another is white. Elements in the same family do not tend to have the same color.

### **Level Two**

1. The color comes from the transition metal ions. Nitrate ions are colorless. Green emeralds and red rubies owe their colors to chromium ions.
2. Repeating rows of eight and eighteen are necessary so that elements with similar chemical and physical properties are in the same families.
3. Members of the same family have the same electron configuration. Group 1A elements have one outermost electron. Group 2A has two outermost electrons. Group 3A has three outermost electrons. Group 4A has four outermost electrons. Group 5A has five outermost electrons. Group 6A has six outermost electron. Group 7A has seven outermost electrons and group 8A has eight outermost electrons.
4. Transition metal atoms form polyatomic ions that result in colored species. These polyatomic ions exhibit bonding in *d* orbitals. Specific wavelengths of light are absorbed by these *d* orbital bonds, and the remaining reflected waves are colors in the visible spectrum.

## **Demonstration 1.3 Copper Sulfate Dilution, Mass Percent, and Color Value**

### **Level One**

1. A *solution* is a homogeneous mixture of a solute and solvent. In a classification of matter, matter is divided into mixtures and pure substances. Mixtures are divided into homogenous mixtures, solutions, and heterogeneous mixtures such as suspensions. Pure substances are divided into elements made up of atoms and compounds made up of molecules.
2. *Mass percent* is the concentration of a solution in grams of solute per grams of solution. The mass percent would be 10%. The calculation is as follows:  $20.0 \text{ g of solute divided by } 200.0 \text{ g of solution } / 100 = 10\%$ .

### **Level Two**

1. Color value can be changed by adding black or white pigment to the solution, by changing the light source used to view the solutions, or by changing the quantity of light that falls on the solutions.
2. The value of a hue changes as a solution is diluted because, in a constant volume, the number of colored particles (ions) is reduced. There are fewer ions to reflect colored light waves. In this demonstration, the number of blue-green copper ions ( $\text{Cu}^{2+}$ ) is reduced.
3. Yes, but these particles are not concentrated enough to see.

## Demonstration 1.4 Color Intensity in a Saturated Solution and in a Pigmented Hue

### Level One

1. A solution is *saturated* if it contains the maximum amount of solute that can possibly be dissolved in a solvent at the existing temperature and pressure conditions. If a solution is saturated, it need not be concentrated. Concentrated refers to the ratio of solute to solvent. A solution is concentrated if it contains a high ratio of solute to solvent. A solution is dilute if it contains a low ratio of solute to solvent. A solution of ammonia gas dissolved in water can be highly concentrated but not saturated. Ammonia gas dissolves easily in water. Barium hydroxide is slightly soluble. A saturated solution of barium hydroxide is very dilute.
2. Adding more colored solute particles to a saturated solution will not increase the intensity of the color of the solution. Since the solution is saturated, no more colored solute particles can dissolve. A way to increase the intensity of a color is to increase the number of colored particles. Adding more solute will not increase the number of solute particles.

### Level Two

1. An observer can add more solute to a solution to see if the solute dissolves. If it dissolves, the solution is unsaturated. If it does not dissolve, the solution is saturated.
2. The complementary color particles will absorb some of the same wavelengths as the original color reflected thereby decreasing the number of originally reflected wavelengths and thus the color intensity.
3. Another way to decrease the intensity of a color is to add black pigment, which will absorb some wavelengths that the color reflects.

## Activity 1.17 Color Relativity: Physical Properties and Physical Change

### Level One

1. Yellow sulfur makes the black carbon powder stand out. A black sign on a yellow background is very visible.
2. Yellow sulfur diminishes the brightness of blue-green copper sulfate. Yellow particles absorb some green and blue wavelengths, so fewer blue-green wavelengths reach a viewer's eye. Imagine a blue-green road sign on a yellow background! This would be an invitation to road chaos.

### Level Two

2. Physical properties are those that can be observed and measured without changing the composition of a substance. They include melting point, boiling

point, and density. In the case of the sign, physical properties can include shape, size, and color. Physical properties often depend on the molecular structure of the substance under consideration.

4. Women use make up on a daily basis to make a physical change in their appearance.

A hair cut or a hair color change alters physical appearance.

Plastic surgery can make a dramatic physical change in appearance.

### **Demonstration 1.5 Color Relativity: Chemical Properties and Chemical Change**

#### **Level One**

1. *Chemical properties* are those exhibited in chemical changes. The following are examples of chemical properties displayed in chemical changes: hydrogen gas and oxygen gas combining explosively to make water; sodium metal reacting violently with water to produce hydrogen gas that burns from the heat of the reaction; copper metal in a solution of silver nitrate slowly becoming coated with silver metal crystals
2. In a *chemical change*, one or more than one substance is changed into one or more different substances. Reactants change into products. The products have different physical and chemical properties from the reactants. Question 1 describes three chemical changes.
3. In the home, almost every time food is cooked chemical changes occur. When a cake is baked, baking soda, sodium hydrogen carbonate, decomposes to produce carbon dioxide gas, and the cake rises. Outside the home, nitrogen-fixing bacteria in the soil are changing nitrogen gas to nitrates useful for plant growth.
4. Magnesium burns violently in oxygen.
5. Magnesium plus oxygen yields magnesium oxide.

Most metals do not burn.

Some alkali metals—cesium, potassium, and sodium—react violently with water to produce hydrogen gas that burns.

6. The black background enhances the brightness of the burning magnesium. Black pigment does not reflect any visible wavelengths. When the magnesium burns in front of a black background, we only see the composite of wavelengths from the burning magnesium that produce white light. There is no interference from the black background with the waves of energy reflected from the burning magnesium. They are blindingly bright. White pigment reflects all wavelengths of visible light. With a white background, light waves from the white background interfere with light waves from the burning magnesium and the brightness diminishes. Light waves cancel each other when the crest of one wave falls on the trough of another wave.

**Level Two**

1. A chemical change occurred because reactants were changed into new substances. The magnesium oxide is a gray powder. The magnesium is a shiny metal and the oxygen reactant is a colorless, odorless gas.
2. The law of conservation of matter states that in a closed system when a chemical change occurs, there is no change in mass. This is because atoms are conserved in a chemical change so atoms must be balanced in a chemical equation. In a balanced equation, coefficients tell the number of reactant and product substances that react and are produced. Subscripts tell the number of atoms of each kind in these substances. When a coefficient is multiplied by a subscript in a substance formula, the number of atoms is determined. Since a mole is an amount of a substance, the coefficients in a chemical equation can stand for the number of moles that react and are produced.
3.  $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
4.  $2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$

# Paint Does Matter

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## *What Is Paint?*



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: Paint has been called “colored dirt.”  
What is paint?**

## INTRODUCTION

A wagon without paint is like a day without sunshine. The plot of the musical play *Paint Your Wagon* involves gold prospectors hoping to make a fortune in the days of the California gold rush. They invite other prospectors to join them: “Paint your wagon and come along!” On a more mundane note, can you remember the little red wagon of your youth, that time of joy and innocence? Would that little red wagon conjure up the same memories had it been unpainted? What is the function and significance of paint as applied to objects?

Objects are painted for many reasons: to prevent rusting and deterioration, to make them attractive, to evoke emotions, and to brighten our lives. Wagons are painted with these goals in mind. An artist has the same goals: permanence, attractiveness, and emotional effect; in addition, an artist paints a work of art to preserve the past.

## A BRIEF BUT COLORFUL HISTORY OF PAINT

### **What are some surprising origins of ancient paint pigments and binders?**

- Ancient paint pigments were found in plants, animal parts, and minerals.
- Caves in southwestern Europe in the Pyrenees Mountains show traces of red pigment and black pigment that is a manganese compound or carbon.
- In the Yuan period in Mongolia in the mid-fourteenth century, ground cobalt painted on clay turned blue when fired. Copper oxide was also used to produce a red color.

The use of paint dates to prehistoric art, mainly about 35,000 years ago, when the long-skull Cro-Magnon people of the Paleolithic period made cave paintings. They were restricted to only a few *pigments* of local colors—earth tones of yellow, red, black, brown, and white—derived from plants, animals, and minerals and mixed with animal fat to make the first paints. These paints required a *binder* to adhere them to cave walls: Chemists think that Cro-Magnon artists used saliva! Today, artists are attempting to duplicate the paints used in these cave paintings.

### Challenge Activity

You are a Cro-Magnon artist. Find a flat rock. On a piece of paper, design a picture that will fit on the rock. It can be an abstract design or a representative drawing. Use a chemistry theme. Next, find some flowers that contain colors needed for your painting. Soak the flowers overnight in alcohol. Pigment will leave the flowers and dissolve in the alcohol. Let the alcohol evaporate at room temperature. Add saliva to the pigment. Use your “paint” to paint your picture on your rock.

#### **Name some colors used by the ancient Egyptians and early Phoenicians.**

- The ancient Egyptians used earth tones—yellow ochre, sienna, red, black, and white—along with blue and green.
- These pigments came from minerals and clays found on the earth’s crust.

#### **What was the composition of the encaustic paints used in early Christian paintings?**

- The encaustic paints used in early Christian paintings—some of these paintings from the Roman Imperial Period—were made of pigments and beeswax.

The ancient Egyptians were adept at creating water paints, which were used to decorate the interiors of their pyramids, temples, and palaces. Much like the cave painters’ paints, their colors were earth tones—yellow ochre, sienna, red, black, and white—but two new colors were added: blue and green. Later, between A.D. 117 and 161, the early Christians in Egypt made paints of pigment particles suspended in hot beeswax. Their works, called *encaustic* paintings, are still well preserved and brilliant in color. In the eighth century, the Phoenicians obtained a vibrant purple dye from a particular kind of oyster.

#### **Why are frescoes painted in the seventeenth century with egg tempera paint still visible and beautiful today?**

- The egg temperas used to paint frescoes in the seventeenth century contained pigments that were absorbed into freshly spread wet plaster and remained vibrant as long as the plaster survived. The paint became part of the plaster.

- Some of the most famous fresco paintings of the Italian Renaissance, such as the frescoes of the Sistine Chapel ceiling painted by Michelangelo, were done prior to the seventeenth century. Several years ago these frescoes were renovated to bring out the original magnificent colors.

### **What were the alchemists trying to do, and why were they not successful?**

- The alchemists were trying to turn lead into gold. They had no scientific basis for their experiments. They dropped gold coins in vats of liquid lead and sadly watched their gold coins melt and disappear.
- They did not know that a nuclear change is necessary to convert one element into another element.
- They did create some laboratory flasks, similar to the Erlenmeyer and Florence flasks that are still used today.

Throughout the Middle Ages, in wall paintings known as *frescoes* and in manuscripts and paintings on wood panels, water-based paints known as *egg tempera* were used to paint pictures bearing religious themes. Egg tempera paint consisted of colored natural pigments and the yolk of an egg mixed with water. More colors began to appear, including a deep blue called ultramarine, bright yellow, intense red, and a brilliant green, adding to an already rich medieval palette. Artists and their apprentices mixed their paints in the master artist's studio. They were constantly experimenting with various formulas and recipes, trying to produce better paint. At the same time, the prechemists, the *alchemists*, were trying to change lead into gold. Modern scientific method, in which theories are proposed and confirmed by controlled experiments, was not accepted until the eighteenth century.

### **What is the main difference between the structure of oil paints and that of water colors?**

- In oil paints, a pigment is combined with oil, and in water color a pigment is combined with gum arabic.
- The best oil for oil paints is cold pressed linseed oil. Poppy oil can be added to the linseed oil to smooth out stringy or sticky paints. The poppy oil should be 20% of the total oil content.

### **Who invented water colors and oil paints?**

- A legend credits Jan van Eyck with the invention of oil painting in the early fifteenth century, but he probably learned oil painting from another artist and perfected the technique himself.
- Also in the fifteenth century, landscape painting in watercolor reached a high point of development.
- The grand master of watercolor was Sesshu, who painted *Autumn Landscape*, a beautiful, simple arrangement of trees, mountains, and a pagoda.
- Albrecht Dürer painted the majority of his watercolors in the early sixteenth century.

Oil paint and watercolor can be traced to the fifteenth century. Oil paint especially became the new medium of choice, and egg tempera slowly dwindled from general use. *Oil paints*, pigment combined with oil, are thought to have been invented by the Flemish painter Jan van Eyck (1385–1441). *Watercolor*, pigments suspended in gum arabic, can be traced to traditional Japanese paintings, and to the German painter and engraver Albrecht Dürer (1471–1528), whose watercolors enhanced his pen drawings of natural history.

By the eighteenth century, thousands of paint colors and many paint formulas were being used by artists. Paint was still mixed by the artist in the studio. During the eighteenth and nineteenth centuries, the medium of watercolor was used extensively by English artists and brought to a high degree of perfection in atmospheric painting of landscapes.

### **In the nineteenth century, what invention made paints available in portable containers?**

- The invention of the metal paint tube provided a portable container for paints so artists could paint outside the wall of a studio.

It was not until the nineteenth century that artists began to purchase ready-made commercial paints. Today paint colors have standardized specifications. Regardless of type, paint still consists of pigment and binder, as it has for centuries. Many colors originally produced from natural pigments are now made synthetically. The metal paint tube was developed in 1841. Paints that for centuries had been mixed and stored by the artist in various ways in the studio were suddenly available in an easily portable container. Artists who had found it difficult to paint on location were able to create many masterpieces outdoors, on location, as a result of tube paint becoming available.

### **What is the composition of acrylic paint, and what advantages does acrylic paint have for an artist?**

- Acrylic paint is made up of colored organic molecules suspended in water. Acrylic paints dry quickly. They are durable and bright colored. An artist can easily control acrylic paint.
- In addition, acrylic paints are water soluble, so they can be thinned with water, and paintbrushes can easily be cleaned with water.
- The best news is that if an artist makes a mistake, acrylic paints (like oil paints) can be painted over, and the mistake is only a memory.

Five centuries after the invention of oil paint, in the late 1930s, acrylic paint entered the art scene. David Alfaro Siqueiros (1896–1974), a Mexican artist, was one of the first to adapt acrylic paint to a work of art. *Acrylic paint* consists of colored thermoplastic resins suspended in water. In the 1930s chemists were experimenting with long-chain organic molecules. When a colored molecule appeared, it was logical to consider the use of the molecule as a pigment in a synthetic paint. Contemporary artists worldwide rapidly embraced acrylic paint for art expression. It dries quickly and is durable, brightly colored, and easily controlled by the artist.

## THE COMPOSITION OF PAINT

### What is a paint?

- A paint is a solution, suspension, or colloid made up of a colored pigment and a binder that suspends or dissolves the pigment and adheres to a surface.

It can be seen that, historically, a paint is anything that contains *pigment*, a colored, powdered substance, and a *binder*, a material that evenly disperses the pigment and adheres to a surface when the paint is applied and then dries. A pigment combined with a binder makes a *paint*. A medium is used to dilute a paint. The composition of watercolor, egg tempera, oil, and acrylic paints is discussed in this chapter.

### What additives can be found in paints?

- Some additives found in paint are glycerin, ox gall, and odorants.
- In addition, metallic salts of lead, cobalt, or manganese can be dissolved in oil to accelerate drying.
- Varnish can be used to thin oil paints.
- Sometimes suspension agents are added to prevent oil paints from hardening in a metal tube.
- Antioxidants can be added to paints to prevent paint spoilage.

A paint can be made from two main ingredients, a pigment and a binder, but other additives are often present. Transparent watercolor, for instance, usually purchased in tubes, contains many more ingredients. The pigment and binder, gum arabic, the sap of the acacia tree, are basic ingredients. Glycerin is added for brushability, ox gall for absorbency, and a preservative for extending the paint's shelf life. An odorant, such as oil of cloves, gives the paint a pleasant smell.

### Where does paint fit into a classification scheme for all matter?

- All paints are solutions. Solutions have two ingredients, a solute and a solvent. In paint, pigment is the solute and binder is the solvent.
- Paints fall into a class of solutions called *homogeneous mixtures*, which are uniform throughout.
- Many paints are *colloidal solutions*, in which the pigment particles are between 1 and 1,000 nanometers in size. These particles do not come together and form larger particles because colloidal particles carry electrical charges of like sign. They repel each other.

When chemists think of paint, they wonder how paint fits into a scheme of classification of all matter. If paint can be classified as a particular form of matter, then generalizations pertaining to that class will apply to paint. These generalizations enable chemists to predict ways of making more unique and more useful paints. Chemists classify matter, anything that takes up space and has mass, as illustrated in Figure 2.1 (page 94).

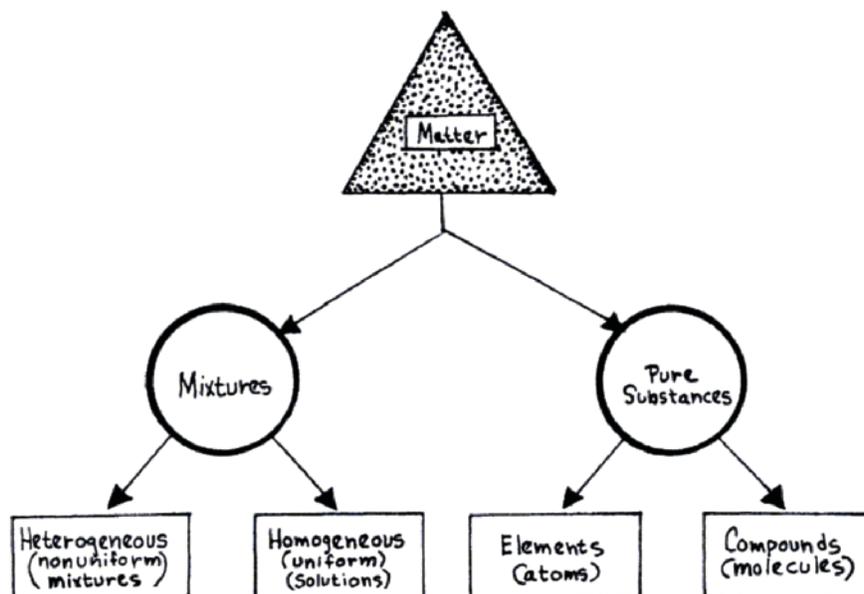


Figure 2.1. Classification of Matter.

**Define mixtures, pure substances, heterogeneous and homogeneous matter, elements, and compounds.**

- *Mixtures* are combinations of two or more different pure substances combined together, not in any set proportions. The composition of a mixture cannot be represented by a single chemical formula.
- *Pure substances* are elements or compounds. An *element* is made up of atoms. All of the atoms in an element contain the same number of protons. An element can be made of individual atoms or atoms bonded together to form molecules. A *compound* is composed of two or more different elements that are chemically combined. *Heterogeneous matter* is not uniform throughout. If two samples are taken of a heterogeneous substance, they will not be the same. If two samples are taken of a homogeneous substance, they will be the same. *Homogeneous matter* is uniform throughout.

All matter is placed into two main classes: mixtures and pure substances. *Mixtures* consist of two or more different particles; *pure substances* consist of the same kind of particles. Mixtures are divided into *heterogeneous mixtures*, which are nonuniform throughout, and *homogeneous mixtures*, solutions, which are uniform throughout. Pure substances are divided into *elements*, which are made of atoms, and *compounds*, which are made of molecules. Paints are mixtures because they are made of at least two different particles: pigment particles and binder particles. Most paints are uniform mixtures throughout, so they are solutions. If we can make some generalizations about solutions, we can better understand paints. The best way to make generalizations is to perform experiments in which a theory is tested and conclusions are drawn from the test results. Before experimenting with solutions, a basic understanding of this category of matter is required.

## Types of Solutions

### Define the two parts of a solution.

- A solution is made up of a solute and solvent. The solute is what dissolves in the solvent. Solutes and solvents can be solids, liquids, or gases.
- Seawater is an example of a solution in which the solutes, solid salts such as sodium chloride and calcium sulfate, are dissolved in liquid water.
- Soda is an example of a gas, carbon dioxide, dissolved in liquid water.
- The alloy, brass, is an example of a solid solute dissolved in a solid solvent. In brass, zinc is dissolved in copper.
- Air is an example of a solution of a gas solute dissolved in a gas solvent. In air, nitrogen gas is dissolved in oxygen gas. (Trace elements such as carbon dioxide gas and argon gas are also present.)

### How are solution concentrations expressed?

- In a science laboratory, the most useful way of expressing the concentration of a solution is a ratio of moles of solute to liters of solution. This is called molarity and is abbreviated M. In a chemical change, it is useful to know the number of moles of solute that react. The formula for calculating molarity is

$$\text{Molarity (M)} = \text{moles solute (m)} \div \text{liters solution (L)}$$

Using this formula the following problems can be solved:

1. What is the molarity of a sodium chloride solution that has a volume of 600. ml and contains 67.0 g of sodium chloride (NaCl)?

$$\frac{67.0 \text{ g NaCl}}{600.0 \text{ ml}} \times \frac{1000 \text{ ml}}{1 \text{ L}} \times \frac{1 \text{ mole NaCl}}{58.5 \text{ g NaCl}} = 1.91 \text{ M}$$

2. How many milliliters of solution are needed to form a 1.5 M solution with 85.0 g of CuSO<sub>4</sub>?

$$85.0 \text{ g} \times \frac{1 \text{ mole CuSO}_4}{159.6 \text{ g}} \times \frac{1 \text{ L}}{1.5 \text{ mole}} \times \frac{1000 \text{ ml}}{1 \text{ L}} = 355 \text{ ml}$$

3. How many grams of KCl are needed to form 300. ml of a .48 M solution?

$$300 \text{ ml} \times \frac{1 \text{ L}}{1000 \text{ ml}} \times \frac{.48 \text{ mole}}{1 \text{ L}} \times \frac{74.5 \text{ g}}{\text{mole}} = 10.7 \text{ g}$$

The two parts of a solution are the solute and solvent. The solvent does the dissolving; the solute is the part that is dissolved. A solution may be unsaturated, saturated, or supersaturated. In an unsaturated solution, additional solute can dissolve in the solvent. In a saturated solution, no more solute will dissolve. In a supersaturated solution, more solute is dissolved than would normally be the case at a particular temperature.

**What is the usual relationship between solute solubility in a solvent and temperature?**

- Usually the higher the temperature, the greater the solubility of a solute dissolved in water. However, lithium sulfate decreases slightly in solubility as temperature increases.
- For gases, usually the greater the temperature, the lower the solubility. That is why a warm glass of soda tastes flat. The higher the temperature, the smaller the amount of carbon dioxide that is dissolved in the soda solution.

Temperature affects the solubility of a solute in a solvent; usually, the higher the temperature of the solvent, the greater the solubility of the solute.

Activity 2.1 is an experiment to see the effects of solution saturation and temperature change on solution color intensity. From this experiment, we can predict how paint color intensity might be changed.

**ACTIVITY****2.1****Saturated Solutions and Temperature Change****Objectives**

1. Students will compare and contrast the physical properties of unsaturated, saturated, and supersaturated solutions.
2. Students will evaluate paint color intensity in the context of each type of solution.
3. Students will discover the effects of temperature change on solute solubility and color intensity.

**Materials**

For each student group: 14.65 g  $\text{NaC}_2\text{H}_3\text{O}_2$  (sodium acetate); three large test tubes; test tube holder; Bunsen burner or alcohol lamp; matches; Celsius thermometer; distilled water; red or blue powdered paint pigment; stirring rod; test tube rack; 10.0 ml graduated cylinder; centigram balance; paintbrushes; 5-x-7-in. watercolor paper.

**Time**

80 minutes

**Procedure**

- A. Prepare unsaturated, saturated, and supersaturated solutions of sodium acetate:
1. Prepare a saturated solution of sodium acetate: In a large test tube, dissolve 4.65 g  $\text{NaC}_2\text{H}_3\text{O}_2$  in 10.0 ml distilled water at  $20^\circ\text{C}$ .

2. Prepare an unsaturated solution of sodium acetate: In a large test tube, dissolve 3.0 g  $\text{NaC}_2\text{H}_3\text{O}_2$  in 10.0 ml distilled water at  $20^\circ\text{C}$ .
3. Prepare a supersaturated solution of sodium acetate. In a large test tube, add 7.0 g  $\text{NaC}_2\text{H}_3\text{O}_2$  to 10.0 ml distilled water and gradually heat the contents of the test tube over a Bunsen burner or alcohol lamp until all the sodium acetate is dissolved. Carefully place the test tube in a test tube rack and let it cool without being disturbed. All the sodium acetate will remain in solution.
4. Observe the appearance of all three solutions, recording observations. Add a small crystal of sodium acetate to each test tube, observe, and record observations.

B. Experiment with temperature change and color intensity:

1. Fill each of two test tubes with 1.0 ml distilled water.
2. Heat the water in one test tube to about  $50^\circ\text{C}$ .
3. Pick either red or blue powdered paint pigment. Add the powdered paint pigment to each test tube until no more pigment will dissolve.
4. Observe the appearance of each solution and record observations.
5. Paint two small pictures having chemistry themes, such as solute and solvent particles dancing around in saturated, unsaturated, and supersaturated solutions. For one, use the room-temperature paint; for the other, use the paint at  $50^\circ\text{C}$ . Make a list of differences between the two paintings. Compare the two paintings, noting differences in color intensity and the effect of the color intensity differences on the general appearance of and the message contained in the paintings.

### Questions and Conclusions

1. What was the appearance of each sodium acetate solution before a crystal of each compound was added?
2. How did the solutions change when the crystals were added? In some cases, did the solutions become heterogeneous (nonuniform) mixtures?
3. In paint, the pigment is the solute and the binder is the solvent. Should a paint solution be unsaturated, saturated, or supersaturated? Why?
4. Imagine paint solutions that are unsaturated, saturated, and supersaturated. How would color intensity appear in each solution?
5. How does an increase in temperature affect the solubility of a solute in a solvent?
6. Was the color more intense in the room-temperature watercolor solution or in the  $50^\circ\text{C}$  watercolor solution?
7. What are some ways to make a paint color more intense?

## A Summary of the Physical Properties of Solutions

### How would you determine whether a solution is unsaturated, saturated, or supersaturated?

- Add a crystal of solute to each solution to see if the solute dissolves (unsaturated) or remains (saturated), or more solute precipitates out of the solution (supersaturated).

A *saturated solution* contains more solute in a given volume of solvent than an unsaturated solution. A *supersaturated solution* contains more solute in a given volume than would normally be present at a particular temperature. A supersaturated solution is unstable. When a crystal of solute is added to a supersaturated solution, excess solute crystallizes out of solution; the remaining solution is saturated as it normally would be at that particular temperature. When a crystal of solute is added to an unsaturated solution, the crystal will dissolve. When a crystal of solute is added to a saturated solution, the added crystal will not dissolve. Most of the time, when the temperature of a solvent increases, the solubility of the solute increases in a given amount of solvent. The more colored solute is dissolved in a given amount of solvent, the more intense the color of the solution will be. Most paints are solutions of pigments (the solute) and binders (the solvent).

### Extension for Activity 2.1

1. *Ionic solids* are soluble in water. When an ionic solid such as sodium chloride (NaCl), or salt, is dissolved in water, the sodium chloride breaks apart into charged particles, called ions, which bond to polar water (H<sub>2</sub>O) molecules. Sodium chloride forms sodium ions (Na<sup>+</sup>) and chlorine ions (Cl<sup>-</sup>) in water.
2. *Polar molecular substances* are also soluble in polar water molecules. When a molecular substance such as ethyl alcohol (C<sub>2</sub>H<sub>5</sub>OH) dissolves in water (H<sub>2</sub>O), polar ethyl alcohol molecules bond with polar water molecules. In general, likes dissolve likes. Polar solutes will dissolve in polar solvents. In addition, *nonpolar solutes* dissolve in nonpolar solvents. Nonpolar octane (C<sub>8</sub>H<sub>18</sub>) dissolves in nonpolar carbon tetrachloride (CCl<sub>4</sub>). It follows that solutes and solvents of opposite polarity do not form solutions. Nonpolar oil does not dissolve in polar water. (*Polar* means bearing a charge.)
3. In a saturated solution, an equilibrium exists between the rate of precipitation of solute particles and the rate of dissolution of solute particles. The rate of precipitation equals the rate of dissolution. The shape of a crystal of solute added to a saturated solution will change after a period of time at a constant temperature and pressure, but its mass will remain the same. The equilibrium between dissolving and precipitation is dynamic, a continuous process.

**Essential Question: Why is a supersaturated solution so unstable?**

After a discussion of the above information, explain how your paintings illustrate solute and solvent particles in solution. Distinguish among unsaturated, saturated, and supersaturated solutions by differences in the ratio of solute particles to solvent particle. The lowest ratio would appear in unsaturated solutions, and the highest ratio would be in supersaturated solutions. In addition, if the solute particles and solvent particles are polar, they would be bonded to each other. Nonpolar solvent and solute particles would not be bonded and could be separated from each other. If a saturated solution is depicted, a crystal in the solution should show the same number of particles leaving the crystal as bonding to the crystal. After considering this information, you may want to make changes to your painting.

**RESOURCES FOR STUDENT VIEWING**

Are you ready to paint your wagon? Now you should understand the composition of various paints—watercolor, oil, egg tempera, and acrylic—and how paints are related to solutions. You should also be able to categorize paint in the vast world of matter as homogeneous solutions. However, are you ready to apply paint to a wagon or a work of art?

Following is a list of films that will help you understand, through demonstration, how paints are applied to surfaces using particular media, as well as a list of artists proficient in particular media. After viewing some films and seeing specific works by the artists listed, decide which paint medium you prefer and explain its advantages and disadvantages. Finally, following the lists of videos and works of art is a list of book references useful for examples that illustrate various painting techniques.

**Films**

*Art Is . . . Acrylic Painting: Getting a Start.* 28 min. Crystal Productions, n.d. DVD. [crystalproductions.com](http://crystalproductions.com)

*Basic Watercolor Techniques.* 20 min. Educational Video Network, 2004. DVD. [evndirect.com](http://evndirect.com)

*Dance of Watercolor: Beginners and Beyond.* 64 min. Julie Cohn Productions, 2005. DVD. [juliecohnproductions.com](http://juliecohnproductions.com)

*Simply Painting Series: Introduction to Acrylics.* 60 min. TMW Media Group, 2004. DVD. [tmw.com](http://tmw.com)

*16 Acrylic Painting Techniques: the Most Complete Guide to Acrylic Painting.* 124 min. Crystal Productions, 2002. DVD. [crystalproductions.com](http://crystalproductions.com)

*Watercolor Workshop.* 63 min. Educational Video Network, 2004. DVD. [evndirect.com](http://evndirect.com)

## Artists

### Acrylic Painting

Barnett Newman (1905–1970)  
Victor Vasarely (1908– )  
Robert Motherwell (1915– )  
Helen Frankenthaler (1928– )

### Oil Painting

Rembrandt van Rijn (1606–1669)  
Paul Cézanne (1839–1906)  
Claude Monet (1840–1926)  
Vincent van Gogh (1853–1890)  
Pablo Picasso (1881–1973)  
Salvador Dalí (1904–1989)  
Jackson Pollock (1912–1956)

### Egg Tempera Painting

Italian fourteenth- and fifteenth-century artists (Giotto di Bondone 1267–1337, Fra Angelico 1387–1455, Paolo Uccello 1397–1475, Fra Filippo Lippi 1406–1469, Piero Della Francesca 1420?–1492, Giovanni Bellini 1430–1516, Sandro Botticelli 1445–1510).  
Ben Shahn (1898–1969)  
Andrew Wyeth (1917– )

## PROS AND CONS—WHICH MEDIUM IS BEST?

### What is your favorite paint medium? Why?

Each artist has a favorite medium that best fits his or her needs. Following is a short description of various paint media—watercolor, egg tempera paint, oil paint, and acrylic paint—and their advantages and disadvantages. A discussion of *poster paint* (or tempera paint), suitable for school use, is also included.

After sharing these advantages and disadvantages with the class, compare your list of advantages and disadvantages for your preferred paint medium (created in “Resources for Student Viewing”) with the advantages and disadvantages that follow. If your list differs, you should provide reasons for your choice, basing your reasons on examples of professional works you have observed. Finally, experiment with various paint media by conducting Activity 2.2.

## Transparent Watercolor

Watercolor is considered by many to be more like a stain on the paper than a paint that lies on the surface of the paper. Colors are applied in thin washes and can be built up, color on top of color. The white of the paper shining through beneath the paint adds a crisp effect to this medium. White paint is not used to lighten colors; this would create an opaque rather than a transparent effect. Colors are lightened by the addition of water.

The advantages of watercolor outweigh the disadvantages, as is evident from the following lists:

### **Advantages**

1. It dries quickly.
2. It is easy to clean up.
3. It lends itself well to atmospheric effects.
4. It is sold in a variety of forms: dry cakes, semi-moist pans, and tubes.
5. It can be wetted and reworked.
6. Color can be lifted off to lighten an area.
7. It is very portable; easy to use outdoors.

### **Disadvantages**

1. It cannot produce actual texture.
2. It is difficult to control for beginners (can look muddy if not used properly).
3. Some colors may fade from exposure to sunlight.

## **Egg Tempera Paint**

Egg tempera was used as a paint medium at least as early as the fourteenth century. It was the dominant medium in Europe until the development of oil paint. In egg tempera, powdered pigment is bound with egg and water. Paint is applied layer upon layer, imparting a luminous quality unlike any other paint medium. The advantages and disadvantages of egg tempera are about equal:

### **Advantages**

1. It is water soluble when wet.
2. It is relatively easy to clean up.
3. It has a unique appearance.
4. It is excellent for detail work.

### **Disadvantages**

1. Artists must prepare their paints from powdered pigments.
2. It is not sold commercially.
3. It is difficult to master.
4. It can be used on only a small area at one time.
5. Once the raw egg yolk has been mixed with pigment, the paint has a brief shelf life.

## **Oil Paint**

Oil paint has been a popular medium since the fifteenth century. An oil painting has depth and a unique, luminous quality. Oil paint is the favored medium of many artists today.

### **Advantages**

1. It dries slowly, so it can be reworked easily.
2. It is versatile: can be applied as a thick or thin coat.
3. It can be applied with a brush or knife.
4. It has a good shelf life, lasting many years.

### **Disadvantages**

1. Cleanup is not easy.
2. It is messy.
3. It requires a non-water-based solvent.
4. It has a strong odor.
5. It may crack and darken with age.
6. It is expensive.

## **Acrylic Paint**

Acrylic paint is the first new paint to be developed in hundreds of years. It is popular with older students and many professional artists. For general use, the advantages of acrylic paint outweigh the disadvantages:

### **Advantages**

1. It can be applied to a variety of surfaces successfully.
2. It does not peel or crack.
3. It does not fade.
4. It is easy to paint over when dry.
5. It is waterproof when dry.
6. It is versatile: can be applied as a thick or thin coat.
7. It has a good shelf life, lasting many years.
8. It can be used with a variety of media to vary effect.

### **Disadvantages**

1. It dries very quickly.
2. Dry areas cannot be reworked.
3. It is difficult to blend.

## **Poster Paint (or Tempera Paint)**

Tempera paint, often called poster paint, is a student-grade, water-based paint suitable for school use, especially in the lower grades. The advantages of poster paint outweigh the disadvantages:

### **Advantages**

1. It is inexpensive.
2. It is water soluble.
3. It is easy to clean up.
4. It dries quickly.

### **Disadvantages**

1. It comes in limited colors.
2. It can have a chalky appearance when dry.

## **ACTIVITY**

### **2.2**

## ***Experimenting with Paint: Similarities and Differences***

### **Objectives**

1. Students will experience the characteristics of watercolor, poster paint, and acrylic paint through hands-on application (all levels).
2. Students will use various tools and methods for applying paint and observe their effects on the paint (Level One).
3. Students will compare and contrast the results of the three paint media used (all levels).
4. Students will classify watercolor, poster paint, and acrylic paint in proper categories under a classification of matter system.

### **Level One: Comparison of Media I**

#### **Materials**

Ruler; pencil; poster paints, watercolors, and acrylic paints in various colors; mixing trays; water container; paper towels; medium (#5) paintbrushes; 12-x-18-in. paper suitable for painting; small sponges.

#### **Time**

50 minutes

#### **Procedure**

1. Divide a sheet of 12-x-18-in. paper into 18 3-x-4-in. rectangles (three rectangles along the 12-in. side by six rectangles along the 18-in. side). Orient the sheet of paper so the 18-in. side is horizontal, then label the rectangles in each row with the numbers 1 through 6.
2. Using one of the three paint media provided, have students paint one six-rectangle row as follows:
  - a. Rectangle 1: With the paintbrush, apply the paint in full strength, or with very little water, using long strokes.
  - b. Rectangle 2: With the paintbrush, apply the paint in overlapping strokes, using at least two colors in this rectangle.
  - c. Rectangle 3: With the paintbrush, apply the paint in watered-down strength.
  - d. Rectangle 4: With the sponge, apply the paint using very little water.
  - e. Rectangle 5: With the sponge, apply the paint using more water than was used in rectangle 4.
  - f. Rectangle 6: Wet the rectangle and apply the paint full strength.
3. Repeat step 2 for the second row, using a second paint medium.
4. Repeat step 2 for the third row, using the third paint medium.

#### **Questions and Conclusions**

1. How are the three paint media alike?
2. How are the three paint media different?
3. Which paint medium do you prefer? Why?
4. Can the three paints be classified as solutions? Explain.

## Level Two: Comparison of Media II

### Materials

Same as Level One, with the addition of chemistry books and books about insects, fish, and birds.

### Time

150–200 minutes

### Procedure

1. From the books provided, choose an interesting picture of a fish, bird, or insect, or of an object such as a crystal or a molecule. Choose fish, birds, or insects with unusual or interesting silhouettes and interesting markings, or a crystal or molecule (for example) that has interesting parts and shapes and a variety of colors.
2. Draw your subject on a sheet of 12-x-18-in. paper. Try to fill the entire page, keeping interior shapes simple and avoiding tiny details.
3. Divide the drawing into three parts, as shown in Figure 2.2. The parts do not need to be equal in size.
4. Paint the first area using various colors of one paint medium.
5. Paint the second area using various colors of a second paint medium.
6. Paint the third area using various colors of the third paint medium.

### Questions and Conclusions

1. Which area do you like most? Why?
2. Which area do you like least? Why?
3. Do you think the picture is a successful, unified composition? Why?
4. Are watercolor, acrylic, and poster paints always homogeneous solutions? Explain.

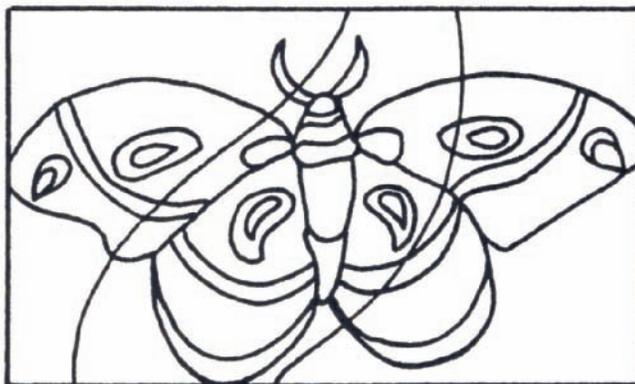


Figure 2.2.

## MAKING PAINTS

We have discussed the composition of paint, the attributes of various types of paint, and the place of paint in a classification of matter. Now you will produce paint by preparing paint pigments and combining these pigments with binders. In addition to preparing paints, you will examine the physical properties of the substances produced in your activities.

### Preparation of Colored Pigments

#### How can you be assured that a paint solution is homogenous?

- If the paint is commercially prepared, be sure that the pigment is thoroughly mixed into the solvent.
- If you are preparing the paint, be sure that the pigment is finely ground.
- For oil paints, to keep the pigment in suspension throughout the oil, stabilizers, such as aluminate stearate or beeswax, can be added.
- For opaque colors, clay can be added to stabilize the solution.

Artists' pigments may be prepared in many ways. The nature of the original materials and the treatment of these materials determine the type of color pigment that will be the final product. Pigments can be prepared by grinding naturally occurring minerals such as cinnabar, a bright-red mineral having the chemical formula  $\text{HgS}$ , or azurite, a brilliant-blue mineral having the chemical formula  $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$ . The finer the mineral is ground, the greater the chance of producing a smooth, even homogeneous paint solution rather than a coarse, uneven heterogeneous paint mixture.

#### How are paint pigments formed through a precipitation reaction?

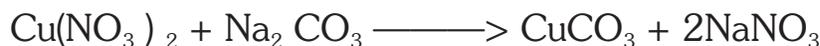
Yellow lead chromate is formed as follows:



White zinc hydroxide is formed as follows:



Blue copper carbonate is formed as follows:



Colored pigments can also be prepared by the precipitation of aqueous ions in solution. Precipitation occurs when ions, charged particles, combine in a water solution to form a solid substance. This solid substance, called a *precipitate*, can be used as a paint pigment. To separate the precipitate from the surrounding liquid, the precipitate and the liquid are poured through a conical filter paper in a funnel. The precipitate remains in the filter paper and the liquid flows through it into a receiving container. The liquid that flows into the container is called the *filtrate*.

**What chemical changes can be used to produce paint pigments?**

- When metals are oxidized, paint pigments are produced. Iron oxide is a red pigment; copper oxide is blue; lead oxide is yellow.
- Metals can be combined with acetic acid to form colorful metal acetates; copper acetate is green.
- To make lead hydroxide and lead carbonate (white lead), lead coils are heated in acetic acid fumes, carbon dioxide, and moisture.

In addition, pigments can be prepared by chemical changes, such as by combining oxygen with metals to form metal oxides or the incomplete combustion of hydrocarbons, carbon hydrogen compounds, to produce carbon.

In Activity 2.3, students will prepare paint pigments by powdering a mineral, precipitating ions in solution, and burning a hydrocarbon. The students will save their pigments for preparing paints in Activity 2.5.

**Essential Question: When two paint colors are mixed, why does a third color result? (Yellow and red make orange; blue and yellow make green.)**

**ACTIVITY****2.3*****Preparation of Colored Pigments*****Objectives**

1. Students will prepare paint pigments from a variety of materials.
2. Students will write balanced chemical equations for the preparation of selected paint pigments.

**Materials**

Mortar; pestle; 100 ml beaker; evaporating dish; funnel; filter paper; tongs; three small test tubes; Bunsen burner or candle; matches; pea-size amount  $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$  (azurite); other soft minerals such as talc; gypsum or calcite; 9.2 g  $\text{CO}(\text{NO}_3)_2$  (cobalt II nitrate); 5.3 g  $\text{Na}_2\text{CO}_3$  (sodium carbonate); 100.0 ml graduated cylinder; distilled water; centigram balance; four small test tubes; small spatula; wash bottle; two 250 ml beakers.

**Time**

50 minutes

**Procedure: All Levels**

Paint pigments, colored powdered substances, come from a large variety of starting materials. We will prepare paint pigments in three different ways from three different resources.

- A. Prepare color pigments from minerals:
1. Place a pea-size portion of  $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$  in a mortar. Repeat with another soft mineral such as talc, gypsum, or calcite.
  2. Using a pestle, grind the mineral to a fine powder.
  3. Save the powder in a small test tube.
- B. Prepare a color pigment from combustion of a hydrocarbon:
1. Light the Bunsen burner or candle. The flame should be yellow. If using a Bunsen burner, adjust the air inlets. If using a candle, removal of oxygen (air) will create a yellow flame. (Most candles will burn with a yellow flame.)
- **Warning!**  
**A lit Bunsen burner should not be placed near flammable materials.**
2. Using tongs, hold the bottom of an evaporating dish about 4 in. above the flame until a black deposit appears on the bottom of the dish.
  3. Using a spatula, scrape the black deposit into a small test tube.
  4. Save the deposit (use the test tube as a container).
- C. Prepare a color pigment from aqueous ion precipitation:
1. Dissolve 9.2 g  $\text{CO}(\text{NO}_3)_2$  and 5.3 g  $\text{Na}_2\text{CO}_3$  separately in 50.0 ml distilled water each (use a 100 ml graduated cylinder for measuring the water).
  2. Combine both solutions in a 250 ml beaker.
  3. Fold the filter paper to fit the funnel, set up the funnel for filtering, and pour the combination of the solutions into the filter paper. Use a 100 ml beaker to collect the filtrate.
  4. Using a water bottle, squirt distilled water into the residue, allowing this wash water to seep through the filter paper and become part of the filtrate.
  5. Discard the filtrate into a container for safe disposal.
  6. Unfold the filter paper and allow the residue to dry.
  7. Save the residue.

**Questions and Conclusions****Level One**

1. Referring to the procedure in this activity, define *paint pigment*.

2. What is the color of each pigment prepared?
3. The pigment prepared by combustion is carbon. Write a word equation for the chemical change that produced the carbon.
4. The pigment prepared by precipitation is copper II carbonate. Write a word equation for the chemical change that produced the copper II carbonate.
5. Make a list of plants and animals that could be used to obtain paint pigments. How could pigment be extracted from each of these plants and animals?

### Level Two

1. Write a chemical equation for the change that produced the carbon.
2. Write a chemical equation for the change that produced the cobalt carbonate.
3. Choose a plant or animal and research it in order to write, in detail, the steps for extracting pigment from the chosen plant or animal(e.g., describe the chemical process for extracting the red pigment from a rose).

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## Preparation of Binders

### What is a binder?

To paint our wagon, we need complete paints. Pigments alone will not make a paint. It is necessary to combine binders with the pigments. *Binders* are substances that hold the pigments in solution so they can be spread evenly over a surface. Depending on the binder used, the resulting paint may be transparent or opaque. Binders must adhere to a surface and dry in a reasonable amount of time. In Activity 2.4, students will prepare binders.

## ACTIVITY

### 2.4

## Preparation of Binders

### Objectives

1. Students will prepare a variety of binders and describe their physical properties.
2. Students will explain the requirements for a binder in a paint.

### Materials

Linseed oil; turpentine; beeswax; 3.0 g  $(\text{NH}_4)_2\text{CO}_3$  (ammonium carbonate); egg yolk; soluble starch; distilled water; 10 ml graduated cylinder; four 250 ml beakers; small test tube; Bunsen burner; stirring rod; four watch glasses; paintbrush; centigram balance.

### Time

50 minutes

### **Procedure**

- A. Prepare a binder for oil paint:
1. Using a 10 ml graduated cylinder for measuring, combine 2 ml linseed oil and 4 ml turpentine in a 250 ml beaker and stir.
  2. Save the binder (use the beaker as a container). Cover the beaker with a watch glass.
- B. Prepare a binder for water-soluble paint, using wax for permanence:
1. Place a 1-in. cube of beeswax and 30 ml distilled water into a 250 ml beaker.
  2. Heat gently over the colorless flame of a Bunsen burner until beeswax melts.
  3. Add 3.0 g  $(\text{NH}_4)_2\text{CO}_3$ , a little at a time, while gentle heating is continued. Decrease the heat if the solution threatens to foam over the top of the beaker.
  4. Save the binder (use the beaker as a container). Cover the beaker with a watch glass.
- C. Prepare a binder for egg tempera paint:
1. Separate an egg yolk from the albumen. Discard the albumen.
  2. Carefully place the egg yolk in your hand and pass it from one hand to the other, without puncturing it, until it is fairly dry.
  3. Place the egg yolk in a 250 ml beaker and puncture it.
  4. Transfer the egg yolk to a 10 ml graduated cylinder and measure the volume.
  5. Add to the egg yolk an equal volume of distilled water and stir the mixture until it is homogenous (has a uniform consistency). The mixture should have a thick consistency.
  6. Save the binder (use the beaker as a container). It will keep for a day or two in the refrigerator but has a very brief shelf life.
- D. Prepare a binder that covers well for temporary purposes, then make the binder more permanent:
1. In a 250 ml beaker, add 2.0 g starch to 4.0 ml cold distilled water and stir to make a paste.
  2. Boil 4.0 ml distilled water in a test tube over the flame of a Bunsen burner. Add this to the starch paste, stirring well. This solution is a temporary binder.
  3. Students will the starch solution, add 2.0 ml linseed oil, a little at a time, while stirring. This solution is a permanent binder.
  4. Save the binder (use the beaker as a container).

## Questions and Conclusions

### Level One

1. Create a chart that lists the four prepared binders in a column on the left and the following binder physical properties across the top: viscosity, texture, adhesion (ability to adhere to a painting surface), and color. Paint a sample of each binder under the binder name. Then evaluate each binder for the physical properties listed in the table squares.
2. Make a list of physical properties that a good binder should have and explain why these properties are important.

### Level Two

1. Explain the use of the turpentine in the binder for oil paint.
2. Explain the uses of the ammonium carbonate and beeswax in the binder for water-soluble paint.
3. What property of egg yolk makes it a good binder?
4. How does oil make a starch binder permanent?
5. Are most binders pure substances or solutions? Explain.

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## Preparation of Paint from Pigments and Binders

### How is a suspension different from a true solution?

- The solute in a suspension has particles larger than 1,000 nanometers, while the solute in a true solution has particles no larger than one nanometer.

Now comes the moment of truth! Will the pigments prepared in Activity 2.3 combine with the binders prepared in Activity 2.4? If the pigments remain suspended in the binders, irregular heterogeneous mixtures will result. The pigment particles will separate from the binders and settle out of the mixtures. This kind of unstable system is called a *suspension*. Solute particles, in this case pigment particles, that are larger than 1,000 nanometers will separate from the solvent (a nanometer is  $1 \times 10^{-9}$  m). If such a mixture is applied to a surface, the paint will not uniformly cover it. Good paints are uniform throughout: homogeneous solutions. In a *true solution*, the solute particles (those particles dissolving in and combining with the solvent) are no larger than 1 nanometer, about the size of a small molecule. Our pigment particles would need to be no larger than 1 nanometer to form a true solution.

### What is a colloid?

- In a colloid, the solute particles are between 1 and 1,000 nanometers in size. These particles scatter light but do not settle out of a solution.
- Sometimes a colloid is classified as a state of matter between a solution and suspension.

However, a usable paint may be formed that is not a true solution. When a pigment is combined with a binder, a *colloid*—a solution in which the solute particles are between 1 and 1,000 nanometers in size—can be formed. Like all solutions, colloids are uniform throughout. Many paints are colloids, so there is a good chance that our pigments will form usable paints when combined with our binders. We shall see!

**ACTIVITY****2.5****Preparation of Paint from Pigments and Binders****Objectives**

1. Students will prepare paints from the pigments and binders prepared previously.
2. Students will explain why many paints are colloid solutions.

**Materials**

Pigments prepared in Activity 2.3; commercial pigments of various colors; binders prepared in Activity 2.4; paintbrushes; 16 small test tubes; stoppers; stirring rods; eye droppers.

**Time**

30 minutes

**Procedure: All Levels**

1. Place a portion of each of the three pigments prepared in Activity 2.3 along with a commercial pigment into four separate test tubes. Each student or group should pick a different commercial pigment.
2. Use an eye dropper to add, drop by drop, enough of each of the four binders prepared in Activity 2.4 to each pigment, mixing thoroughly, to make a colloidal suspension.
3. Paint a sample of each prepared paint on a chart prepared in the following manner: List the four pigments in a column on the left side of a sheet of paper and the four binders across the top.
4. Place stoppers in test tubes to save remaining paints to use in Activity 3.4.

**Questions and Conclusions****Level One**

1. Using your chart, determine:
  - a. What combination makes the best paint? Why?

- b. What combination makes the worst paint? Why?
2. Do your paints appear to be solutions, suspensions, or colloids? Decide for each paint and explain your decision.
3. If you were to create a paint for your personal use, what qualities would you want it to have? What would you use the paint for, and how would each quality enhance that use?

### **Level Two**

1. Consider the solute particles and solvent particles involved in the process of making paint. In what ways can solute particles (pigment) combine with solvent particles (binder) to form a solution or colloid? When these particles combine, we say that they “bond.”

At last, we have some paints! Are they good enough to paint our wagon and head for gold-mine territory? Probably not, but we have a basic understanding of paint: a chemical solution or colloid consisting of a pigment and a binder. Good paints will cover a surface uniformly and completely and dry in a reasonable amount of time. In Activities 3.3–3.5, students will use their paints creatively. Meanwhile, we will need to use commercial paints to paint our wagon and seek our fortune.

### **Challenge Activity**

Create a pallet of natural paints. Find colored rocks. Black coal also works. Identify their chemical composition. Grind each rock using a mortar and pestle. Add a binder to the powdered rock. Binders can be glue, starch paste, or egg yolk. Now you have paints. Use these paints in a drawing. Try to identify an element or a combination of elements that produces certain colors.

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## FILMS

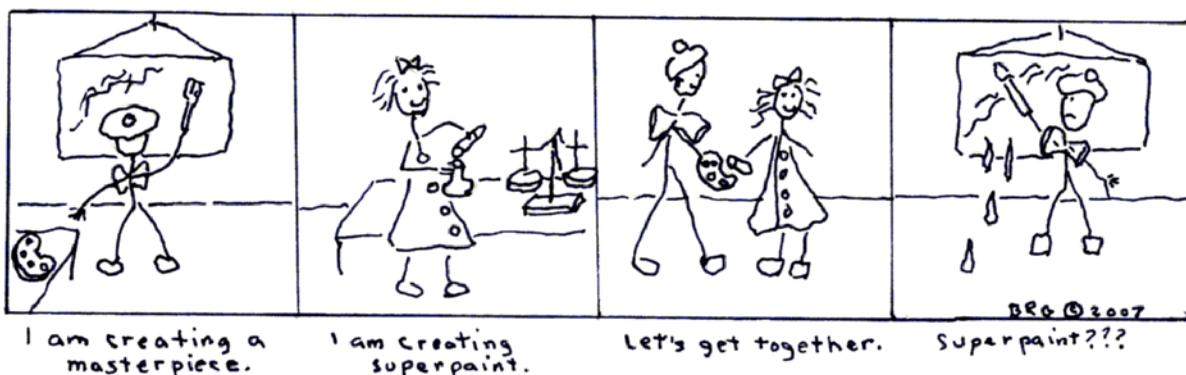
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## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 2.1 Saturated Solutions and Temperature Change

1. Each solution appeared clear and colorless.
2. In the unsaturated solution, the added crystal dissolved and the solution appeared homogenous, as it did before the crystal was added. In the saturated solution, the added crystal remained and the solution became heterogeneous. Since the solution process is dynamic, the added crystal should become more uniform as time passes. In this dynamic process, dissolved solute particles are precipitating out onto the crystal surface at the same rate as crystal surface particles are dissolving. In the supersaturated solution, excess solute precipitated out of the solution, which was then a heterogeneous mixture.
3. A paint solution should be unsaturated if less color intensity is desired or saturated if more color intensity is needed. Either solution would be homogenous which is needed for consistency. A supersaturated paint solution would be unstable and unpredictable, and therefore undesirable.
4. As one progresses from unsaturated to saturated to supersaturated solutions, the number of solute particles increases and therefore the intensity increases.
5. Usually, when a solid solute dissolves in water, as the temperature increases, the solubility increases.
6. The color was more intense in the 50°C watercolor solution. More solute could dissolve at 50°C than at room temperature.
7. Add more pigment to the paint solution to prepare a completely saturated solution. Increase the temperature of the paint solution and then add more pigment.

### Activity 2.2 Experimenting with Paint: Similarities and Differences

#### Level One

1. All three paints dry quickly. They are easy to clean up. They are all water soluble. They are all portable and can be used outside.
2. Poster paints come in limited colors. They can have a chalky appearance. Watercolors cannot be used to produce actual texture. Some of the colors fade when exposed to sunlight. Colors can be lifted off to lighten an area. Colors can be applied so they are transparent to light. Acrylic paints are easily painted over when dry. However, they are sometimes difficult to blend.
3. All three paints are homogenous solutions. If paints were not solutions, the pigment would be irregularly dispersed and the resulting paints would spread color unevenly.

**Level Two**

3. Students should assess their paintings to see if there is a strong focal point or center of interest, if the viewer's eye moves through the painting in a manner intended by the student, if the balance is symmetrical or asymmetrical and if there is interesting positive and negative space. In a successful painting, all the elements of design—line, texture, light and dark contrast, shape, and color—should fit together.
4. If watercolor paints are in dry cake form, the dry cake must be mixed with water to make a paint. Improper mixture can result in a heterogeneous mixture. When acrylic and poster paints are diluted with water, heterogeneous mixtures can also result.

**Activity 2.3 Preparation of Colored Pigments****Level One**

1. A *paint pigment* is a powder derived from grinding a colored mineral. It is a colored precipitate formed when certain ions combine. A black pigment is carbon derived from the combustion of a hydrocarbon. In the past bones were burned to produce carbon black.
2. The copper compounds are blue. The carbon is black. Cobalt compounds also are shades of blue.
3. Methane yields carbon plus hydrogen.
4. Cobalt nitrate plus sodium carbonate yield cobalt carbonate plus sodium nitrate.
5. Animal bones are burned to produce carbon black. Indigo blue is extracted from certain plants in India. Woad, a plant native to Europe, produces a color similar to indigo. A yellow pigment, Indian yellow, has been obtained from the dried urine of cows that were fed on mango tree leaves. (Happily, this is no longer used.) Squid produce a black ink used as a paint pigment. Most plant pigments are extracted from plants using solvents such as alcohol or acetone.

**Level Two**

1.  $\text{CH}_4 \text{ (g)} \rightarrow \text{C} \text{ (s)} + 2\text{H}_2 \text{ (g)}$ .
2.  $\text{Na}_2\text{CO}_3 \text{ (aq)} + \text{Co}(\text{NO}_3)_2 \text{ (aq)} \rightarrow \text{CoCO}_3 \text{ (s)} + 2\text{NaNO}_3 \text{ (aq)}$ .

**Activity 2.4 Preparation of Binders****Level One**

2. A binder should not turn yellow when exposed to light. It should mix with the paint pigment to form a creamy, dense solution that can be diluted if necessary. It should allow the paint to hold together after drying. These

binder properties are required to produce true colored, easily applied, permanent paint.

**Level Two**

1. It evenly disperses the pigment to form a homogenous paint solution.
2. The ammonium carbonate and beeswax tend to soften the paint and keep the pigment in solution for long periods of time.
3. Egg yolk acts as an emulsion and makes the paint water soluble. It does not yellow, crack, or darken the paint. Egg tempera paints are more permanent than paints mixed with any other binder.
4. It helps to emulsify the paint so the starch binder can act to keep the paint together after drying.
5. Most binders are solutions, such as linseed oil, which is composed of a number of fat and fatty acid molecules. Egg yolk is composed of water, fat molecules, lecithin, protein, dextrose, cholesterol, lutein, and other trace substances. These compositions of binding solutions allow more opportunities for uniform pigment adhesion and permanent paint qualities.



# Supports and Grounds

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*Down Under: What Is Underneath?*



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: In addition to gravitational force, what makes one object stick to another object?**

## INTRODUCTION

Most of us try to keep our feet on the ground, so to speak. Fortunately, the force of gravity helps us to remain attached to the earth and keeps us from floating off into space on an endless journey through the universe and beyond. Attachment to a surface is basic to life on Earth. It is also important to an artist creating a two-dimensional work of art. The support and surface on which the artist applies materials has a major effect on the final work.

### How is the support different from the ground?

- The support is the surface on which a two-dimensional artwork is supported, such as wood or canvas.
- A two-dimensional work of art can be created directly on the canvas.
- However, the ground can be added to the support in preparation for the addition of pigmented material.
- Paper can serve as a ground or a support.
- An Impressionist artist, Henri Toulouse-Lautrec (1864–1901), painted pictures of dance hall patrons and dancers directly on brown paper supports. Other artists painted on canvas coated with *gesso*, a chalky substance mixed with glue and water. This is a popular ground still used by artists today.

A painting usually has more than one layer. First, there is the *support*, which is the foundation for the painting. Support materials may be manufactured, such as paper and

canvas, or naturally occurring, such as wood and stone. The next layer, the *ground*, can be defined as the surface on which an artist draws or applies pigment. It is the background in a two-dimensional work of art or the substance applied to a painting or drawing support in preparation for the pigmented material. Next, of course, comes the paint or pigmented material. Finally, a protective coating, such as varnish or fixative, may be added.

## A BRIEF HISTORY OF SUPPORTS AND GROUNDS

### Ancient Times

- In addition to cave walls, stone walls of shrines and animal skins served as supports for paintings in ancient times. An artist applied water-suspended pigment on a surface of freshly spread plaster to make a fresco painting. The paint and the plaster fused. The fresco painting survived as long as the plaster remained intact.
- Probably the greatest of all frescos are those of the Italian Renaissance. During this time, Michelangelo was at work on the frescoes of the Sistine Chapel

### **Are the painting supports used in 50 B.C. and in the fourteenth and fifteenth centuries still used today?**

- The cave wall support for a work of art has a modern equivalent. Today, public building walls, cement barriers, and structural supports also serve as supports for modern paintings that make social and political statements or merely decorate a drab, dreary location and enliven its appearance.
- Diego Rivera (1886–1957), a Mexican mural artist, painted a four-wall panorama at the Detroit Institute of Arts illustrating every job in the automobile industry.
- Modern artists still use wood supports for paintings.
- More often, modern artists use canvas supports for their paintings and coat their canvases with gesso. In 1979, Andrew Wyeth used such a canvas to paint *Braids*, a portrait of a woman. Interestingly, he used egg tempera paints similar to those used hundreds of years ago.

In ancient times, the support for a work of art was a cave wall. As caves were replaced by housing, the walls of dwellings served as supports for artwork. In the city of Pompeii, in southern Italy, fresco paintings on building walls dating back to 50 B.C. are well preserved to this day. In the fourteenth and fifteenth centuries in Italy, painting on specially prepared wood panels with egg tempera paint was one method used by artists of the day. By 1450 the printing press had been invented and was in prevalent use; this enhanced the availability of paper for books and artwork. Throughout the ages, cloth, such as canvas, has been used as a painting support.

### Modern Times

#### **Name some painting surfaces used in modern times.**

- Painting surfaces used in modern times can be the same as those used in ancient times: walls, wood, bark, and animal skins.

- Today, two-dimensional artworks can appear on glass, plastic, mirrors, and metal surfaces.
- Artist often make their own paper, as we will do in Activity 3.4.

In modern times, artists continue to use a variety of supports. Henri de Toulouse-Lautrec painted on brown paper in the 1880s and 1890s. His dull, brown backgrounds helped to emphasize his lively, colorful figures. Today, artists in the United States commonly use canvas or paper for their artwork. However, if we travel to Olido, Nigeria, in western Africa, we will find that *body painting* is common. These body paintings often coexist with wall paintings; both show the same motifs, despite the contrasting painting surfaces. Continuing our journey to England, we will see sidewalk artists creating their fragile, temporary works of art on the concrete for passersby to admire, and, in the case of Mary Poppins, for fantasy seekers to enter and become a part of the drama portrayed. Even today, the list of materials for painting supports, what is down under, is seemingly limitless.

**Essential Question: Will electronic messages and digital art replace our need for supports such as paper? Explain.**

## Fresco Painting

### How is a fresco painting executed?

- In a fresco painting, paint and plaster fuse. The artist uses water suspended pigment, which is absorbed on a surface of freshly spread plaster. The plaster must have the proper degree of moisture to absorb the paint.
- Because of the need to apply only the amount of plaster needed for one session's work, Michelangelo could paint only about one square yard of ceiling in a day.

### Why do fresco paintings last for hundreds of years?

- The painting becomes part of the plaster wall. As long as the plaster wall remains, the painting remains.
- In Assisi, Italy, the Basilica of St. Francis has fresco-painted walls that are virtually the same today as when they were painted in the thirteenth century.

For one type of fresco painting, *buon fresco painting*, the ground is freshly spread plaster. Paint pigment is applied to the wet plaster, which absorbs the pigment as it dries. The painting and wall are one. Buon frescos are very durable, but the artist must prepare only a small area of fresh plaster at a time, then work quickly before the plaster dries. Among the most well-known frescos is Michelangelo's work on the ceiling of the Sistine Chapel at the Vatican in Italy. This fresco was completed in the sixteenth century and underwent extensive renovation from 1980 to 1989. Years of soot, salt stains, and coats of glue build-up were removed, revealing the original brilliant color. In modern times, artists still use the fresco technique to paint murals depicting objects on a grand scale. As recently as the 1900s, fresco painting was embraced by Mexican artists to express events and feelings engendered by Mexican social and political upheaval.

**How is a gesso painting different from a fresco painting?**

- In a fresco painting, freshly prepared plaster is the support and the ground for the painting.
- In a gesso painting, a board support is layered with a plasterlike ground, the gesso, and a painting is made on this ground.
- Instructions for two gesso preparations are in Activity 3.2.
- Either of these gesso grounds will provide a brilliant white painting surface. Unlike a fresco painting, in a gesso painting the artwork is painted on a dry surface and does not soak into the surface.

*Gesso painting* is a version of the fresco technique in which the painting support is not associated with a building. While the buon fresco painting technique employs a ground of freshly prepared plaster on a building wall support, a gesso ground is prepared by applying layers of plasterlike paste, or gesso, to a masonite board. As each layer dries, a new layer is added. The final ground has a brilliant white, dry, hard surface. With a gesso ground, the paint remains on the surface instead of being absorbed into the ground, as it would in buon fresco painting.

Gesso is also used when preparing a canvas for oil or acrylic painting. Canvas stretched on a frame is the support. The gesso ground is applied with a brush to the support, a procedure called *priming*. The gesso acts to seal the canvas fabric so that the paint applied will not soak into the canvas.

**PREPARING GROUNDS: CHEMICAL CHANGES****Define *chemical change*.**

- In a chemical change, reactant substances, with an exchange of energy, change into new product substances.
- A chemical change, at the molecular level, results in a new arrangement of the starting atoms without a gain or loss in the number or kind of atoms.

**What two types of chemical reactions are used in Activity 3.1 to prepare whitening compounds?**

- In Activity 3.1 students will perform a composition reaction and a double displacement reaction.
- In a composition reaction, two or more reactants form one product. In this composition reaction, two compounds, water and calcium oxide, form one product, calcium hydroxide. In more common composition reactions, two elements form a compound. An example is magnesium reacting with oxygen to form magnesium oxide.
- The double displacement reaction in Activity 3.1 is typical. Two reactant compounds form two new compounds: sodium carbonate plus calcium chloride yield sodium chloride plus calcium carbonate.

In Activity 3.1, the students will prepare *whitening compounds*, substances that impart a brilliant white to a ground, which will be combined with other chemicals to produce a gesso paste. In Activity 3.2, the gesso paste will be applied to masonite board to prepare a

ground, which will be used in a subsequent activity as a painting surface for pictures that students will create using the paints they made in Chapter 2 (Activities 2.3–2.5, pp. 107–113). In the preparation of the whiting compounds, students will observe two types of chemical reactions: a composition reaction and a double displacement reaction. Students will review chemical change and examine four basic types of chemical changes—composition, decomposition, single displacement, and double displacement—and examine two classes of compounds, acids and bases.

**ACTIVITY****3.1****The Preparation of Grounds: Preparing Whiting Compounds****Objectives**

1. Students will prepare two whiting compounds and observe the chemical changes involved.
2. Students will write balanced chemical equations for the chemical changes observed and explain that an equation is balanced to reflect the conservation of atoms in a chemical change, as required in the law of conservation of matter.
3. Students will classify equations according to a simple system.
4. Students will identify the whiting compounds prepared as acidic or basic and research the chemical and physical properties of acids and bases.

**Materials**

Large funnel; filter paper; two 1 L beakers; five 250 ml beakers; 1 L graduated cylinder; distilled water; red and blue litmus paper; 21.2 g  $\text{Na}_2\text{CO}_3$  (sodium carbonate); 22.2 g  $\text{CaCl}_2$  (calcium chloride); 10.0 g  $\text{CaO}$  (calcium oxide); stirring rod; two watch glasses; distilled water; wash bottle.

**Time**

40 minutes

**Procedure: All Levels**

- A. Prepare  $\text{CaCO}_3$  (calcium carbonate):
  1. In a 1 l beaker, dissolve 21.2 g  $\text{Na}_2\text{CO}_3$  in 1 l distilled water to prepare a 0.2 M (molar) solution of  $\text{Na}_2\text{CO}_3$ .
  2. In a 1 l beaker, dissolve 22.2 g  $\text{CaCl}_2$  in 1 l distilled water to prepare a 0.2 M solution of  $\text{CaCl}_2$ .
  3. In a 250 ml beaker, combine 100 ml 0.2 M  $\text{Na}_2\text{CO}_3$  with 100 ml 0.2 M  $\text{CaCl}_2$  and observe the chemical change.

4. Filter the product. Collect the filtrate into a 250 ml beaker. (Note: The filtrate can be discarded down a sink drain.) Save the residue and discard the filtrate (liquid).
  5. Using a wash bottle, wash the residue several times with distilled water. Discard the additional filtrate in a sink drain.
  6. Test the residue with red litmus paper and blue litmus paper and record the results.
  7. Scrape the residue on the filter paper into a 250 ml beaker. Cover with a watch glass to prevent drying and save for Activity 3.2.
- B. Prepare  $\text{Ca}(\text{OH})_2$  (calcium hydroxide):
1. Place 10.0 g  $\text{CaO}$  in a 250 ml beaker.
  2. Add enough distilled water to make a thick paste. Stir with a stirring rod.
  3. Test the paste with red litmus paper and blue litmus paper and record the results.
  4. Scrape the residue on the filter paper into a 250 ml beaker. Cover with a watch glass to prevent drying and save for Activity 3.2.

## Questions and Conclusions

### Level One

1. Write a word equation for the chemical changes that produced the two whiting compounds:  $\text{CaCO}_3$  (calcium carbonate), sometimes called *precipitated chalk*, and  $\text{Ca}(\text{OH})_2$  (calcium hydroxide), sometimes called *slaked lime*. After writing the equations, find for each equation the correct classification: composition, decomposition, single displacement, or double displacement (see the next subsection, “An Artist’s Materials and Chemical Change”).
2. Compare the whiting compounds,  $\text{CaCO}_3$  and  $\text{Ca}(\text{OH})_2$ , for brightness, texture, and consistency. Which compound would be a better whitener for a gesso ground? Why?
3. An acid turns blue litmus paper red and a base turns red litmus paper blue. Are the whiting compounds acidic or basic?

### Level Two

1. Write balanced chemical equations for the formation of the two whiting compounds (see the next subsection, “An Artist’s Materials and Chemical Change”).
2. Research the physical and chemical properties of acids and bases and list these properties. Explain why the whiting compounds are bases.
3. After classifying the chemical changes that produced the whiting compounds, explain the reason for placing each chemical change in a particular class.
4. Why is a whiting compound used in a gesso solution? (See Activity 3.2, p. 128.)

## An Artist's Materials and Chemical Change

### When artists prepare art materials, why are they promoting chemical changes?

- Artist's materials are chemical substances made of specific molecules. Often, a change in one or two atoms in a pigment molecule can change the pigment hue or color.
- Most artists mix paints and solvents when creating an artwork. This mixing results in chemical changes.
- A pottery glaze is a mixture of chemical compounds. When the glaze is heated, chemical changes take place. As a potter works with clay, the clay properties (its elasticity, its color, its texture) change as chemical changes take place within the clay structure.
- An artist's studio is a virtual chemical factory, and an artist is a chemist making significant chemical changes to create a perfect work of art.

### What is the law of conservation of matter?

- Antoine Lavoisier (1743–1794), a French chemist, studied chemical changes involving oxygen, measuring the mass of the reactants before the chemical change and the mass of the products after the chemical change. He observed that the masses were the same.
- The law of conservation of matter states that in a chemical change, matter is neither created nor destroyed but is rearranged to produce new substances.

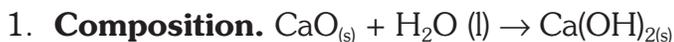
**Essential Question: How is a nuclear change different from a chemical change?**

When an artist prepares art materials, such as grounds, to be used in artwork, the artist becomes immediately involved in chemical change. Chemical changes deal with changes in the structure of substances, the reactants. Bonds between atoms in reactants are broken and atoms are rearranged and bonded into new substances called *products*. In the process of chemical change, atoms are conserved. That is, all the atoms present in the reactants are present in the product, a requirement of the law of conservation of matter.

### Challenge Activity

In chemistry, chemical symbols are used to represent chemical elements. In chemical changes, these symbols are used along with numerals to show reactants and products. Develop your own set of symbols to represent the reactants and products in a chemical change. For example, to show oxygen and hydrogen gases forming water, a symbol for oxygen can be a person breathing, to symbolize hydrogen you can show the Hindenburg blimp, and water can be represented by a glass of clear liquid. Instead of representational art symbols, you can use nonobjective symbols. Triangles, squares, lines, and other shapes can be coded to represent chemical elements. Think of Egyptian hieroglyphics and Chinese word symbols as a way to represent the elements. Use your code system to write equations for chemical changes. Have other students guess the chemical change that you are representing.

Four basic classes of chemical changes (reactions) are used to classify most simple chemical changes: composition, decomposition, single displacement, and double displacement. In a composition reaction, reactant substances (e.g., elements, compounds, ions) combine to form one product, a compound. This reaction is symbolized as  $A+B \rightarrow AB$ . In a decomposition reaction, one reactant (a compound) forms more than one product:  $AB \rightarrow A+B$ . In a single displacement reaction, an element reacts with a compound to form another element and compound:  $AB + C \rightarrow AC + B$  (nonmetal single displacement) or  $AB + C \rightarrow CB + A$  (metallic single replacement). In a double displacement reaction, two compounds combine to form two different compounds:  $AB + CD \rightarrow AD + CB$ . The following balanced chemical equations illustrate these four classes of chemical changes [(s) = solid, (g) = gas, (aq) = aqueous, (l) = liquid]:



■ *Note:*

This equation shows the formation of a whiting compound in Activity 3.1.



■ *Note:*

This equation shows the formation of a whiting compound in Activity 3.1.

Notice that in all these reactions, atoms are conserved. Equations are balanced by adding coefficients to the reactants and products.

## Acids and Bases: Special Types of Substances

### What must be true if compounds are to belong to a class?

- The compounds must have the same or similar chemical and physical properties.
- Sodium hydroxide and potassium hydroxide are both bases because they both taste bitter, feel slippery, and produce an excess of hydroxide ions in solution. In addition, they turn red litmus blue.
- Hydrochloric acid and sulfuric acid are acids because they both taste sour, burn skin, and produce an excess of hydrogen (hydronium) ions in solution. In addition, they turn blue litmus red.

When a group of compounds have similar chemical and physical properties, they are given a special name and are called a class of compounds. Acids and bases are such classes. Before defining these classes, we should consider their relationship to grounds. The whitening compounds prepared in Activity 3.1 are bases. They make the gesso white and are fairly nonreactive when dry. Therefore, an artist can paint on the gesso ground without concern that the gesso will react with the paints and cause changes in color. Also, if the gesso is left unpainted in certain areas, these areas will remain white. Some papers used as supports for watercolor paint are advertised as being nonacidic. Similarly, these papers are desirable because they will not cause changes in the color of the paint, and areas left unpainted will remain white, the color of the paper. This is not to say that bases are not reactive substances, but they remain more stable than acids in the presence of particular paints.

### What is an acid?

- Acids taste sour, burn your skin, and turn blue litmus red.
- They are corrosive.
- They react with some metals to produce hydrogen gas.
- They produce excess hydronium ions in solution.
- They have a pH below 7. The definition of pH is minus the power of the hydronium ion concentration. If the pH of a solution is 6, then the hydronium ion concentration is  $10^{-6}$  M and an acid is present. According to the Arrhenius definition of an acid, an acid is a substance that dissociates in water to produce hydrogen ions,  $H^+$ .

### What is a base?

- Bases taste bitter, feel slippery, and turn red litmus blue.
- They react with acids to produce salts and water.
- They have a pH above 7. If the pH of a solution is 11, then the hydronium ion concentration is  $10^{-11}$  M and a base is present. According to the Arrhenius definition of a base, a base is a substance that dissociates in water to produce hydroxide ions,  $OH^-$ .

The words *acid* and *base* are commonly used and can be defined by their properties. The physical properties of these substances are simple. Acids taste sour (consider the taste of a lemon), and they can burn your skin. Bases taste bitter and feel slippery. Soaps and

most cleaning solutions are bases. Many chemical reactions can be used to identify acids and bases. Acids turn blue litmus paper red and phenolphthalein (another commonly used indicator) clear. Bases turn red litmus paper blue and phenolphthalein red. Acids react with some metals, such as magnesium and zinc, to produce hydrogen gas. Acids and bases react with each other, in a process called *neutralization*, to form salts and water.

**ACTIVITY****3.2****The Preparation of Grounds: Using Whiting Compounds to Prepare Gesso Solutions****Objectives**

1. Students will construct gesso grounds.
2. Students will compare and contrast the properties of various types of gesso grounds.
3. Students will debate the pros and cons of using a gesso ground for a painting.

**Materials**

Dry-curd cottage cheese; rabbit-skin glue; 2-x-2-in. masonite boards; cheese cloth; 1-in.-wide paintbrushes; fine-grit sandpaper; 100 ml graduated cylinder; two 250 ml beakers; two 100 ml beakers; utility knife;  $\text{TiO}_2$  (titanium dioxide);  $\text{ZnO}$  (zinc oxide); plaster of Paris;  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$  (hydrated calcium sulfate); hot plate; distilled water;  $\text{CaCO}_3$  (calcium carbonate) prepared in Activity 3.1;  $\text{Ca}(\text{OH})_2$  (calcium hydroxide) prepared in Activity 3.1; centigram balance; stirring rods; 20 g  $\text{TiO}_2$ ; 20 g  $\text{ZnO}$ ; 20 g  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$  watch glass; Bunsen burner or alcohol lamp; weighing paper; hot plate.

**Time**

100 minutes (extra time will be needed for applied gesso layers to dry)

**Procedure**

- A. Prepare a glue-based gesso:
  1. Place 7.0 g of rabbit-skin glue in a 250 ml beaker.
  2. Using a Bunsen burner or alcohol lamp, warm 100 ml of distilled water. Do not boil.
  3. Add the warm water to the glue and stir.
  4. Find the mass of each of the whiting compounds prepared in Activity 3.1:  $\text{CaCO}_3$  and  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ . Select the compound of greater mass. Combine it with an equal mass of  $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ .
  5. Add the combination prepared in step 4 to the glue mixture prepared in step 3 and stir until a thick, creamy consistency is achieved.

6. Apply the gesso to a masonite board (see item C). Cover the beaker with a watch glass. Store the gesso in a refrigerator between applications (it will gel between applications and should be warmed on a hot plate until it is just melted before using).
  7. Repeat the above preparation, but use a commercially prepared whiting compound such as about 20 g  $\text{TiO}_2$  or about 20 g  $\text{ZnO}$  in step 4. Continue with steps 5 and 6.
- B. Have students prepare a casein-based gesso:
1. Place 6.0 g dry curd cottage cheese in a 100 ml beaker.
  2. Place 1.0 g  $\text{Ca(OH)}_2$  on weighing paper.
  3. In a 100 ml beaker, combine 7.0 g  $\text{ZnO}$  with 7.0 g  $\text{TiO}_2$ .
  4. Mix together the solids prepared in steps 1–3 and add enough distilled water (about 7.0 ml) to form a thick paste.
  5. Strain the mixture through cheese cloth and apply the gesso to a masonite board (see item C). Store the gesso in a covered 250 ml beaker in a refrigerator between applications.
- C. Have students create a gesso ground by applying the gesso to a masonite board:
1. Using a utility knife, score one side of a 5-x-7-in. masonite board.
  2. Using a 1-in.-width paintbrush, apply a thin layer of gesso to the scored side of the board.
  3. After the layer dries (about four hours), apply a new layer, making brush strokes at a right angle to the strokes made for the first layer.
  4. Continue applying layers of gesso (alternating the direction of brush strokes) until the gesso surface is about 3 ml thick.
  5. When the final layer is dry, sand the gesso surface using fine-grit sandpaper.
  6. Save all gesso grounds for use in Activity 3.3.

## Questions and Conclusions

### Level One

1. Compare the gesso grounds prepared with regard to color and texture.
2. In a class discussion, have students decide which gesso ground is the best ground for a two-dimensional work of art.

### Level Two

1. Research the names of artists who painted on gesso grounds. Find reproductions of their paintings. Using one of these reproductions, explain how the gesso ground provided a unique background for the two-dimensional work of art.

2. For each chemical used in this activity, explain its role in creating the gesso product.
- 

## **NONOBJECTIVE ART: NO OBJECTS, BUT PLENTY OF FEELING**

### **What is nonobjective art?**

- Nonobjective art implies a lack of standardization and lack of adherence to observable, identifiable, and quantifiable characteristics of the subject matter.
- Nonobjective art is highly subjective. This type of art does not satisfy an object-oriented person. A viewer does not necessarily perceive the intent of the artist. However, this is not necessary. What is important is that the artwork speaks to the viewer in a new and unique way.
- A nonobjective artwork should be able to communicate to the viewer at several different levels of understanding. This is what makes nonobjective art so interesting to a wide arena of diverse viewers.

The ground for a work of art is the choice of the artist. *Nonobjective art* is an art form that often makes the ground a significant part of the work. Nonobjective art is not based on any observed subject matter. It frequently addresses aspects of life that cannot be seen, such as emotion and feeling, music, and sound. These aspects are expressed in visual form through the use of lines and shapes that are free-form or geometric. Color provides the nonobjective artist with another visual tool for evoking emotion and arousing feelings.

The following artists are among those of the twentieth century who have worked in the nonobjective style:

Jackson Pollock (1912–1956)	Piet Mondrian (1872–1944)
Hans Hoffman (1880–1966)	Vassily Kandinsky (1866–1944)
Franz Kline (1910–1962)	

In Activity 3.3 you will experiment with nonobjective art using the gesso grounds prepared in Activity 3.2 and egg tempera paint prepared in Activity 2.5. Egg tempera was used by many artists in Europe during the fourteenth and fifteenth centuries. Today, it is still used by some artists, notably Andrew Wyeth. In this technique, egg yolk is mixed with distilled water to form a binder, and a pigment is added to make egg tempera paint, which is applied to a gesso ground.

You should view works by Andrew Wyeth and the other artists listed above. Also, appropriate parts of the following video about nonobjective art will help to explain this art form:

*Cubism and Non Objective Art and Surrealism*. 53 min. Aspen, CO: Crystal Video, 1993.

**ACTIVITY**

### 3.3

## **Nonobjective Art: Egg Tempera Paint on a Gesso Ground**

### **Objectives**

1. Students will mix pigment with egg yolk and distilled water to prepare egg tempera paint (or use prepared egg tempera paint).
2. Students will apply paint to a prepared gesso ground.
3. Students will learn the meaning of the term *nonobjective* by creating nonobjective works of art.
4. Students will express movement and ideas through the use of nonobjective shapes, lines, and colors in paintings.

### **Materials**

Egg yolks, pigments (see below), powdered or liquid tempera (poster paint) in assorted colors, and distilled water, or egg tempera paint prepared in Activities 2.3–2.5; gesso grounds prepared in Activity 3.2; narrow-width paintbrushes with soft bristles; paper towels; mixing trays; water containers; pencils.

### **Time**

30 minutes

### **Procedure**

#### **Preliminary**

1. If egg tempera paints remain from Activity 2.5, they should be used. If not, follow Activity 2.5 to prepare egg tempera paints. (In Activity 2.5, students combined pigments with binders to make paints.) These paints will be blue (cobalt carbonate pigment), deep blue (azurite pigment,  $2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$ ), and black (carbon pigment).
2. New and/or different color egg tempera paints can be prepared as follows:
  - a. Follow steps in Activity 2.4, Procedure item C.
  - b. Add powdered or liquid tempera paints of various colors to portions of the prepared egg yolk binder to produce paints of desired colors. Powdered or liquid tempera may be added to the egg yolk solution to make egg tempera paint in additional colors.

#### **Level One**

1. Paint on the gesso ground to create a feeling of movement—across, up, down, around, in, out, or any combination of these—using shapes and lines.

Try to vary the size and type of shapes and lines, vary the colors, and use the entire gesso surface.

2. Display your work and try to identify the movement expressed in your classmates' pictures.

### **Level Two**

1. Choose a descriptive, chemistry-related word, phrase, or term, such as *acid*, *base*, *energy*, *molecule*, *explosive chemical change*, *the solution process*, or *atoms bonding to form molecules* that could be expressed in a nonobjective painting. Then paint your idea on a gesso ground using egg tempera paint. Avoid painting a picture of an object, and try to use only shape, line, and color to express your ideas.

### **Level Three**

1. Listen to a brief excerpt of music that evokes a strong feeling of rhythm or strong emotion. Suggested musical selections include the following:

*La Mer* by Claude Debussy

*Capriccio Espagnol* by Rimsky Korsakov

*Moonlight Sonata* by Ludwig van Beethoven

*The Elements* by Tom Lehrer

jazz, rock, or pop selections

2. Create a nonobjective painting, varying the size and type of shapes and lines, and varying the colors, to express an interpretation of the music.

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## **SUPPORT FOR THE ARTIST: PAPER**

### **The Great Paper Chase: A Brief History**

#### **When and by whom was the first paper invented?**

- Even though the Egyptians invented paper more than 4,000 years ago, the papermaking process has not changed much since then.
- Papermaking involves two stages. The first is to break up a raw material to form a suspension of individual fibers. and the second is to form sheets of paper by spreading the suspension on a suitable porous surface through which water can drain.

Throughout history, there has been a need to write messages on a surface. Humanity has always been involved in a paper chase. However, paper, as we know it today, is different than the paperlike surfaces that came before it, the first of which was invented by the Egyptians around 2000 B.C. The Egyptians made a flat surface from the papyrus plant that grew in the marshes of their country. By flattening the inner fibers and attaching them side by side, a flat sheet was formed. A second layer was pasted crosswise on the first layer;

this process was continued until the surface was strong. Our word *paper* comes from the Egyptian word *papyrus*.

**When used as a painting support, how is parchment different from paper?**

- Parchment can be thicker and more irregular than paper, and it has a long-lasting quality.
- It can support a wide variety of grounds and painting materials without interacting with them and thus deteriorating.
- A fine quality of parchment, vellum, is made from the skins of kids, lambs, and young calves.

In the second century B.C., parchment was developed in the city of Pergamum, in Asia Minor. It was made from the hides of animals and was a better surface than papyrus for writing. It could be rolled into a scroll or cut and made into pages for a book. Still, it was thick and irregular.

**Relate the history of true papermaking, from A.D. 105 to modern times.**

- The first true paper was made in A.D. 105 by Ts'ai Lun, a eunuch from the Eastern Han Court of the Chinese emperor Ho Ti. His paper was made from the bark of the mulberry tree on a mold of bamboo strips.
- In 1947 papyrus and leather (animal skin) Hebrew and Aramaic manuscripts were found in caves located at the northeast end of the Dead Sea in Israel. These manuscripts have been labeled the *Dead Sea Scrolls* and were created between 200 B.C. and A.D. 68. This confirms that papyrus and parchment were the “papers” of choice during that era.

In China, around A.D. 105, the first true *paper* was made. The Chinese emperor of the day decreed that this discovery must be kept a secret, and for 500 years it was! Papermaking eventually spread to Korea and, in A.D. 610 a Korean monk named Dancho brought paper from Korea to Japan. Papermaking then traveled across Asia to Egypt in the tenth century, then to Spain in the twelfth century. From Spain, it spread through Europe. In 1690 paper making came to America. In Europe and America, until the end of the eighteenth century, paper was made by hand from rags. When a machine was invented to manufacture such paper, the demand for rags increased until a new source of raw material was needed. Suddenly, it was discovered that paper could be made from cellulose fiber found in trees. This discovery dramatically increased the production of paper, as well as the varieties of paper.

**In addition to wood chips, what other starting materials can be used to make paper?**

- There is some evidence that rag paper was made in China between A.D. 105 and 605, the 500-year period when the discovery of paper making was kept secret. To make rag paper, fibers are separated, put into a mold, press, and dipped in glue.
- Other starting materials can be bark, leaves, straw, flax, cotton, jute, hemp, and used paper.

- Any source of cellulose can be used to make paper.

Today paper is still made in essentially the same way as it has been for decades. Wood chips are treated with solvents to clean and separate wood containing cellulose fiber. This fiber, known as pulp, is spread on a flat surface, where a machine shakes it for even distribution and to interlock individual fibers. This mixture is then rolled and pressed to squeeze out excess water and solvent. A flat piece of wet paper is the result. Finally, the paper is hung to dry.

## **Characteristics of Paper: Watercolor Paper**

### **How is hot press watercolor paper different from cold press watercolor paper?**

- Hot pressing results in a smoother surface paper than does cold pressing.

Artists use many different types of paper to create their artwork. Artists using watercolor, for example, paint on paper that is specially designed for this medium. Watercolor paper may be rough in texture, medium textured, or smooth. Rough- and medium-surfaced papers are called cold press (CP) paper because the textured surface is effected by rolling the newly formed sheet through a set of cold rollers. Smooth-surfaced paper is called hot press (HP) paper because the newly formed sheet is rolled through a set of hot rollers to effect a smooth surface.

### **What is the different between 140-pound watercolor paper and 72-pound watercolor paper?**

- Each sheet of 72-pound watercolor paper weighs about half as much as a sheet of 140-pound watercolor paper.
- Each sheet of 140-pound watercolor paper is about twice as thick as a sheet of 72-pound paper.

In addition to the different textures of paper, watercolor paper is made in various weights. Watercolor paper, whether cold press or hot press, is available in weights from 72-pound to 400-pound; a typical weight is 140-pound. The larger the number, the thicker the sheet of paper. Pound-weight is determined by the weight of a stack of 500 22-x-30-in. sheets of the particular paper. Therefore, the designation “140-pound” means that 500 22-x-30-in. sheets of the paper weigh 140 pounds.

### **Describe how watercolor paper is stretched.**

- Stretching watercolor paper as described below produces a paper that is not distorted when an artist applies water to the paper to paint a wet-into-wet painting and then lets the artwork dry.
- The resulting paper remains flat and smooth.

When purchasing watercolor paper, the pound-weight system helps identify the paper needed for a particular purpose. The heavier weights of papers can be painted on without any support beneath them to keep them flat. Lighter weights of papers—72-pound, 90-pound, and 140-pound—must be supported or stretched. Stretching involves soaking the paper in a tray of cool water for several minutes, causing the fibers of the paper to relax,

until the paper becomes limp. The paper is removed and all excess water is allowed to drip. Next, the paper is stapled or taped to a flat surface. For stapling, an ordinary office stapler will do the job. Care should be taken to place the staples about  $\frac{1}{2}$  in from the edge and about  $\frac{1}{4}$  in. apart from one another. Gummed water-based tape may be used instead of staples. Strips of tape should be cut slightly longer than the four edges of the paper. Care should be taken to center the tape between the edge of the paper and the board so that the paper will be held securely. Wet the tape and press it firmly in place. When the paper is dry, the fibers have tightened and the paper will appear taut. If paint is applied to paper that has not been stretched, the paper will ripple and, when dry, remain uneven. Stretching the paper provides the artist with a flat working area and an even-surfaced painting.

**Explain how the most expensive grade of watercolor paper is different from less expensive grades.**

- More expensive papers do not easily deteriorate.
- Also, very heavy watercolor paper, such as 300-pound, may not need stretching.
- Less expensive papers can yellow with age. They may become brittle and break apart. They need stretching.

Watercolor paper, in addition to having various finishes and weights, is also available in a variety of grades. The best and most expensive paper has 100% linen rag content, meaning only linen cloth fibers have been used to make the paper. Less expensive grades contain cotton and wood fibers and synthetic substances. There are many suitable papers for painting in watercolor in addition to those already discussed. Interesting effects can be achieved using Japanese rice papers, fine art printing papers, and illustration boards. There are ground-wood papers with no chemical purification, such as manila drawing paper, and wood pulp papers chemically purified for better color strength and longevity. Each provides the artist with a unique result, and all help to create interesting effects.



### **3.1**

## ***Comparing Results of Paint Applied to Various Watercolor Papers***

### **Objectives**

1. Students will observe differences in the appearance of watercolor paint when it is applied to a variety of watercolor papers.
2. Students will examine a variety of watercolor papers and note their differences.

### **Materials**

Variety of watercolor papers, each piece cut to the same size (suggested papers: cold press, one medium texture, one rough texture; hot press, manila; white drawing; rice; and other available papers); watercolor paint; paintbrushes; mixing containers; water containers; water; masking tape.

**Time**

10 minutes

**Procedure**

1. The teacher should arrange the papers so that the edges touch. To hold them together, it may be necessary to tape them from the back. The papers need not be stretched for this demonstration.
2. Paint a wide line of watercolor across the sheets several times. Observe the various results as the paint moves from one surface to another.
3. After the paint dries, compare the results and determine which papers are suitable for watercolor paint.

**Questions and Conclusions**

1. Explain why one paper is more suitable than another.
  2. Many artists prefer 300-pound watercolor paper to 140-pound or 72-pound watercolor paper. Why?
- 

**ACTIVITY****3.4**

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**Papermaking****Objectives**

1. Students will make a fiber paper.
2. Students will evaluate the qualities of the fiber papers.
3. Students will calculate grams of solute and grams of solvent and determine the mass percent of a solution.
4. Students will explain oxidation and how it relates to papermaking.
5. Students will calculate the molarity (M) of a solution.

**Materials**

Lint from clothes dryers (papier-mâché pulp can also be used); kitchen blender; transparent or masking tape; animal hide glue; embroidery hoops; thinly woven fabric; trays slightly larger than embroidery hoop; NaClO (5% sodium hypochlorite solution: bleach); 250 ml beaker; red and blue litmus paper; watercolor paint prepared in Activity 2.5; commercial watercolor paint; paintbrushes; mixing trays; water containers; centigram balance; hot plate; watch glass.

## Time

First day 50 minutes; second day 200 minutes

## Procedure: All Levels

Have students make paper from lint:

1. In a 250 ml beaker, prepare a mixture of lint (or papier-mâché pulp) and water about the consistency of cream.
2. Place the mixture in a blender and blend at medium speed until smooth.
3. Add about 5 g of the blender mixture to 10 g of starch and blend. The mixture should resemble a very thick gravy.
4. Add 5.0 ml NaClO (bleach) to the mixture and blend.
5. Pour the mixture into a tray and test with litmus paper to determine whether it is acidic or basic. (An acid turns blue litmus red; a base turns red litmus blue.)
6. Stretch thinly woven fabric over an embroidery hoop and dip the hoop into the tray, spreading the mixture evenly over the cloth.
7. Lift the hoop out of the tray and let the lint mixture dry in the hoop.
8. Remove the paper from the hoop.

## Questions and Conclusions

### Level One

1. Describe the color, texture, and strength of the paper. Was the paper pulp acidic or basic?
2. Describe the functions of bleach and of starch in the papermaking processes.
3. Use watercolor paint prepared in Activity 2.5, as well as commercial watercolor paint, to paint pictures on the prepared paper.

### Level Two

1. Use watercolor paint prepared in Activity 2.5, as well as commercial watercolor paint, to paint a picture that incorporates the paper's shape and texture.
2. Research acid-free paper and explain the chemical process through which paper is made free of acid.
3. Solution concentrations are often presented as a percent concentration (mass percent). Ten percent NaOH solution is used to break down wood fibers often used to make paper. For this example, how many grams of solute are added to how many grams of solvent to prepare 100 g of 10% NaOH solution?
4. Solution concentration can also be presented as moles of solute in 1 L of solution. This is called the molarity (M) of the solution. Calculate the molarity

of a solution that contains 10 g of NaOH in 0.01 L of solution. Remember molarity (M) is calculated by dividing the number of grams of a substance by the molar mass. The molar mass of NaOH is 40 g.

5. In making paper, bleach (NaClO) acts as an oxidizing agent for whitening the paper. An oxidizing agent reacts with another substance, removing atoms from colored molecules. Explain how the  $\text{ClO}^-$  ion in bleach acts as an oxidizing agent when it changes from the  $\text{ClO}^-$  ion to the  $\text{Cl}^-$  ion. Research oxidation numbers and use that concept in the explanation. (See the next subsection.)

## Oxidation-Reduction

### How is a colored compound converted to a colorless compound in an oxidation-reduction reaction?

- Zinc metal reacts with blue copper sulfate to produce colorless zinc sulfate and copper metal. The net ionic equation for the reaction is:  $\text{Zn}_{(s)} + \text{Cu}_{2+}^{(aq)} \longrightarrow \text{Zn}_{2+}^{(aq)} + \text{Cu}_{(s)}$ .
- The sulfate ion is a spectator ion.
- Zinc metal is the reducing agent. It is oxidized and loses electrons.
- The copper ion is the oxidizing agent. It is reduced and gains electrons.

### What is a redox reaction?

- In a redox reaction, a reducing agent loses electrons while reacting with an oxidizing agent that gains electrons.
- In the zinc/copper sulfate reaction illustrated above, zinc metal, the reducing agent, loses electrons, and copper ion, the oxidizing agent, gains electrons.

Bleach is often used to whiten clothes. It can also be used to whiten paper pulp that will be converted into sheets of paper. Bleach (NaClO, or sodium hypochlorate) belongs to a class of compounds called *oxidizing agents*. Oxidizing agents whiten substances by changing the atomic structure of colored molecules. The new molecule, said to have been “reduced,” is usually colorless. The chemical change is called an *oxidation-reduction*, or *redox reaction*. If a new, reduced molecule is exposed to the air, which contains 20% oxygen ( $\text{O}_2$ ), it may recombine with oxygen atoms, become oxidized, and return to its colored state. This occurs when white newspaper yellows with age.

**Essential Question: How would the surface of the earth change if oxidation-reduction reactions did not occur?****What are oxidation numbers?**

- Oxidation numbers are arbitrary numbers assigned to atoms involved in a chemical change to identify the chemical species that are oxidized and reduced. These numbers represent an atom's apparent electrical charge.
- A system for assigning oxidation numbers is explained below.

Many substances act as oxidizing agents and whitening materials. Even though many oxidizing agents contain oxygen atoms, oxidizing agents cannot always be identified by their molecular structure. We must examine redox reactions to identify the oxidizing agents involved in the chemical change. To find the oxidizing agent, an arbitrary system of numbers called *oxidation numbers* is used. This system helps a chemist keep track of the number of electrons gained or lost by an atom during the chemical change. When oxidation occurs, an oxidizing-agent atom gains electrons and a reducing-agent atom loses electrons.

**Oxidation Numbers**

The system of oxidation numbers is designed as follows:

1. The oxidation number of an atom in a pure element is 0 (e.g., the oxidation number of chlorine [Cl] in  $\text{Cl}_2$  is 0). The oxidation number of iron (Fe) in metallic iron is 0. For 4, 5, and 6 below, we can look to the periodic table to find generalizations about oxidation numbers.
2. In most compounds, oxygen (O) atoms have an oxidation number of  $-2$  and hydrogen (H) atoms have an oxidation number of  $+1$ .
3. Finally, the sum of the oxidation numbers in a neutral compound is 0; the sum of the oxidation numbers in a polyatomic ion (an ion with at least two atoms) is equal to its ionic charge.
4. Looking at the periodic table of elements, the oxidation number of a group IA atom in a compound is  $+1$ ; the oxidation number of a group IIA atom in a compound is  $+2$ .
5. For group VIIA atoms, the oxidation numbers of chlorine (Cl), bromine (Br), and iodine (I) are  $-1$  except when they combine with oxygen (O) or Fluorine (F).
6. Oxidation numbers for the transition metals, the group B atoms, in compounds are equal to their ionic charges.

## **Oxidation-Reduction in Papermaking**

### **How can an oxidation number be used to identify an oxidizing agent or a reducing agent?**

- An oxidizing agent gains electrons. Since electrons have a negative charge, the oxidation number of an oxidizing agent becomes more negative as the reaction takes place.
- A reducing agent loses electrons. This causes the ratio of protons (positively charged) to electrons to increase, resulting in a more positive oxidation number.

The active ingredient in bleach is NaClO (sodium hypochlorite). In water, the NaClO ionizes into  $\text{Na}^+$  and  $\text{ClO}^-$ . The  $\text{ClO}^-$  ion is the oxidizing agent. In a basic solution, this ion removes color by oxidizing pigments and, in so doing, changes to the  $\text{Cl}^-$  ion. The oxidation number of the chlorine atom changes from +1 in the  $\text{ClO}^-$  ion to -1 in the  $\text{Cl}^-$  ion. For the  $\text{ClO}^-$  ion to oxidize pigments, it must gain electrons (negative charge) from atoms in the pigment molecule. Therefore, when an oxidizing agent oxidizes another species, such as an element, compound, or ion, and gains electrons, its oxidation number must decrease. The substance in an oxidation-reduction reaction that shows a decrease in its oxidation number is the oxidizing agent.

Oxidizing agents are good bleaches.  $\text{ClO}_2$ , a reddish-yellow gas, is also used to bleach paper pulp. However,  $\text{ClO}_2$  is such a strong oxidizing agent that it is explosive in high concentrations; therefore, it is only used in low concentrations.

### **What is a basic solution?**

- According to the Arrhenius theory of acids and bases, a basic solution has more hydroxide ions than hydrogen ions.
- The solution will be slippery, taste bitter, and turn red litmus blue and can neutralize acids to form a salt and water.

In Activity 3.4, paper is made in a basic solution. For paper in which wood fibers are used, NaOH (sodium hydroxide) can make the pulp mixture basic by providing an excess of  $\text{OH}^-$  ions. The NaOH breaks down cellulose fibers in the wood and other plant materials that form the primary paper structure. A suspension of these fibers can be placed on fabric on an embroidery hoop. Also,  $\text{ClO}^-$  ions can act as oxidizing agents in the basic solution. Finally,  $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$  (potassium aluminum sulfate: Alum) is added to the cellulose fibers to coagulate the pulp (clay is added when it is not naturally present). The aluminum ion ( $\text{Al}^{3+}$ ) helps the clay loosely bond to the cellulose fibers so that the resulting paper is dense and smooth.

## **Film Resources for Papermaking**

Lever, Vicki. *Practical Papermaking*. 60 min. Colfax, CA: Victorian Video Productions, 1990.

*Western Papermaking I*. 30 min. Iowa City: University of Iowa Press, 1994.

## COLLAGE

### What is a collage?

- When a variety of found objects such as buttons, cloth, and leather, which supply actual textures, are combined with painted or drawn textural effects on a two-dimensional ground, a collage is created.
- A collage may or may not take the form of a representational image.
- Some collage artists choose not to use a prepared flat ground as a surface for arranging objects. Instead, they arrange their objects in boxes. This type of collage is labeled an assemblage. In 1924 Max Ernst (1891–1976) painted and constructed with wood a collage entitled *Two Children Are Threatened by a Nightingale*.

Collage involves combining various media in one picture. In a collage, both two- and three-dimensional materials may be combined in the picture. Materials such as paint, newspaper, pieces of cloth, magazine pictures, and thread might be used. Written words might also be added. It would be helpful to examine collage works by the following artists:

Pablo Picasso (1881–1973)  
 Juan Gris (1887–1927)  
 Georges Braque (1881–1963)

Jean Arp (1888–1966)  
 Kurt Schwitters (1887–1948)

### ACTIVITY

## 3.5

### Handmade Paper and Collage

#### Objectives

1. Students will make a collage using paint and handmade paper.
2. Students will apply the principles of good composition and the creative process to an original work of art.

#### Level One: Collage I

#### Materials

Handmade paper; tempera paint (poster paint); oil or egg tempera paint prepared in Activity 2.5; paintbrushes; mixing trays; water containers; water; construction paper, newspaper, magazine pages, and other available paper; bits of cloth, thread, and other materials; scissors; glue; 12-x-18-in. collage ground, such as cardboard.

#### Time

50 minutes

**Procedure**

1. Use paint prepared in Activity 2.5, as well as tempera paints, to paint an image on a piece of handmade paper. The shape or contour of the handmade paper may suggest an animal or object. Try to create an interesting unit of painted paper.
2. Glue the painted paper in some position on the collage ground. The painted paper should be the center of interest in the collage, though it need not be at the center of the collage.
3. Choose a theme suggested by the painting.
4. Arrange and glue other pieces on the collage ground to complement the painting and reinforce the theme of the collage.
5. If desired, paint some areas in the collage.

**Level Two: Collage II****Materials**

Handmade paper; paint prepared in Activity 2.5; narrow-width soft paintbrushes; various watercolor papers; drawing paper, paper towels, brown paper bags, tissue paper, tracing paper, notebook paper, and other available papers torn or cut into various sizes and shapes; 12-x-18-in. collage ground, such as cardboard or illustration board.

**Time**

100 minutes

**Procedure**

1. Create a collage made of various sizes and types of unpainted paper glued to a collage ground. The pieces of paper should overlap and cover all or most of the ground, and all corners should be secured so that the paper is as flat as possible. Include your handmade paper in the collage.
  2. Select one of the following themes for your collage:
    - Down Under—elements, compounds, and minerals found inside the earth
    - Above and Beyond—hydrogen and helium: atoms of our universe
    - Inside Out—chemical change: from inside matter, out comes energy
    - Here and There—atoms, atoms everywhere
    - Upside Down—relative terms
  3. Paint a picture, based on your theme, using the collage of various papers as a ground. It is not necessary to paint all areas of the collage. The picture can be realistic, a fantasy, or nonobjective, and paint prepared in Activity 2.5 should be used in at least one area of the picture.
-

### **Challenge Activity**

Make a periodic table collage. Include 112 elements. Keep metals, metalloids, nonmetals, and noble gases in separate groups. Metals can be divided into subgroups: alkali metals, alkaline-earth metals, transition metals, and other metals such as indium and gallium. Use materials representative of these groups. Metals can be represented by shiny materials. Nonmetals can be brittle, textured, dull materials. Label your materials with element symbols. Make an attractive collage.

## **THE FUTURE OF PAINTING SUPPORTS AND GROUNDS**

**Can an artist create a two-dimensional work of art without a support and ground? Explain.**

- Computer-generated artworks are stored electronically and available via digital recall. They can forever be works in progress. They may never be reduced to a support and ground. They exist at the whim of the artist.

In this chapter we have examined painting supports and grounds for two-dimensional works of art. Just as humanity is anchored to the earth by the force of gravity, a two-dimensional work of art is affixed to a support and ground by the artist. However, humanity constantly seeks to defy gravity by creating a means for escaping its pull. Will future artists find a means to create two-dimensional works of art without the need for painting supports and grounds? In this era of digital imaging, nothing is impossible.

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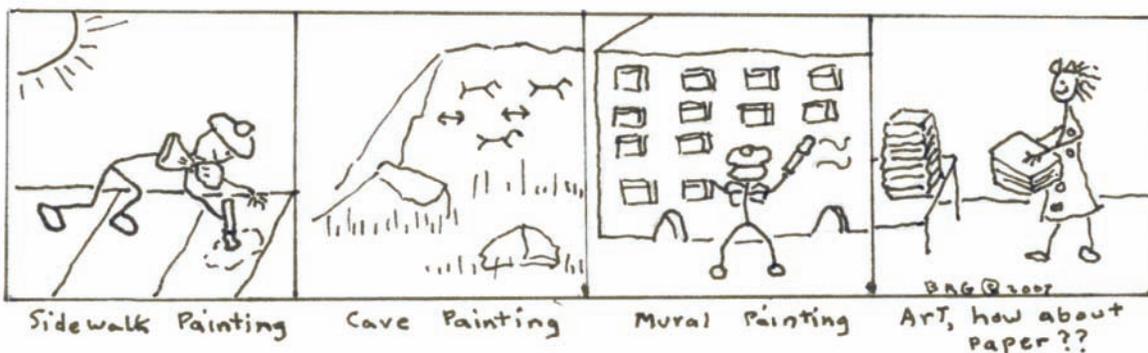
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## ANSWERS TO ACTIVITY AND DEMONSTRATION QUESTIONS AND CONCLUSION

### Activity 3.1 The Preparation of Grounds: Preparing Whiting Compounds

#### Level One

1. Calcium oxide and water yield calcium hydroxide; a composition reaction. Calcium chloride and sodium carbonate yield calcium carbonate and sodium chloride; a double displacement reaction.
2. The whiting compound with the smoothest texture. The surface should resemble paper.
3. The whiting compounds are basic. Calcium hydroxide ionizes in water, producing an excess of hydroxide ions that indicates the presence of a base. Calcium carbonate ionizes slightly in water, producing carbonate ions that combine with hydrogen ions, leaving an excess of hydroxide ions. (In water, the number of hydroxide ions equals the number of hydrogen ions until this balance is disrupted.)

#### Level Two

1.  $\text{CaO}_{(s)} + \text{H}_2\text{O}_{(l)} \rightarrow \text{Ca}(\text{OH})_{2(s)}$ ;  $\text{Na}_2\text{CO}_{3(aq)} + \text{CaCl}_{2(aq)} \rightarrow 2 \text{NaCl}_{(aq)} + \text{CaCO}_{3(s)}$ .
2. Regarding the physical properties of acids, they taste sour and leave a burning sensation on one's skin. Chemically, they are corrosive and lose their physical properties when in contact with basic solutions. In solution, they produce an excess of hydrogen or hydronium ions. Regarding physical properties of bases, they taste bitter and feel slippery. Chemically, they react with acids to form salts and water. In solution, they produce an excess of hydroxide ion. The whiting compounds produce excess hydroxide ions in solution.
3. A system is needed to organize chemical changes after they are identified. If one knows the class for a chemical change, the outcome or products produced can be predicted. Most but not all chemical changes fit into one of the four classes.
4. A whiting compound is an insoluble, very white substance that provides a smooth, solid coating needed in a gesso ground.

### Activity 3.2 The Preparation of Grounds: Using Whiting Compounds to Prepare Gesso Solutions

#### Level One

1. Both grounds should have approximately the same degree of whiteness and should have the same texture, that of a fine powder.

**Level Two**

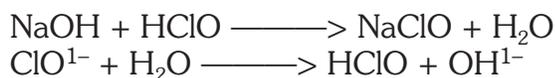
1. Gesso grounds, gesso layered on wood panels, were commonly used for paintings in Gothic and Renaissance periods, from about A.D. 1200 to 1500. In 1235 Bonaventura Berlinghieri painted *St. Francis Altarpiece*; in 1280 Cimabue painted *Madonna Enthroned*; in 1309 Duccio painted *Christ Entering Jerusalem*; in 1310 Giotto painted also painted a *Madonna Enthroned*; and in 1452 Leonardo da Vinci painted *Ginevra de'Benci*. The most unique gesso ground paintings were made in the 20th century when modern artists, Andrew Wyeth, Thomas Hart Benton and Paul Cadmus revived Renaissance and medieval techniques and painted a series of gesso ground works of art. An example is Andrew Wyeth's painting *Braids*, which was revealed to the public in 1986.
2. The rabbit-skin glue or the cottage cheese provide adhesives to bind the whiting compounds into a thick, creamy solution that can be applied to a masonite board and built up layer by layer to form a solid ground. Calcium sulfate and calcium hydroxide dehydrate as the gesso dries and solidify to form a cement ground. They also provide a white solution that is made more brilliant with the addition of titanium dioxide.

**Demonstration 3.1 Comparing Results of Paint Applied to Various Watercolor Papers**

1. A cold-pressed paper is useful when a painting requires texture. Hot-pressed watercolor paper provides a smooth painting surface.
2. A 300-pound watercolor paper can be scrubbed to remove unwanted paint. The painting surface remains relatively unchanged. Also, 300-pound watercolor paper can absorb large quantities of water and remain unwrinkled. It is not necessary to soak and stretch this paper. During the painting process, it remains smooth and receptive to varying amounts of liquid.

**Activity 3.4 Papermaking****Level One**

1. The paper pulp should be basic. Sodium hypochlorite (NaClO) is a salt prepared from a strong base (NaOH) and a weak acid (HClO). Salts of strong bases and weak acids are basic. The solution is basic because the hypochlorous ion ( $\text{ClO}^{1-}$ ) bonds with hydrogen ions ( $\text{H}^{+}$ ) from water leaving an excess of hydroxide ions ( $\text{OH}^{1-}$ ). The following equations describe the salt formation and the hydroxide ion formation:



2. Bleach ( $\text{NaClO}$ ) is an oxidizing agent. It removes oxygen from colored molecules so they become colorless. The bleach whitens the paper. Starch is a polysaccharid produced by joining glucose monomers in a process called *dehydration synthesis*. This long chain molecule acts to bind the papermaking ingredients after they are suspended in solution and then pressed and dried.

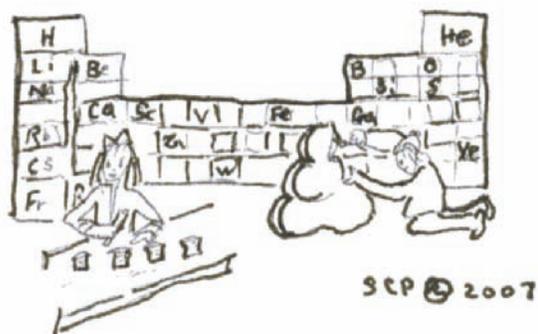
### **Level Two**

2. Many papers contain aluminum salts such as aluminum sulfate and aluminum nitrate. These are salts derived from a weak base, aluminum hydroxide, and strong acids, sulfuric acid and nitric acid, respectively. This combination produces acidic salts. The paper becomes acidic when the aluminum salts react with water in the air to form acids. Most paper contains these salts because aluminum salts prevent ink from soaking into paper. Paper made with calcium carbonate, a fairly neutral salt since it is derived from a weak acid (carbonic acid) and a weak base (calcium hydroxide), will not readily react with water in air. They are acid-free. Acid-free papers do not easily discolor and disintegrate.
3. 10 g of  $\text{NaOH}$  added to 90 g  $\text{H}_2\text{O}$ .
4. Ten grams divided by 40.0 g per mole equals 0.25 mole  $\text{NaOH}$  divided by 0.10 liter of solution equals a 2.5M solution. of  $\text{NaOH}$ .
5. An oxidizing agent gains electrons, or becomes more electronegative, in a chemical reaction. The chlorine in the  $\text{ClO}^{1-}$  ion in bleach has an oxidation number of +1. (Oxygen in  $\text{ClO}^{1-}$  has an oxidation number of -2, so the chlorine must have an oxidation number of +1.) The oxidation number of a monatomic ion is equal to its charge, so the oxidation number of  $\text{Cl}$  is -1. When the  $\text{ClO}^{1-}$  chlorine ion converts to  $\text{Cl}^{1-}$ , two electrons are gained. Oxidizing agents react readily with metals and most nonmetals. In these reactions, they convert colored molecules to colorless molecules.



# Three-Dimensional Works of Art

## *Playing with Clay*



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: String theory describes a universe with 10 dimensions. How might a molecule be modeled in such a universe?**

### INTRODUCTION

If we examine the past or the present, or look into the future, somewhere we will observe someone playing with clay. Playing with clay is very satisfying. Clay is plastic and pliable. It is cooperative. It responds to pushing, pulling, pounding, and pinching. It's no wonder that playing with clay has survived throughout the history of humanity.

Clay has many moods, and many small children are especially intrigued with the feel and easy versatility of clay. They like to squeeze, roll, punch, flatten, and shape it. They can impress it with designs, scratch it, hollow it out, and cut it. In liquid form, it can be poured into a mold. Many children make their first three-dimensional work of art while they are playing with clay. Often they use clay three-dimensional works of art to express emotions that they cannot express in words.

### A BRIEF HISTORY OF CLAY, POTTERY, AND CERAMICS

#### What is clay?

- Clay is basically a powdery form of rock that has been broken into fine particles through the forces of wind, water, and glacial action over millions of years.
- The formula for clay might be  $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ .
- Primary clay, known as *kaolin*, is found in the same place as the parent rock. Kaolin is formed by the weathering of feldspar. Kaolins are coarse in particle size and therefore nonplastic compared to most sedimentary clays. Kaolins are relatively free of mineral impurities such as iron.

- Secondary clay has been transported from the site of the parent rock. As a result, this clay has fine particles and might be contaminated with iron, quartz, mica, and carbonate compounds. Ball clays are secondary clays. They are higher in iron content, more fusible, finer in particle size, and more plastic than kaolin clays.
- Terra cotta is another kind of clay; it has an open, coarse grain structure that permits rapid and even drying. Terra cotta is used to construct large clay pieces.

### **How did clay molding techniques evolve from 10,000 B.C. to modern times?**

- In ancient times, clay was used for food and water container construction. Civilizations in the Middle East understood the techniques of ceramics as early as 5,000 B.C. The first ceramic vessels were made by pinching. In addition to containers, small figurines were molded. The pinching method did not allow large item construction. Slab construction, rolling clay into a sheet so the clay could be cut in pieces, opened the door for crafting a wide variety of objects.
- Some of the largest, most spectacular terra cotta figures ever found are the more than 6,000 life-sized terra cotta warriors, carriages, and horses found in 1974 buried in Xian, China. The question is often asked, Why did Qin Shi Huang, the emperor who founded the Qin dynasty in 221 B.C., use so many large terra cotta figures as funerary objects? During prior dynasties, slaves were buried alive with the slave owners and aristocrats when they died. This practice aroused the indignation of the people of Qin. Duke Xian banned this practice when he ascended the throne of the State of Qin in 384 B.C. Thus the terra cotta figures were created. They are all different, probably representing local citizens. It took more than 30 years to create the figures for Duke Xian's funeral. The figure heads were formed using the additive method, and the body construction appears to have employed slab methods.
- Between the third and sixth centuries A.D., small terra cotta animals such as horses were placed around Japanese burial mounds. Clay molding techniques spread to Europe from China, and beautiful ceramic pieces were created.
- In 1919 in the United States a now famous Pueblo potter, Maria Martinez, developed large, finely shaped black-on-black pots from red clay by firing the pots in a smothered, dung-fueled bonfire.

Clay is an old material used by many ancient peoples. Around 10,000 B.C., Neolithic peoples used clay to make shaped vessels for holding food and water. Centuries later, as early as the predynastic period of 4000–3500 B.C., the Egyptians used clay to make vessels with linear and geometric designs, as well as animals and human figures.<sup>1</sup> Some of the oldest manuscripts, the Dead Sea Scrolls, written more than 2,000 years ago, were found preserved in clay jars. Clay has been a key factor in the preservation of our past.

As early as 1100 B.C., the Greeks were producing pots decorated with geometric designs. Later the pot decorations changed to plants and animals, and in the sixth century B.C. warriors and processional figures adorned some of the finest examples of clay and ceramic pieces ever to be made.

The clay work of China can be traced to prehistoric times. In the thirteenth century, Marco Polo probably brought the first Chinese clay or ceramic pieces to Europe from the East.<sup>2</sup> These pieces were made of a special clay heated to a high temperature to produce a

strong, durable ceramic that we refer to by the name of its place of origin, China. Around 1300 the art of ceramics took on a new life during the Renaissance in Italy in the form of majolica, a style using bright colors and designs learned by the Italians from the Arabs. European ceramic work of Italy, Holland, and Spain, as well as many other parts of Europe, continued to develop in the centuries following, reflecting the individual characteristics of each area. In Italy during the fifteenth and sixteenth centuries beautiful terra cotta pieces were made by the Della Robbia family. Throughout the eighteenth century many technical advances were made in the field of ceramics, leading to a great variety of forms and finishing techniques. Names such as Delft, Meissen, and Wedgwood, to mention only a few, are still famous today in the field of ceramics.

Mention must also be made of the clay work of the Native Americans of North and South America. Made primarily for everyday use, their pieces have a beauty of form and decoration unique to their cultures.

### **Examples of Pottery Types**

It would be helpful to observe examples of the types of works discussed above. Following is a chronological list of significant examples, pictures of which can be found in pottery and art books.

Neolithic pottery	Dutch Delft, seventeenth century
Egyptian pottery	English Wedgwood, eighteenth century
Egyptian hieroglyphic tablet	German Meissen, eighteenth century
Greek black-face or red-face vase, fifth century B.C.	Mayan Native American pottery
Chinese vase, Sung dynasty	Pueblo Native American pottery
Della Robbia Italian ceramic work, sixteenth century	

## **THE THIRD DIMENSION: ADDITIVE AND SUBTRACTIVE CONSTRUCTION METHODS**

When we look at a painting or read a book, the surface we are looking at is flat. If we look out the window or view a sculpture or a piece of pottery, we are looking at something in three dimensions (or 3-D). Three-dimensional artwork might be solid and massive, or it might be linear, or it might be a combination of both massive and linear parts.

### **Define additive and subtractive clay construction methods**

- In the additive clay construction method, clay is added piece by piece to form an object.
- In the subtractive method, clay is removed from a clay piece to form an object.
- Large, hollow objects can be formed using the coiling method. Here clay is rolled into ropelike strands that are coiled one upon another and joined together.

To create a work of art in three dimensions, the artist has a choice of materials and construction methods. Three-dimensional pieces can be constructed by adding material to create a form, or by removing material to reveal a form. These two methods represent the

additive and subtractive methods of construction. A material such as clay is appropriate for the additive method; pieces of clay can be pressed onto an existing form. (See Figure 4.1.) The form can be built up by adding piece after piece of clay. Clay can be very easily added and pushed into shape, making it an ideal medium for the beginning three-dimensional artist.

The subtractive method involves removing portions of the material. (See Figure 4.2.) A sculptor working in stone, for instance, chisels away areas of marble or granite to create the three-dimensional image. A wood carver removes areas of the material to reveal a shape. Generally, in the subtractive method, once pieces of the material are removed, they cannot be replaced (clay is an exception).

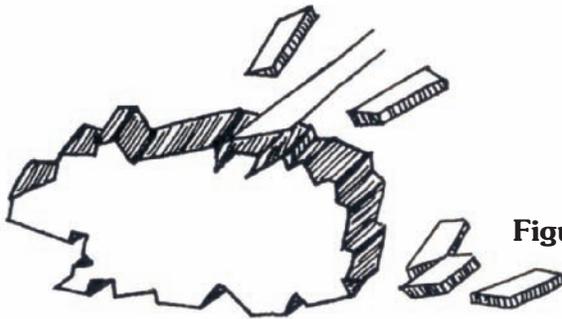
**Explain casting as a clay construction method.**

- In the casting method, when clay is poured into a mold it is necessary to avoid trapping air bubbles.
- When the clay piece is removed from the mold, separation and removal from the mold requires careful manipulation of the clay piece.



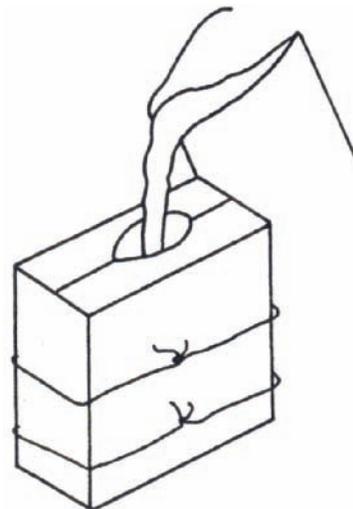
**Figure 4.1. Example of the Additive Method.**

A third construction method involves creating a form in three dimensions by casting. *Casting* is a technique that requires a mold, into which a material such as plastic, metal, or clay in liquid form is poured or injected. (See Figure 4.3.)



**Figure 4.2. Example of the Subtractive Method.**

Of all the materials used for three-dimensional construction, clay can be used in the greatest variety of ways, making it the most versatile of materials. We can push, pull, bend, and twist it. It never complains. Why is clay so versatile? What is this thing called clay?



**Figure 4.3. Example of the Casting Method.**

**Essential Question: If clay can be pushed, pulled, bent, and twisted, how are atoms and molecules arranged within a clay sample?**

## CLAY

### Natural Clay

#### How is natural clay formed?

- Clay is a product of the geological weathering of the surface of the earth. When the earth was formed, the earth's crust was probably a uniform crust of igneous rock. About two billion years ago, the forces of geological change began to act on the recently cooled, igneous rocks.
- Water in the atmosphere began to condense and torrential rains started, probably lasting for millions of years. Even though rock appears to be insoluble, over millions of years rock is broken down into tiny particles and washed away. Soluble chemicals in the rock are dissolved. Mineral particles carried in water are abrasive and break down rocks into smaller and smaller particles.
- In addition, plant roots invade rock cracks and speed up rock breakdown into small particles. After mountains form by the upward thrust of rock, erosion tears them down, and the resulting silt is deposited in stratified layers. This process repeats, leaving clay deposits.

#### What is its composition?

- North Carolina kaolin has the following chemical composition: silicon dioxide,  $\text{SiO}_2$ , 46.18%; aluminum oxide,  $\text{Al}_2\text{O}_3$ , 38.38%; water,  $\text{H}_2\text{O}$ , 13.28%; sodium oxide,  $\text{Na}_2\text{O}$ , 1.22%; iron oxide,  $\text{Fe}_2\text{O}_3$ , .57%; and magnesium oxide,  $\text{MgO}$ , .42%.

There are many types of clay. *Natural clay* is earth or soil generally found beneath topsoil. Found almost everywhere, natural clay is formed when rocks—mostly feldspar, which is a mixture of potassium oxide ( $\text{K}_2\text{O}$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), and silicon dioxide ( $\text{K}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{H}_2\text{O}$ )—breaks down under the action of weather and through chemical reactions. Variations in this empirical formula, and the addition of other substances such as  $\text{Na}_2\text{O}$  (sodium oxide), change the clay's color and texture. Natural clay becomes plastic and cohesive when moist because it consists of platelets made of silicon (Si), oxygen (O), hydrogen (H), and aluminum (Al) atoms, bonded into an arrangement having the empirical formula  $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ , which slide over one another when water is present. Natural clay becomes hard when exposed to heat, either from the sun or when baked or fired in a kiln. Ordinary baked clay pottery has a rough, porous surface. To make it more attractive, waterproof, and useful, it is given a smooth, shiny surface by a process called *glazing*.

### **Challenge Activity**

Make your own clay. Find an area in your community where the soil is tightly packed and resembles clay. Dig out a ball of this soil. Add just enough water to make the soil plastic. Sculpt your “clay” into a molecular shape. It might be a bent water molecule or a tetrahedral-shaped methane molecule. Let your molecular model dry in sunlight. Paint your molecular model sculpture.

### **Plasticene, Low Fire, and Self-Hardening Clays**

#### **What are some uses for plasticene clay?**

- Plasticene clay is useful in the classroom.
- Art students use it to learn clay construction methods and make and remake clay objects.
- Small children use plasticene clay to make objects that do not harden and crack. They can work on one object for several days.

Plasticene clay includes synthetic polymers (see Chapter 5) so that it does not harden. It can be modeled repeatedly, and it has many of the qualities of elasticity that natural clay has, but it cannot be fired and glazed to make it permanent.

Low-fire clay is available in a variety of colors and can be used successfully for making small decorative items. It will harden when baked in a regular kitchen oven at a low temperature, but it cannot be glazed. Various brands of self-hardening clay are available. It will harden in air, drying with a permanent finish, and it is available in a variety of colors suitable for small decorative objects such as beads and jewelry.

### ***Keramikos, Keramos, Ceramics***

#### **What Is It?**

*Ceramics* is the art of molding and firing or heating clay to a high temperature, resulting in hard, permanent objects. The Greeks, who played an important role in the development of ceramics, called their works *keramos*, from *Keramikos*, a section of Athens, Greece, where most of the ceramic artists worked and sold their art. Our word *ceramics* comes from this Greek word.<sup>3</sup> Today, the word *ceramics* indicates something much broader than just the art of pottery. It includes the making of such products as bricks, kitchen sinks, bathtubs, floor tiles, and walls. Ceramics are used in many industries to make components that resist high temperatures. Ceramics are a part of our everyday lives.

### **The Life Cycle of a Natural-Clay Ceramic Piece**

#### **The Baby Is Born**

##### **How and why is clay wedged?**

- Clay is kneaded or wedged to remove any pockets of air and to disperse lumps to make it smooth and homogeneous.

- In addition, a machine much like a meat grinder can force clay through a chamber to remove air pockets. To make this more effective, the clay extrusion can occur in a vacuum. This produces a smooth, dense clay impossible to produce by hand.

A ceramic piece, like a human being, has a life cycle that begins at birth and ends at death. At birth, a ball of wet, natural clay emerges as the new baby. The new baby must be properly prepared for the harsh world it has entered. First, the ball of wet natural clay must be wedged to remove any air trapped inside. In other words, the baby is burped. This is necessary because a clay piece containing pockets of air will explode or shatter when heated in an oven or kiln. To wedge clay, it is slammed or thrown onto a hard, nonporous surface until it is free of air pockets. The baby is spanked, and what a spanking it is! If the clay is too soft, it is wedged on a plaster slab, which absorbs excess water from the clay. To check for air pockets, the lump of clay is cut into two pieces with a wire (harsh treatment for this baby clay, but necessary). If free of air pockets, the clay is ready to be formed into a ceramic piece.

### **Childhood, the Teenage Years, Adulthood, and Death**

#### **What is leather-hard clay?**

- Leather-hard clay is formed when a natural clay piece is allowed to slowly dry to a partially dry state.

A natural-clay baby can be formed into a multitude of desired shapes, unlike a human baby. After a desired shape is achieved, the clay piece is allowed to dry. As it dries, it becomes lighter and shrinks about 10% as water evaporates. The baby gets smaller as it grows older. This process of evaporation may take several days.

When the piece is partly dry, it is known as *leather-hard clay*. At this point, it is stiff and will hold its shape, but it can still be smoothed to remove imperfections, and it can be scratched to add designs. It is a teenager experiencing the pains of growing up, which can be minimized with love and affection, and wearing the designs of its teen culture. When the piece is completely dry, it is known as greenware. It is a green teen. At this point, its shape can no longer be changed, but if it is placed in water, it will dissolve into its original state. A few tears will dissolve a teenager into a babylike state.

#### **What is greenware?**

- *Greenware* is clay that is completely dry.

#### **What is bisque ware?**

- *Bisque ware* is clay that is heated in a kiln to a high temperature at which it becomes totally dry, hard, and permanent.

#### **What is a glaze, and why is it applied to a clay piece?**

- A *glaze* is glass with a specialized composition that allows it to stick to the surface of a clay piece.
- Glazes are applied to clay objects to decorate them and make them attractive.
- In addition, glazes seal clay vessels so they can hold liquids without seepage.

When greenware is placed in an oven or kiln and heated to a high temperature, it becomes hard and permanent. It is now a young adult. At this stage, it is known as bisque ware. If placed in water after firing, it will absorb water but will not lose its shape. A permanent change has taken place with heating to make the piece permanent. A liquid sealer or glaze is applied to the surface and the piece is fired once more.

This final firing results in the stage known as glazed ware. The clay piece is an adult. It can live for hundreds of years with proper care. Death occurs only when someone is careless and mishandles the clay piece. Being dropped is a common cause of death.

## THE GLAZE MAZE

In glazing, a thin layer of a liquid mixture called a glaze is applied to a clay object. Glazes can be applied with a paintbrush, sprayed on, or the object can be dipped into the glaze. The glaze should be applied after the object has been baked in a kiln one time.

### What are the rules of glazing?

- In addition to the rules below, glazed pieces should be placed in a kiln without touching each other.
- In order to coat an object evenly, a glaze may be applied by painting, dipping, or pouring.
- When painting a glaze, the potter should use a soft brush and short strokes, applying at least three coats.
- When a clay piece is dipped, it should be rapidly immersed, shaken vigorously while under the glaze surface, and then drawn out and shaken again to remove excess glaze.
- Glaze can be poured on a piece while the piece is rapidly turned.

When glazing, it is necessary to observe the following rules:

1. The bottom of a piece should not be coated with glaze. Coated bottoms, when heated, will melt and stick to the shelf of the kiln. (Kiln firing is discussed later in this chapter.)
2. More than one coat of glaze must be applied, usually two or three.
3. When applying the glaze, coat the object evenly to avoid thick and thin spots in the glaze finish.

Glazes are usually tested on small samples of bisque-fired clay called *test tiles* or *clay slabs* (see Activity 4.3, p. 173). It is advisable to test glaze colors first to determine if they are suitable before using them on ceramic pieces.

### Name some glaze ingredients.

- Metal oxides such as zinc oxide, strontium oxide, calcium oxide, magnesium oxide, and barium oxide act as fluxes in glazes and add color to the finished product.
- Silicon dioxide increase the fusion point of a glaze.
- Diboron trioxide can be used to prepare low temperature glazes because its melting point is about 600°F.

Glazes are made of a variety of ingredients. Each glaze ingredient has a role in producing an attractive, waterproof, and useful product. Some ingredients determine the glaze color; others produce particular textures. A glaze finish may appear shiny or dull. A dull finish is called a *matte* finish. A shiny finish is called a *glass* finish. A glaze must contain ingredients that integrate the glaze into the object's surface, so that the glaze and clay become a single substance. (We will be examining the chemical makeup of glazes to understand how they work.) Glazes have preserved works of clay for centuries. They allow us to admire an object made 2,000 years ago, as well as recently created works of art.

### Challenge Activity

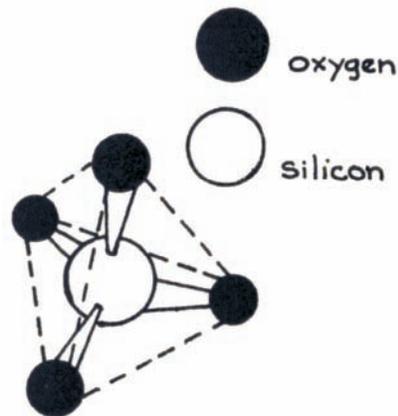
In *Bartholomew and the Oobleck*, Dr. Seuss has Oobleck fall from the sky and create havoc within a kingdom. Make Oobleck by combining 1½ cups starch with 1 cup water and a few drops of green food coloring. Is Oobleck a solid or a liquid? Imagine that our planet was covered by Oobleck. Design a city that can exist on an Oobleck foundation. Your design should include buildings, cars, bridges and airplanes. Make models of these objects. See if the models can stay on Oobleck without sinking. This can be a class project.

## GLAZE OR GLASS: WHAT IS IT?

### What is a glass?

- A glass is a noncrystalline substance that is transparent or translucent. It is an elastic solid.

A glaze is a glass, which is a solid that sometimes behaves as a liquid at a temperature when it should normally be solid. It cannot make up its mind! A glass has this identity problem because of its molecular structure. Glass ionic structure (see Figure 4.4) is based mainly on tetrahedral-shaped silicate ions ( $\text{SiO}_4^{4-}$ ). These negative ions, or anions, are connected to one another not in an orderly fashion as in a crystalline solid but with a large degree of disorder. Glass usually appears to be a solid. It has a definite shape and volume. However, on occasion, when a glass sheet remains in one place over a long period of time, glass will flow. Evidence of this is the appearance of old glass windows that have become uneven, having waves with thick and thin portions. The glass in the window has slowly flowed like a viscous liquid to make the window uneven. Glass has a constant identity problem: It appears to be a solid, but it has an atomic structure different than that of a typical solid.

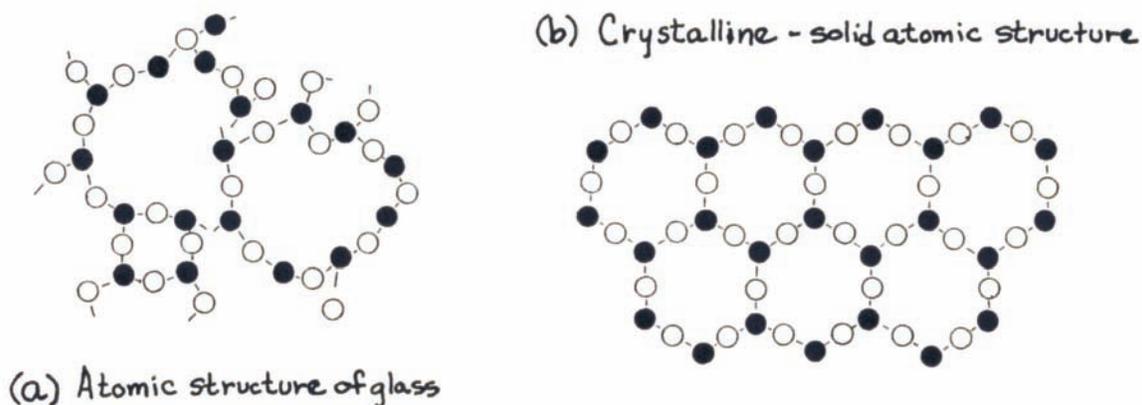


**Figure 4.4. A Silicate Anion.**

**Distinguish between crystalline solids and glass.**

- When crystalline substances are melted or liquefied and then cooled, the particles tend to form into a regular lattice that repeats every time the substance is cooled.
- A melted glass when cooled forms an elastic, transparent, or translucent substance lacking a regular lattice structure.
- Crystalline solids have sharp melting points. A glass has a range of temperatures over which it softens.

Note that a crystalline solid is not a glass. A crystalline solid is made of particles arranged in a very definite order (see Figure 4.5). In emeralds, silicate tetrahedral anions, negative ions, crystallize in a hexagonal pattern, while in asbestos, the crystalline structure consists of an extended chain of double tetrahedral silicate anions. A crystalline solid has a regular shape. The particles in a glass, however, are in disarray (see Figure 4.5). A glass is an *amorphous solid*. A glass has an irregular shape.



**Figure 4.5. Atomic Structure of Glass vs. Crystalline-Solid Atomic Structure.**

## Crystalline Solids: Three-Dimensional Works of Art

### What is an allotropic form of an element?

- Allotropic forms of an element have different bonding patterns or arrangements. The different bonding arrangements result in allotropic forms having different chemical and physical properties.
- Rhombic sulfur is yellow and quite stable. Monoclinic sulfur is orange and less stable than rhombic sulfur. “Plastic” sulfur is almost black and slowly reverts to rhombic sulfur.
- As allotropic forms of carbon, graphite is gray and slippery, while diamond is clear, hard, and an excellent conductor of heat.

### Explain the differences among atomic, ionic, and molecular crystalline solids.

- In atomic crystalline solids, atoms are covalently bonded to each other. In covalent bonding, electrons are shared equally by the bonding atoms.
- In some cases, such as in diamond, atoms bond in covalent network bonds.

- In ionic solids, positive and negative ions bond through electrostatic attractions.
- In molecular solids, atoms or molecules bond using hydrogen bonds or dipole-dipole dispersion forces. This bond occurs when temporary dipoles are induced in adjacent atoms.
- In addition, metals bond using metallic bonds to form metallic crystalline solids.

At one time or another, many children will attempt to make sugar candy, crystals of sugar, or sucrose ( $C_{12}H_{22}O_{11}$ ), that form on a string placed in a saturated sucrose solution. This saturated solution becomes supersaturated when some of the water evaporates. In nature, crystals are formed in a similar manner. A rock surface may harden, leaving mineral-filled liquid inside the rock. Slowly, water evaporates from the rock interior and crystals form. Anyone who has cracked open a geode has observed such crystals.

There are three main types of crystalline solids: atomic, ionic, and molecular. Phosphorus (P), sulfur (S), and carbon (C) form atomic crystalline solids. All three of these elements exist in allotropic forms: different forms of the same element at the same temperature and physical state. Phosphorus has two allotropic forms, red and white. Red phosphorus has  $P_4$  units bonded in a chain, and white phosphorus is made of tetrahedral-shaped  $P_4$  molecules. The bond angles in a tetrahedral-shaped molecule are 109.5 degrees. Sulfur has three allotropic forms. Rhombic sulfur, the most stable form, has eight sulfur atoms ( $S_8$ ) bonded in a puckered ring. In the puckered ring, the bonding angles are 105 degrees. Monoclinic sulfur has eight sulfur atom rings packed to form a monoclinic crystal, and “plastic” sulfur has sulfur atom chains tangled together so that the atomic structure more closely resembles a glass than a crystal. Carbon has two allotropic forms, graphite and diamond. In graphite, six atoms are bonded to form a planar hexagon, which bonds to other planar hexagons. In diamond, four carbon atoms bond to form a tetrahedral, which is bonded to other tetrahedrals, making a strong, three-dimensional network of atoms.

Sodium chloride (NaCl) is an ionic crystalline solid. In sodium chloride, there is an extended regular array of sodium ions ( $Na^+$ ) and chlorine ions ( $Cl^-$ ); each ion is surrounded by six ions of the opposite charge to form a cubic crystal.

Ice ( $H_2O$ ) is a molecular crystalline solid. Six water molecules bond to each other to form a hexagonal pattern. This pattern is reflected in the hexagonal geometry exhibited in snowflakes. In Activity 4.1, you will construct models of basic crystalline solids and “grow” molecular-solid crystals. Then you will consider the basic structures of crystalline solids and look upon these structures as three-dimensional works of art.

### Challenge Activity

Select an element, such as sulfur, carbon, or phosphorous, that appears in different allotropic forms. Using the atomic structure of these allotropic forms as described above, make a collage depicting the allotropic forms of your selected element. Disks can be used for atoms. Strings can be used for bonds. The different allotropic forms can be intertwined and connected to a collage base. Have students guess what element is represented by your collage. Students can work in groups on this project.

**ACTIVITY****4.1****Atomic, Ionic, and Molecular Crystalline Structures: Three-Dimensional Works of Art****Objectives**

1. Students will construct models of four basic crystalline structures, noting the different possibilities for crystalline-solid particle arrangement.
2. Students will compare and contrast the atomic, ionic, and molecular structures modeled with the atomic structure of a glass.
3. Students will describe crystalline-solid models as three-dimensional works of art and determine if they are solid works, linear works, or a combination of both.

**Materials**

Styrofoam balls (13 ½-in.-diameter balls and 54 2-in.-diameter balls per student or group); toothpicks; 230 g sucrose ( $C_{12}H_{22}O_{11}$ —enough for an entire class); NaCl (sodium chloride); hand magnifying lens; 250 ml beaker, 1 l flask; about 15 g  $KAl(SO_4) \cdot 12H_2O$  (potassium aluminum sulfate: alum); petri dishes; paper and pencil; distilled water; spatula.

**Time**

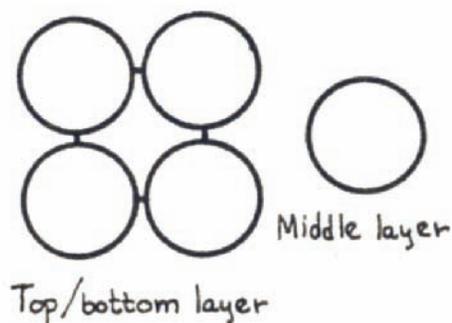
50 minutes, several days for evaporation, then 30 minutes

**Procedure: All Levels**

In the four models prepared below, the three layers (top, middle, and bottom) should not be secured to each other.

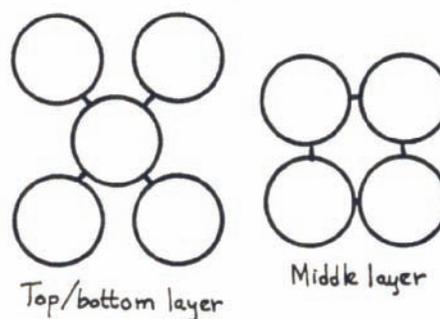
A. Prepare models of four basic crystalline solids using Styrofoam balls:

1. The alkali metals barium (Ba) and uranium (U) are atomic crystalline solids. Their atoms pack in a body-centered cubic arrangement. Use nine 2-in.-diameter balls and eight toothpicks to form three layers of a body-centered cubic crystal, as illustrated in Figure 4.6 (the top layer is the same as the bottom layer). Put the layers together like a sandwich. Draw a picture of this atomic crystalline solid.

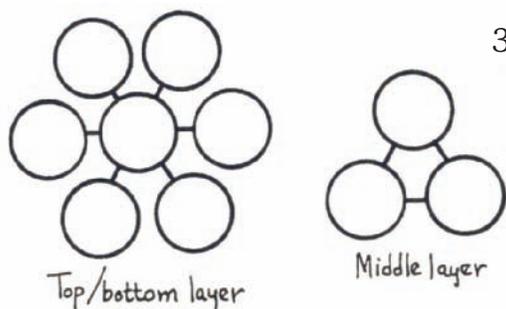


**Figure 4.6. Body-Centered Cubic Crystal.**

2. Copper (Cu), silver (Ag), and gold (Au) are also atomic crystalline solids. Their atoms pack in a face-centered cubic arrangement. Use 14 2-in.-diameter balls and 12 toothpicks to form three layers of a face-centered cubic crystal, as illustrated in Figure 4.7 (the top layer is the same as the bottom layer). Put the layers together like a sandwich. Draw a picture of this atomic crystalline solid.



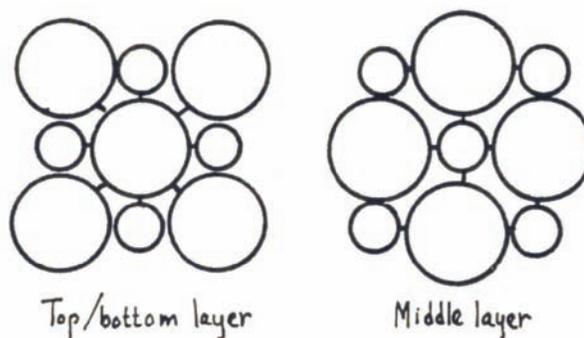
**Figure 4.7. Face-Centered Cubic Crystal.**



**Figure 4.8. Hexagonal-Closest Packing Crystal.**

3. Magnesium (Mg) and zinc (Zn) are atomic crystalline solids that pack in a hexagonal-closest packing arrangement. Use 17 2-in.-diameter balls and 15 toothpicks to form three layers of a hexagonal-closest packing crystal, as illustrated in Figure 4.8 (the top layer is the same as the bottom layer). Put the layers together like a sandwich. Draw a picture of this atomic crystalline solid.

4. Prepare a model of an ionic crystalline solid, such as sodium chloride (NaCl). Use 14 2-in.-diameter balls, 13 1/2-in.-diameter balls, and 28 toothpicks to form three layers of an ionic crystal, as illustrated in Figure 4.9 (the top layer is the same as the bottom layer). Put the layers together like a sandwich. Draw a picture of this ionic crystalline solid.



**Figure 4.9. Ionic Crystal.**

- B. Prepare a molecular crystalline solid (choose one preparation, either potassium aluminum sulfate or sucrose):
1. Preparation of alum (potassium aluminum sulfate) crystals:
    - a. Pour 100 ml distilled water into a very clean 50 ml beaker.
    - b. Add  $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$  and stir. Using a spatula, keep adding about 2 g increments until no more will dissolve.
    - c. Let the beaker stand uncovered in a cool place where it will not be disturbed. Observe daily.
    - d. When the water has evaporated, observe the crystals with a hand magnifying lens.
    - e. Draw the crystals, showing their shape.
  2. Preparation of sucrose crystals:
    - a. Pour 100 ml distilled water into a very clean 1 l flask.
    - b. Add 230 g of sucrose and stir.
    - c. If necessary, heat until all sucrose is dissolved.
    - d. Pour solution into petri dishes.
    - e. Let petri dishes stand until water evaporates and crystals appear.
    - f. Observe a crystal with a hand magnifying lens.
    - g. Draw the crystal, showing its geometric shape.
- C. Use a hand magnifying lens to examine store bought crystals of the ionic solid  $\text{NaCl}$  with molecular solid  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$  or molecular solid  $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ , then draw these crystals, showing their shape.

## Questions and Conclusions

### Level One

1. This activity includes models of atomic, ionic, and molecular crystalline solids. List the names of the solids represented by each of these models. Make a generalization about the shape of the solid crystal and the type of solid.
2. Describe the crystalline-solid models prepared in this activity as three-dimensional works of art that are solid (massive), linear (made mostly of thin, line-like parts), or both, explaining why they are solid or linear works of art.
3. A glass is an amorphous solid. How would the atomic structure of a glass differ from the particle structure of a crystalline solid?

### Level Two

1. From this activity, it would appear that metals form atomic crystalline solids. However, different metals have adopted different atomic packing arrangements. Offer an explanation for this occurrence.

2. Research three-dimensional works of art that resemble the atomic packing arrangements of crystalline solids and explain the artwork in terms of the structures of crystalline solids.
3. Consider your models of three atomic solids and one ionic solid. Are atomic solids more dense or less dense than ionic solids? Explain your answer.
4. When a glass cracks, it shatters. When a crystal cracks, it cleaves along a flat plane. Explain why.
5. Compare the shape of store bought sucrose crystals and laboratory prepared sucrose crystals. Explain any differences.

From Activity 4.1, it can be seen that crystalline solids are made of atoms, ions, or molecules that line up in an orderly fashion and form a predictable crystalline shape. It is not known why different metals choose different atomic packing arrangements such as body-centered cubic, face-centered cubic, or hexagonal-closest packing. Differences in atomic size and electron configuration might be determining factors. Certainly the difference in size between the sodium ion ( $\text{Na}^+$ ) and the chlorine ion ( $\text{Cl}^-$ ) accounts for cubic ion packing in a sodium chloride crystal, which is not a closest packing arrangement. Here ions are not touching one another. There is unfilled space when small ions and large ions are arranged alternately in a three-dimensional array. However, face-centered cubic packing and hexagonal-closest packing result in solids in which the atoms are actually touching one another. Because of this touching, a calculation of atomic radii is possible. In a glass, the disorderly particle arrangement does not allow any such calculation. Atomic or ionic radii calculated from crystalline solid measurements of touching atoms or ions can be used to predict crystalline solid structures for a large variety of crystalline solids containing these atoms or ions. Also, we can use atomic radii to make correct molecular models.

The models prepared in Activity 4.1 have the properties of a solid and linear three-dimensional work of art. The toothpicks give the work a linear look and the Styrofoam balls provide mass. The closer the atoms, ions, or molecules are packed, the more the artwork appears to be solid and massive, not linear.

Many works of art, two-dimensional as well as three-dimensional, depict subject matter resembling (or resemble, in the case of sculpture) structures of crystalline solids, such as the following:

*Cube* (sculpture), Sol Lewitt, 1967

*Twelve Cadilacs* (silk screen on canvas), Andy Warhol, 1962

*Green Coca-Cola Bottles* (oil on canvas), Andy Warhol, 1962

*Untitled* (nine steel units), Robert Morris, 1967

*White Cascade* (mobile metal), Alexander Calder, 1972–1973

*Study of the Regular Division of the Plane with Horsemen* (India ink and watercolor), M. C. Esher, 1946

All these works of art include an orderly arrangement of a particular object, similar to the arrangement of structural units in a crystalline solid: atoms, ions, or molecules.

## Crystalline-Solid Formation versus Glass Formation

### How does glass formation differ from crystalline-solid formation?

- Although silica, silicon dioxide, alone would make outstanding glass objects, it is too difficult to melt and form. Therefore, fluxes are added to lower the melting point and make possible the melting and forming of glass at reasonably low temperatures. Sodium oxide and calcium oxide are fluxes that lower the melting point of silicon dioxide.
- Glass is formed around 1600°C.
- Crystalline solid formation is a slow process that can occur at room temperature.. It can occur through chemical change (see Activity 4.1). It can occur when a supersaturated solution is disturbed. It can also occur when a saturated solution slowly evaporates.

It is necessary to consider the method of formation of a crystalline solid as compared to the formation of a glass to understand why a crystalline solid is made of particles distributed in a uniform manner, whereas a glass has a disordered particle structure. Demonstration 4.1 compares glass formation to crystal formation. Because the preparation of a glass requires temperatures above 1600°C, prepared glass is melted in this demonstration (requiring a much lower temperature) to show glass formation.

**DEMONSTRATION**

### 4.1

## The Difference Between Crystalline-Solid Formation and Glass Formation

### Objectives

1. Students will state observed differences between crystalline-solid formation and glass formation.
2. Students will explain why glasses have disordered particle arrangements and crystals have orderly particle arrangements.
3. Students will write a word equation and a chemical equation for the preparation of silver (Ag) crystals.

### Materials

Large test tube; distilled water; 30 cm 12- to 14-gauge copper (Cu) wire; pencil; 15 ml 0.1M AgNO<sub>3</sub> (silver nitrate); two lengths of 20 cm soft glass tubing; paper and pencil; Bunsen burner; matches; wash bottle; 250 ml beaker.

### Time

30 minutes

## Procedure

1. Heat the tip of a 20 cm length glass tubing in the hottest part of a Bunsen burner's flame (directly above the inner cone) until the glass melts and a globule of molten glass is formed.

■ *Note:*

Because it would be impractical to prepare glass from silicon dioxide ( $\text{SiO}_2$ ), requiring temperatures above  $1600^\circ\text{C}$ , prepared glass is melted to represent the stage of glass making before the glass is cooled.

2. Remove the glass from the flame and let it cool. Have students record the length of time needed for cooling and draw a picture of the globule.
3. Repeat steps 1–2 with another piece of glass tubing.
4. Pour 15 ml 0.1 M  $\text{AgNO}_3$  into a large test tube. **(CAUTION: SILVER NITRATE WILL TURN CLOTHES AND HANDS BROWN.)**
5. Twist a piece of copper wire around the length of a pencil, leaving a portion of the wire straight to form a handle. Remove the pencil from the twisted copper wire and immerse the twisted portion of the wire in the  $\text{AgNO}_3$  solution.
6. Observe the copper wire every five minutes until a large quantity of silver crystals is seen.
7. Remove the copper wire from the solution and gently wash the crystals with distilled water. Use a wash bottle filled with distilled water to remove the crystals from the wire, washing them into a 250 ml beaker. Decant the wash water from the crystals into the sink.
8. Have students draw a picture of several of the crystals and observe the color of the remaining solution.

## Questions and Conclusions

### Level One

1. Do both glass globules have the same shape? If both glass globules do not have the same shape, what does this mean about the atomic structure of glass?
2. Do all the silver crystals have the same geometric shape? If all the silver crystals have the same geometric shape, what does this mean about the atomic structure of a metallic crystal?
3. Write a word equation for the chemical change that occurred in this demonstration.
4. Describe a physical change that occurred in this demonstration.
5. Review oxidation-reduction reactions as discussed in Chapter 3. Explain why the copper/silver nitrate reaction in this activity is an oxidation-reduction reaction.

**Level Two**

1. Using evidence presented in this demonstration, explain why crystalline solids have uniform atomic structures and glasses have disordered atomic structures.
2. Write a balanced chemical equation for the chemical reaction that occurred in this demonstration. Identify the class of chemical reactions to which this reaction belongs.
3. What causes the blue color to appear in the solution as the reaction involving copper and silver nitrate proceeds?
4. This reaction is an oxidation-reduction reaction. Review rules for assigning oxidation numbers. Identify the oxidizing agent and the reducing agent.

Demonstration 4.1 shows that the formation rate makes the difference. Glass, as it cools, solidifies quickly from the molten state. There is no time for the atoms and ions to line up in an orderly structure. They are frozen in place like pebbles in ice. Silver crystals, however, form slowly as silver atoms line up in a face-centered cubic arrangement. The atoms are as uniform as soldiers waiting for inspection.

### **Glass Components Determine Glass Properties**

**Name some chemical compounds used in a glaze preparation and explain why they are needed.**

- Silicon dioxide forms the main body of a glaze.
- Other oxides such as sodium oxide, potassium oxide, and lead oxide are fluxes. They lower the melting point of the silicon dioxide.
- Aluminum oxide helps to harden the melt.
- When diboron trioxide is added to a glaze preparation having a slight amount of iron oxide, the resulting glaze may be milky or an opalescent blue.
- Copper oxide and zinc oxide used together produce brilliant turquoise greens.
- When cobalt oxide is added to glazes containing magnesium oxide, the resultant color is purple.
- Calcium oxide has little effect on glaze colors but contributes to the hardness and durability of glazes.

Glasses contain a number of substances that impart particular physical properties to the glass. The main ingredient in a glass is silicon dioxide ( $\text{SiO}_2$ ), which forms a tetrahedral crystalline structure with a silicon atom at the center surrounded by four oxygen atoms, having the formula  $\text{SiO}_4^{4-}$ . When sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) is added to the silicon dioxide, common glass results. Adding diboron trioxide ( $\text{B}_2\text{O}_3$ ) to a glass composition and decreasing the amounts of calcium oxide ( $\text{CaO}$ ) and sodium oxide ( $\text{Na}_2\text{O}$ ) in the formulation will result in a glass that will not easily expand during heating or contract

during cooling. The addition of potassium oxide ( $K_2O$ ) to a glass composition will produce a very hard glass.<sup>4</sup> Colored glass is made by adding small amounts of certain transition-metal oxides, such as copper oxide ( $CuO$ ), chromium oxide ( $Cr_2O_3$ ), and cobalt oxide ( $CoO$ ), which produce blue-green glass, orange glass, and cobalt-blue glass, respectively. The color possibilities for glasses, and therefore glazes, are endless. By using specific amounts of selected substances, glazes can be designed to please even the wildest and most exotic of tastes.

## Preparing a Glaze

**What is added to a glaze composition to make the glaze adhere to a clay object?**

- Most of the oxides found in glaze formulas are found in naturally occurring clay. These clays, such as feldspars, contain small amounts of potassium, sodium, aluminum, and silicon oxides. When glazed pieces are fired, the clay oxides and glaze oxides become one.

Not only must we include the above-mentioned components in a glaze composition to provide desired physical properties, but we also need ingredients that will make the glaze adhere to the surface of a clay object and make it waterproof. Therefore, a glaze composition will contain a large variety of chemical compounds equipped to fulfill a medley of glaze objectives. Not only is it important to have specific chemical compounds in a glaze composition, it is important to include the correct amount of each component in the glaze formula. In preparing a glaze, one way to formulate a glaze composition is to consider the number of molecules of each compound used rather than the mass of the compounds needed. How can we do this? Can we count the number of molecules in each compound used? If molecules were large enough for us to see and count, what a strange world this would be!

## RELATIVE WEIGHTS: PERIODIC TABLE BASICS

**What is the modern basis for the arrangement of elements in the periodic table?**

- The elements in the modern periodic table are arranged according to atomic number, the number of protons in the atom.

Fortunately, there is a way to know how many molecules are in a particular mass of a compound. In Chapter 1, we investigated the periodic table to determine if it was arranged by element color. We discovered that there was no such arrangement. However, we noted that families, vertical columns on the table, had similar physical and chemical properties. The periodic table was originally arranged according to the relative weights of the elements, in order of increasing relative weight, where most elements of similar physical and chemical properties fell into place in vertical columns when rows of eight and eighteen elements were established. However, some elements, such as argon and potassium and tellurium and iodine, were not in the correct columns. It was then determined that the number of protons in each element would provide a means for placing the elements in

their correct columns. The elements on the periodic table are now arranged according to increasing atomic number.

## Relative Weights: Relative to What?

### What is the law of definite proportions?

- The law of definite proportions, sometimes called the law of constant composition, was established in 1799 by Joseph Proust. He said a given compound always contained the same elements in the same proportion by mass. For example, water is always 88.9% oxygen by mass and 11.1% hydrogen by mass.
- To find the mass of one atom compared to another, we assign a mass of 12 atomic mass units to carbon atoms having 6 protons and 6 neutrons in their nuclei. Other isotopes of carbon exist in nature in very small quantities. Carbon-13, with 6 protons and 7 neutrons, is 1.11% of a sample of carbon. Carbon-14, with 6 protons and 8 neutrons, is also present in tiny amounts in a carbon sample.

In 1808 John Dalton proposed his atomic theory, which included the statement that when atoms of two or more elements combine to form a compound, they combine in a definite ratio by number of atoms and by mass. This is called the law of definite proportions. This provided a means to determine the mass of one atom relative to another. It was necessary to assign a mass to one element to find the mass of another element in a compound. Today we use the most common carbon isotope, assigned a mass of 12.00 atomic mass units (amu), as the basis for comparative weights of the atoms.

## Relative Weights and the Mole

### What is the relative weight of an atom?

- The *relative weight of an atom* is the weight of an atom compared to a carbon atom having 6 protons and 6 neutrons and an assigned weight of 12 amu.
- If the mass percent of the isotopes of an element is known, then the average atomic weight can be calculated. For example, naturally occurring bromine has one isotope with a mass of 78.918 amu and makes up 50.69% of a bromine sample. Another isotope has a mass of 80.916 amu and an abundance of 49.31%. The average atomic mass of bromine equals the percent abundance of the first isotope divided by 100 times the mass plus the percent abundance of the second isotope divided by 100 times the mass:  $(.5069)(78.918) + (.4931)(80.916) = 79.90$ , the average atomic mass of bromine.

### What is the relative weight of a compound?

- The *relative weight of a compound* is the sum of the relative weights of the elements in the compounds.

### What is a mole?

- A *mole* is the number of elementary particles that is contained in one relative weight of an element or compound.

- Also, a mole is the mass of a substance that contains the same number of elementary particles as there are in exactly 12 g of the carbon-12 isotope. This number of atoms is  $6.02 \times 10^{23}$ .

The relative weights of the elements represent the mass of one kind of atom relative to another kind of atom. For example, the relative weight of a carbon (C) atom is 12.0 amu; the relative weight of a magnesium (Mg) atom is 24.3 amu. This means that a carbon atom has about half the mass of a magnesium atom. If we add together the relative weights of the elements in a compound, we will find the relative weight of the compound. For sodium chloride (NaCl), the relative weight of sodium is 23.0 amu, and the relative weight of chlorine is 35.5 amu. Therefore, the relative weight of sodium chloride is 58.5 amu. The relative weight of lithium oxide ( $\text{Li}_2\text{O}$ ) is 6.9 amu twice (13.8 amu) plus 16.0 amu, which is 29.8 amu. In one relative weight of every compound, there is the same number of molecules. We can change amu to grams and prepare 58.5 grams of sodium chloride and 29.8 grams of lithium oxide. Both amounts contain the same number of molecules. You might be thinking, what is this number? A very large number:  $6.02 \times 10^{23}$  molecules. This number is called a *mole*, abbreviated as mol (and not related to the small, burrowing animal of the same name). Because  $6.02 \times 10^{23}$  molecules are a mole of molecules, and because the relative weight of a substance contains this number of molecules, then the relative weight of a substance must be one mole of that substance.

Glazes can be prepared by combining a particular number of molecules of each ingredient. This can be accomplished using moles, which Activity 4.2 allows you to do.

**Essential Question: How did scientists discover the number of particles ( $6.02 \times 10^{23}$ ) in a mole of a substance?**

**ACTIVITY****4.2****Glazing Pottery: Calculations Needed to Prepare a Glaze****Objectives**

1. Students will calculate the relative mass of each compound needed to prepare a pottery glaze that waterproofs and decorates a pottery piece for Activity 4.7.
2. Students will use the periodic table to determine the relative weights of elements and compounds.
3. Students will determine the mass of one mole of an element and the mass of one mole of a compound.
4. Students will learn that one mole of a substance represents the number of particles contained in that substance.

- Students will learn that the relative weight in grams of a compound contains one mole of molecules.

**Materials**

Calculator; periodic table.

**Time**

30 minutes

**Procedure**

- Use a calculator and a periodic table to calculate relative weights for the following compounds: MgO (magnesium oxide), CaO (calcium oxide), and SiO<sub>2</sub> (silicon dioxide). (Answer: for MgO, 24.3 plus 16.0 equals 40.3 amu; for CaO, 40.1 plus 16.0 equals 56.1; for SiO<sub>2</sub>, 28.1 plus 16.0 equals 44.1.)
- Record the mass of one mole of each of these compounds. (The relative weight of a compound is the weight of one mole of the compound.)
- Calculate the mass of 0.203 mole of magnesium oxide, MgO, 0.15 mole of calcium oxide, CaO, and of 1.75 mole of silicon dioxide, SiO<sub>2</sub>. (Answer: for MgO, 0.203 mole times 40.3 grams/mole equals 8.18 grams; for CaO, 0.15 mole times 56.1 grams/mole equals 8.4 grams; for SiO<sub>2</sub>, 1.75 mole times 44.1 grams/mole equals 77.2 grams.)
- Using the procedure above, calculate the mass of the following number of moles of each compound listed:  
0.05 mole ZnO (zinc oxide)  
(Answer: 0.05 mole times 81.4 grams/mole equals 4.1 grams.)  
0.10 mole K<sub>2</sub>O (potassium oxide)  
(Answer: 0.10 mole times 94.2 grams/mole equals 9.4 grams.)  
0.12 mole Al<sub>2</sub>O<sub>3</sub> (aluminum oxide)  
(Answer: 0.12 mole times 101.96 equals 12.2 grams.)
- The masses calculated in steps 3 and 4 will be used to prepare glazes in Activity 4.3.

**Questions and Conclusions****Level One**

- In one mole of each of the compounds considered in this activity, how many molecules are present? (Hint: Is the number of eggs in a dozen eggs different than the number of oranges in a dozen oranges?)
- One mole represents a very large number,  $6.02 \times 10^{23}$ . Find ways to explain just how large this number is. For example, if we were to make a stack of a mole of notebook papers, how high would the stack be?

**Level Two**

1. Explain why one mole of MgO has a smaller mass than one mole of CaO.
2. Sometimes a small amount of clay is added to a glaze composition. What is the function of the clay?
3. If copper compounds are added to a glaze composition, after firing, what will most likely be the color of the glaze? Explain your answer.

■ *Note:*

The relative weights of MgO, CaO, and SiO<sub>2</sub> are 40.3 amu, 56.1 amu, and 60.1 amu, respectively. Therefore, 0.203 mole MgO is 8.18 g, 0.15 mole CaO is 8.4 g, and 1.75 mole SiO<sub>2</sub> is 105 g. The masses of one mole of ZnO, K<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub> are 81.4 g, 94 g, and 102 g, respectively, so 0.05 mole ZnO is 4.1 g, 0.10 mole K<sub>2</sub>O is 9.4 g, and 0.12 mole Al<sub>2</sub>O<sub>3</sub> is 12.2 g.

## GLAZE INGREDIENTS: THE KEY TO GLAZE PROPERTIES

There are unlimited combinations of compounds and elements that result in glaze formations. The elimination or addition of one substance can radically change the product. In Activity 4.3, a glaze and variations of the glaze will be prepared. Then the prepared glazes will be applied to bisque ware clay slabs, which will be fired. The results obtained from the different glazes will be compared.

## THE KILN: CLAY IN THE OVEN

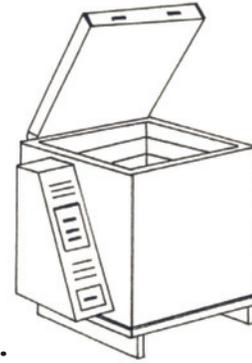
### Hansel and Gretel's Worst Nightmare

#### When pottery is glazed using a kiln, what problems can occur?

- If pottery pieces are placed too close together, they will stick to each other. Also, if glaze drips onto the pottery rack, the pieces can stick to the rack.
- Improper cool down temperatures will cause pieces to crack, especially if the cooling is too fast.
- Volatile colors, especially chromium compound colors, may migrate from one clay piece to another, staining the glazes.
- Bits of brick or mortar may fall from the crown of the kiln onto glazed surfaces.
- Sometimes glazes will drip off one piece down onto another piece.

A *kiln* is a specially designed oven for heating or firing clay. The word *kiln* comes from the Latin word *culina*, meaning “kitchen.” A kiln is constructed to withstand the high temperatures necessary to change greenware into bisque ware and to melt the glazes applied to the surface of clay pieces. Depending on the type of clay, different temperatures are needed to make these changes occur. Hansel and Gretel would never make it in this oven! (See Figure 4.10, p. 172.)

The first kilns were used around the sixth century B.C. It was quickly realized that the amount of oxygen in the kiln could determine the color of the glaze. Iron oxide ( $\text{Fe}_2\text{O}_4$ ) will lend a red color to a glaze when much oxygen is available. If little oxygen is available, the  $\text{Fe}_2\text{O}_4$  will donate oxygen to the kiln fire by releasing an oxygen atom and converting to black iron III oxide ( $\text{Fe}_2\text{O}_3$ ). When little oxygen is available, the fire is referred to as a reduction fire (see Chapter 3 for a detailed discussion of oxidation-reduction).



**Figure 4.10. Top-Loading Kiln.**

## Clay Glazes and Apple Pie Glazes: The Same Concept

### Describe how a kiln should be managed.

- In addition to the rules below, in handling shelves and ware, care must be taken not to allow fire ashes and crumbs of clay or brick to fall on the glazes.
- All kiln shelves must be firmly supported, and any that are badly cracked should be discarded.

A kiln works very much like a kitchen oven. When clay reaches a particular temperature, it changes into a hard, permanent material, and the glaze melts and adheres to the surface of the piece, much the way a brown-sugar glaze on an apple pie melts and sticks to the apples at a particular oven temperature. When firing the kiln, it is necessary to raise the temperature slowly over a period of several hours. At first, the lid of the kiln should be propped open to allow moisture trapped in the seemingly dry clay to escape. Then the lid is closed and the temperature is increased to its final level. Most ceramic kilns have a temperature gauge that allows the user to know when to shut off the kiln (*ceramic* is used here as a general term for materials prepared from clay and made rigid by high-temperature treatment). Some kilns are equipped with an automatic shutoff, which shuts off the kiln when the appropriate temperature is reached. When firing, greenware can be stacked, one piece inside another, with surfaces touching. Bisque ware that has been glazed, however, must be set in the kiln carefully so that pieces do not touch one another. (For information on the hazards and dangers of kiln firing, see Chapter 10.)

**ACTIVITY****4.3*****Preparing Glazes and Clay Slabs and Testing the Glazes on the Clay Slabs*****■ Warning!**

**Proper ventilation is necessary during glaze firing. See Chapter 10.**

**Objectives**

1. Students will prepare glazes and clay slabs, apply their glazes to bisque ware clay slabs, and compare the physical properties of the glazes after the slabs have been fired.
2. Students will research the glaze ingredients used to determine why each ingredient is used.
3. Students will design a glaze formula, predict the physical properties of the glaze, and test their predictions.

**Materials**

MgO (lead oxide), CaO (calcium oxide), SiO<sub>2</sub> (silicon dioxide), ZnO (zinc oxide), K<sub>2</sub>O (potassium oxide), Al<sub>2</sub>O<sub>3</sub> (aluminum oxide), CaCO<sub>3</sub> (calcium carbonate), CuCO<sub>3</sub> (copper carbonate), Fe<sub>2</sub>O<sub>3</sub> (iron III oxide), CoO (cobalt oxide), NiO (nickel oxide), and white clay (see below for amounts); distilled water; four small beakers; kiln; four watch glasses; rolling pin.

**Time**

50 minutes; one day firing time

**Procedure**

1. In a small beaker, combine the following amounts of the ingredients discussed in Activity 4.2: 8.18g MgO; 8.4 g CaO; 105.0 g SiO<sub>2</sub>; 4.1 g ZnO; 9.4 g K<sub>2</sub>O; 12.2 g Al<sub>2</sub>O<sub>3</sub>.
2. Add to the ingredients in item 1: 5.0 g CaCO<sub>3</sub>, 0.9 g clay, and an additional 18.6 g SiO<sub>2</sub>.
3. Add distilled water to the combined ingredients to make a mixture with the consistency of cream.
4. Divide the mixture into four equal parts in the beakers and add the following (The beakers should be labeled Glaze 1, Glaze 2, Glaze 3, and Glaze 4.): Glaze 1: 14.7 g CuCO<sub>3</sub>; Glaze 2: 11.8 g Fe<sub>2</sub>O<sub>3</sub>; Glaze 3: 5.9 g CoO; Glaze 4: 1.47g NiO.
5. Prepare bisque clay slabs by:

- a. Wedging a ball of clay;
  - b. Rolling the clay to a uniform thickness (about  $\frac{1}{4}$  in.);
  - c. Cutting out rectangular slabs; and
  - d. Firing the dried slabs at about  $1841^{\circ}\text{F}$  ( $1031^{\circ}\text{C}$ ).
6. Apply each of the four glazes prepared to a separate fired clay slab. (Some of each glaze should be saved for a natural-clay pinch pot in Activity 4.7.) Cover beakers with watch glasses.
  7. Fire the slabs in a kiln at recommended temperature (usually about  $1950^{\circ}\text{F}$ ).
  8. Prepare a table as follows. Along the left side of a sheet of paper in a vertical column, list Glaze 1, Glaze 2, Glaze 3, Glaze 4; across the top, list color, opaque or transparent, texture. Record your observed properties for each glaze.

## Questions and Conclusions

### Level One

1. What is the purpose of adding the following ingredients to the glazes:  $\text{SiO}_2$ ,  $\text{CuO}$ , and  $\text{Al}_2\text{O}_3$ ?
2. What problems will be encountered if the glaze is too thick? Too thin?
3. How can you tell that the glaze is a glass?

### Level Two

1. Research the physical property imparted by each glaze ingredient.
2. Propose the addition of a new ingredient to the glaze formula and predict the outcome in glaze appearance from this addition. Check the safety and availability of your proposed ingredient with your teacher. Test your prediction by preparing your proposed glaze, applying it to a bisque ware slab, and having it fired in a kiln.

### ■ **Warning!**

Lead compounds should not be used. Lead vapor can be harmful.

To provide colored glazes, the following compounds can be added (The percentages are by mass.): for brown, 5 to 10% iron oxide, for blue, 5 to 10% copper carbonate, for blue-green, 1.0% cobalt oxide.

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## THE PERIODIC TABLE

### Relative Weights: A Historical Perspective Involving the Periodic Table

#### How are relative weights related to the periodic table?

- Before Henry Moseley (1887–1915), a British chemist, found that elements could be arranged according to their number of protons (atomic number), elements were arranged according to relative weights, also called *atomic mass*.
- Dmitri Mendeleev (1834–1907), a Russian scientist and creator of the modern periodic table, discovered that if elements were lined up according to atomic weights and arranged in rows of 2, 8, 18, and 32, atoms with similar chemical and physical properties appeared in the same column. However, there were some exceptions. Argon and potassium were out of place. So were iodine and tellurium. Mendeleev thought his relative weights were incorrect.

We used relative weights and the mole concept to prepare glaze formulas based on the number of glaze ingredient molecules needed for the glaze formula. Now we will consider the relative weights of the elements and their importance in developing the modern periodic table. In 1808 Joseph Louis Proust, a French chemist, found that when pure compounds were prepared, they always required the same mass ratio of constituent elements. This was called the law of definite proportions. John Dalton, an English scientist, introduced his atomic theory in 1803 and, using Proust's law of definite proportions, subsequently determined experimentally the relative weights of a number of elements. In 1817 Johann Dobereiner (1780–1849), a German chemist, found several groups of three elements that had similar properties. He grouped these together as triads. The average of the relative weights of the heaviest and lightest elements in a triad equaled the relative weight of the middle element. Chlorine (Cl), bromine (Br), and iodine (I) are such a triad. The average of the relative weight of chlorine, 35.5 amu, and the relative weight of iodine, 126.9 amu, is 81.2 amu. The relative weight of bromine is 79.9 amu.

#### Dobereiner's Triads Come Home

#### Trace the development of the modern periodic table.

- Scientists developed the modern periodic table by looking for regularities.
- Dobereiner found regularities in groups of three elements, triads, that had similar chemical and physical properties.
- Mendeleev found regularities in chemical and physical properties of elements arranged by atomic weights in specific rows.
- Moseley solved Mendeleev's reversed pair dilemma when he arranged the elements by atomic numbers.

Dobereiner's triads found a home in Mendeleev's periodic table, published in 1872. Mendeleev arranged the elements according to their relative weights, beginning with the lightest element, hydrogen (H). He placed elements with similar properties together vertically so that Dobereiner's triads appeared within Mendeleev's periodic table. About

52 elements had been discovered at the time of Mendeleev's periodic table. He used his table to accurately predict the discovery of additional elements, such as gallium (Ga), selenium (Se), and germanium (Ge). In 1914 Henry Moseley found that elements with similar chemical and physical properties fit more properly in columns when the elements are arranged according to atomic number, the number of protons in the atomic nucleus. The modern periodic table is arranged according to atomic number.

## **The Modern Periodic Table: Order from Chaos**

### **Metals, Nonmetals, and Metalloids**

#### **What information about the elements is found on the periodic table?**

- In addition to the information below, the periodic table shows trends in atomic size, ionization energy, electronegativity, valence electrons, and melting points.
- As one moves across the rows, atomic size decreases; ionization energy, the energy required to remove an electron from an atom in the gas phase, increases; electronegativity, the ability of an atom in a molecule to attract electrons to itself, increases; and melting points increase until the transition metals, where titanium and nickel have the highest melting points in row 4, molybdenum has the highest melting point in row 5, and tungsten has the highest melting point in row 6. After the transition metals, melting points rapidly diminish, except for carbon, silicon, tin, and bismuth.
- Valence electrons can be determined by examining group A elements. The number of valence electrons increases from 1 to 7 as one progresses from group IA to group VIIA.

The modern periodic table provides us with volumes of information about the elements. Metals are on the left side of the table, nonmetals are on the right side, and metalloids divide these two groups. In general, metals are shiny, malleable, ductile, and conduct electricity. Nonmetals are dull, brittle, and do not conduct electricity (many nonmetals are gases at room temperature). Metalloids have properties of both metals and nonmetals.

### **Families: They Get Along Fairly Well**

#### **On the periodic table, what is a family?**

- A *family* is a vertical column of elements on the periodic table that contains elements with similar chemical properties, physical properties, and electron configurations.

A column of the periodic table is called a *family*. Some families have special names. Group IA elements are called *alkali metals*, group IIA elements are called *alkaline earth metals*, group VIIA elements are called *halogens*, and group VIIIA elements are called the *noble gases*. The group B elements are called *transition elements*. Elements with atomic numbers from 58 to 71 are called *lanthanides*, and elements with atomic numbers from 90 to 103 are called *actinides*. Families have similar chemical and physical properties. For example, the alkali metals are soft metals at room temperature; they are shiny, conduct

electricity, and react vigorously with water, producing hydrogen ( $H_2$ ) that burns from the heat produced by the reaction.

### **Rows and Families: They Get Trendy**

#### **Discuss periodic trends down a column and across a row.**

- In addition to the periodic trends down a column discussed above and below, columns and rows can be used to find electron configurations.
- Looking down the columns, groups IA and IIA have 1 and 2 valence electrons, respectively, in s orbitals. The transition metal families from left to right have 1 to 10 valence electrons, respectively, in d orbitals. Groups IIIA to VIIA have 3 to 8 valence electron, respectively, in p orbitals.

Looking across a row (from left to right), or period, of the periodic table, or looking down a column, or family, one will see trends in element properties develop. Generally, moving across a row, atomic radii decrease, ionization energy (the minimal energy needed to remove an outermost electron from a neutral atom in the gaseous state) increases, and metallic properties diminish. Moving down a column, atomic radii increase, ionization energy decreases, and metallic properties remain the same or, in groups IIIA, IVA, VA, and VIA, decrease.

### **The Periodic Table and Electron Configuration**

#### **Explain how electrons fill into orbitals.**

- Electrons fill in equal energy orbitals, so that a maximum number of unpaired electrons result (Hund's Rule).
- The Pauli exclusion principle states that an orbital can hold a maximum of two electrons and the two electrons must be spinning in opposite directions.
- The Aufbau principle states that in the ground state of an atom, the electrons occupy the lowest energy levels available.

We learned in Chapter 1 that electrons are outside the atomic nucleus. Though we do not know the exact location of these electrons, we can use equations to determine their most probable location. This location or region in atomic space is called an *orbital*. Electrons fill into orbitals around the atomic nucleus. As the electrons fill into orbitals, they move farther from the nucleus. Their distance from the nucleus is described as their energy level, or shell. The first shell is closest to the nucleus. The periodic table organizes the elements according to their electron configurations.

### **Eight Is Great!**

#### **In electron configuration, why is eight such an important number?**

- Since atoms are the most stable when they have eight valence electrons (examples are the noble gas atoms), they participate in chemical change reactions spontaneously when the stable eight valence electron configuration can be easily attained.

Atoms are most stable when they have eight outermost electrons, called *valence electrons*. Considering the group A elements as we move across the periodic table, each kind of atom has one more valence electron than the previous kind of atom. The alkali metals have one valence electron. The noble gases have eight valence electrons. Almost all of the elements want to be like the noble gases: They want some stability in their lives. Hydrogen (H) and helium (He) are exceptions to the eight-electron stability rule. Helium is quite stable with two valence electrons, and hydrogen can achieve stability by losing, gaining, or sharing one electron. Upon gaining or sharing an electron, hydrogen achieves the electron configuration of helium and is quite stable and content.

### **Describe two ways that atoms can acquire eight outermost electrons.**

- Atoms can gain or lose electrons and form stable ions with eight outermost electrons.
- Atoms can also share valence electrons to achieve eight outermost electrons.

There are two principal ways for atoms to acquire eight outermost electrons: by sharing electrons or by transferring electrons. The alkali metals have one valence electron, and the alkaline earth metals have two valence electrons. It is easy for them to transfer these loosely held valence electrons to atoms needing only one or two electrons to achieve eight valence electrons. Electron transfer gives stability to the atoms. The halogens have seven valence electrons, and the atoms from the oxygen (O) family have six valence electrons. Between these families, we see a great possibility for electron transfer. Sodium (Na) loses an electron, and chlorine (Cl) gains it. Magnesium (Mg) loses two electrons, and oxygen gains them. Sharing electrons is a very compatible arrangement. Sharing of electrons also works to achieve a stable, eight-electron arrangement. Two oxygen atoms can share two valence electrons so that both atoms have eight valence electrons, and an oxygen molecule ( $O_2$ ) is produced. In the same way, two chlorine atoms can share a valence electron to have the magic number, eight, and a chlorine molecule ( $Cl_2$ ) results.

### **Atomic Electron Configurations**

#### **How is the periodic table used to determine element electron configuration?**

- The periodic table can be read from left to right to determine the electron configuration of any element. The principal energy level is equal to the element's row. For the d elements, the principal energy level is one less than the row. Therefore, the electron configuration of iron, reading from left to right, is  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$ .

The outermost electrons in atoms fall into a neat pattern in the periodic table. All the group IA elements, the alkali metals, have one outermost electron. The group IIA elements, the alkaline earth metals, have two outermost electrons. Group IIIA elements have three outermost electrons, group IVA have four, group VA five, group VIA six, group VIIA seven, and group VIIIA eight. A pattern emerges. By looking at the periodic table, the viewer can predict how atoms bond and, thus, determine molecular formulas. Oxygen atoms need two valence electrons to have eight, and hydrogen atoms can share one electron, so two hydrogen atoms will provide an electron arrangement good for all. Accordingly, the formula for water is  $H_2O$ .

**ACTIVITY****4.4****Construction of a Three-Dimensional Periodic Table****Objectives**

1. Students will construct a work of art based on a three-dimensional periodic table and using the principles of good composition.
2. Students will show that their periodic table includes all the information presented in a two-dimensional periodic table.
3. Students will debate the advantages of using their periodic table rather than a traditional periodic table.

**Materials**

Periodic table; scissors; string; tape; colored markers; small rods.

**Time**

50 minutes

**Procedure**

1. Cut a periodic table into portions appropriate for constructing a three-dimensional table.
2. Use string or tape, or both, to reconnect the parts of the table into a three-dimensional table that is more useful than the traditional table.
3. Consider making a mobile three-dimensional periodic table. (See Activity 5.6, p. 225.) Remember that families and rows must be kept intact. To construct a balanced mobile, it is easier to start at the lowest section. Add periodic table sections and balance the section. Then work toward the top. Make the periodic table mobile useful. An observer should be able to locate an element and know its physical and chemical properties.

**■ Note:**

To decrease the length of the table, the inner transition metals of the traditional periodic table should be cut out of their positions according to increasing atomic number. Include the inner transition metals in the main body of the three-dimensional table.

One approach to constructing a three-dimensional periodic table is to arrange the elements by increasing atomic number in a spiral, where families remain in a vertical relationship. Inner transition metals will be included in the main body of this three-dimensional periodic table.

4. Use markers to color the various parts of the three-dimensional table to show important divisions and sections.
5. Display the three-dimensional periodic table in a prominent location.

### Questions and Conclusions

#### Level One

1. Point out the following on the three-dimensional table: atomic number (number of protons), mass number (relative weight), alkali metals, alkaline earth metals, transition metals, metalloids, nonmetals, halogens, noble gases, and rare earths.
2. Element 118 was created in a laboratory but only lasted for a tiny fraction of a second. Where would elements numbered 110 to 118 appear on the table?
3. As a three-dimensional work of art, is the table mainly solid (massive) or linear (made of thin, line-like parts)? Describe a famous work of art that resembles this table (refer to an illustrated book about art history for examples).

#### Level Two

1. Explain the advantages and disadvantages of the three-dimensional periodic table compared to a traditional table.
2. Sometimes hydrogen (H), by itself, is called a family. Point out where hydrogen is placed on the three-dimensional table. Why would hydrogen by itself be called a family?
3. How can the three-dimensional table include new elements as they are created in the laboratory? How will the table grow?
4. Using the three-dimensional table, explain why it is called a *periodic* table.
5. Explain why the three-dimensional table is not only useful but also an attractive three-dimensional work of art.

---

## BONDS IN MARRIAGE AND IN ATOMS

### Sharing, Transferring, and Bonding

#### What is a chemical bond?

- A *chemical bond* can be defined as an interaction between two or more atoms that holds them together by reducing the potential energy of their electrons. In most bonds between two atoms, electrons are either shared or transferred. Another type of bond between two atoms is a coordinate covalent bond. In this bond, the bonding pair of electrons originates on one of the bonded atoms.  $\text{H}_3\text{N}-\text{BF}_3$  is a molecule that has a coordinate covalent bond. The dash in the formula indicates the bond position where both electrons are contributed by the nitrogen atom.

A *chemical bond* is a force between atoms in particular forms of matter. When a sodium (Na) atom loses an electron, it acquires a positive charge. We call it a sodium ion ( $\text{Na}^+$ ), or, in general, a *cation*. A chlorine (Cl) atom that receives an electron from a sodium atom acquires a negative charge. We call it a chlorine ion ( $\text{Cl}^-$ ), or, in general, an *anion*. In science, opposites attract. A positive sodium ion is attracted to a negative chlorine ion, so they form a bond, specifically, an *ionic bond*. This bond is the force that allows the formation of sodium chloride ( $\text{NaCl}$ ) as a cubic crystalline solid. In general, ionic bonds result when electrons are transferred from one atom to another. When two oxygen atoms share a pair of outermost electrons, a *covalent bond* results. For example, one chlorine atom can share an outermost electron with another chlorine atom. These two atoms are not oppositely charged, as is the case with sodium ions and chlorine ions. Here, the two chlorine atoms are held together by a covalent bond.

## Covalent Bond or Ionic Bond: Eight Is Still Great

**The octet rule states that atoms tend to gain, lose, or share electrons in order to acquire eight valence electrons. Are there exceptions to the octet rule?**

- Examples of compounds that have fewer than eight valence electrons are beryllium hydride,  $\text{BeH}_2$  and boron trifluoride,  $\text{BF}_3$ .
- Examples of compounds with more than eight valence electrons are nitrogen trifluoride,  $\text{NF}_3$ , and phosphorus pentafluoride,  $\text{PF}_5$ .

As discussed previously, many atoms are most stable with eight outermost electrons. Notice that when a sodium atom loses an electron and forms a sodium ion, eight outermost electrons remain. When a chlorine atom gains an electron, it has eight outermost electrons. It is not surprising that two chlorine atoms share an outermost electron to attain the magic number of electrons, eight, in their outer energy level, or shell. The noble gases have eight outermost electrons and are perfectly happy to remain alone. They do not want to bond. They remain single.

## Classifying Crystalline Solids by Their Bonds

**How are bonding forces in a substance identified?**

- Physical properties such as solubility, melting point, and electrical conductivity, and chemical properties such as flammability of substances indicate bonding types.

In Activity 4.1, students described and modeled crystalline solids according to the way their atoms packed into a regular structure. We found that their atoms could pack into face-centered, body-centered, or hexagonal-closest arrangements. Another way to understand the structure of a crystalline solid is to consider the bonding forces between its structural units.

### Ionic Solids

**How do we know that a substance is held together by ionic bonds?**

- Substances with ionic bonds are good conductors of electricity in the liquid phase and in water solutions.

- In the solid phase they are hard, have high melting points, and have poor electrical and thermal conductivity.

Solids such as sodium chloride ( $\text{NaCl}$ ) and zinc chloride ( $\text{ZnCl}_2$ ) are made of ions that are held together by the attractive force of these oppositely charged particles. If ionic solids are dissolved in water, their ions are separated and can conduct an electric current. This physical property of ionic solids can be used to decide if a solid is held together by ionic bonds.

### **Molecular Solids**

#### **How do we know that certain solids are molecular solids?**

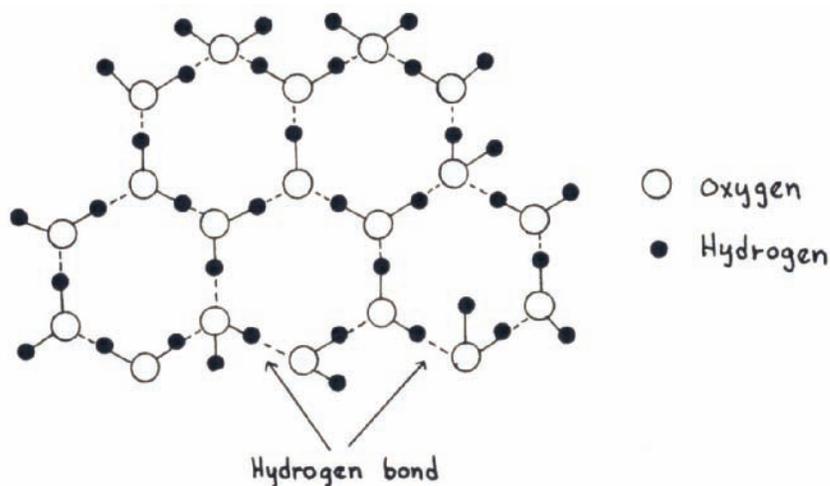
- Molecular solids are soft.
- Compared to ionic solids, molecular solids have low melting points.
- Molecular solids have poor electrical and thermal conductivity.

*Molecular solids* are crystalline solids in which molecules are held together by weak electrical forces between molecules. These bonds between molecules are usually weaker than bonds within molecules. Molecular solids dissolved in water are not good electrical conductors. Examples of molecular solids are sulfur ( $\text{S}_8$ ); phosphorus ( $\text{P}_4$ ); and water, or ice ( $\text{H}_2\text{O}$ ).

#### **Define polar molecule.**

- A *polar molecule*, also called a *dipole*, has one end with a negative charge and one end with a positive charge.

Bonds between  $\text{H}_2\text{O}$  molecules in ice are stronger than bonds between  $\text{S}_8$  molecules and  $\text{P}_4$  molecules. This is because  $\text{H}_2\text{O}$  is a polar molecule. The shape of the  $\text{H}_2\text{O}$  molecule and the intramolecular bonds (within the  $\text{H}_2\text{O}$  molecule) give the molecule positive and negative ends. The negative end of one  $\text{H}_2\text{O}$  molecule bonds to the positive end of another  $\text{H}_2\text{O}$  molecule, and ice is formed (see Figure 4.11). This intermolecular bond (between  $\text{H}_2\text{O}$  molecules) is called a hydrogen bond. We will look more closely at the shape of the  $\text{H}_2\text{O}$  molecule in Chapter 5.



**Figure 4.11. Crystalline Structure of Ice.**

## Metallic Bonds

### How do we know that a substance is held together by metallic bonds?

- Metallic solids are excellent electrical and thermal conductors. They are ductile and malleable. When a piece of metal is forced to take a different shape, it continues to hold together since its electrons can shift to bond the metallic atoms in their new positions.
- Metals range from soft to hard and have low to high melting points. Most metals are solids at room temperature. Mercury is a liquid at room temperature; gallium and cesium have melting points slightly above room temperature.

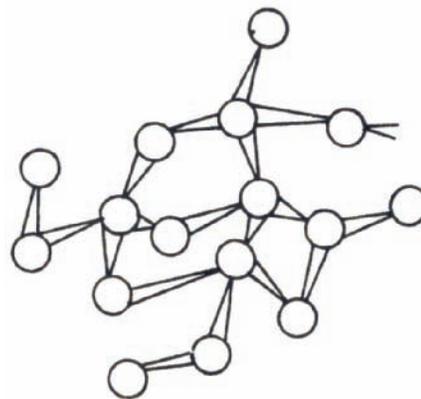
Metal atoms bond into solid structures because the positively charged metal ions attract free-flowing negative electrons. *Metallic bonds* have been described as uniformly arranged metallic cations surrounded by a sea of electrons. Needless to say, these mobile electrons provide good electrical conductivity.

## Covalent Network Bonds

### Describe a covalent network bond.

- In some solids, atoms are bonded to each other with strong covalent bonds but molecules are not formed. Instead, the covalent bonds form a network of atoms extending throughout a solid crystal.
- Covalent network solids have high melting points.
- Diamond, graphite, silicon dioxide, and silicon are examples of substances that form covalent network solids.

In covalent network solids, large numbers of atoms are held together by covalent bonds. The resulting particle structures are like large Tinkertoy™ constructions resembling spiders or centipedes, in which the body is the central atom and the legs are bonds holding surrounding atoms in place. A common geometric shape for the atoms in a covalent network solid is the tetrahedron. The diamond form of carbon is a covalent network solid with tetrahedrally bonded carbon atoms (see Figure 4.12). More important, the molecule needed to make glass and glazes, silicon dioxide ( $\text{SiO}_2$ ), found in sand and quartz, is covalently bonded in chains of  $\text{SiO}_4$  molecules to make a network solid.



**Figure 4.12. Bonding Structure of Diamond.**

○ Carbon

**Essential Question: Why are some chemical bonds strong and others weak?**

**ACTIVITY**

## 4.5

### ***Solid Bonding and Clay Construction***

#### **Objectives**

1. Students will model in clay a three-dimensional work of art that represents the bonding structure of a crystalline solid.
2. Students will discuss the differences and similarities in the four bonding structures of crystalline solids using the three-dimensional clay artwork.

#### **Materials**

Clay; toothpicks; descriptions of molecular, ionic, metallic, and covalent network bonding structures in solids (see “Classifying Crystalline Solids by Their Bonds,” pp. 181–183). (Teachers should reproduce this section for student reference.)

#### **Time**

50 minutes

#### **Procedure**

1. Read descriptions of the four types of solid bonding structures and select one type to model in clay.
2. Make a model of the bonding structure using clay and toothpicks. The clay should represent atoms or ions and the toothpicks should represent bonds. Your model should have at least one structural unit. The additive method of three-dimensional construction should be used.
3. Label your model with the type of bonding structure represented.

#### **Questions and Conclusions**

##### **Level One**

1. For each type of bonding structure (molecular, ionic, metallic, and covalent network), describe the structural units in the solid phase and explain how they are bonded. How are the four types similar and different?
2. What are some examples of substances with these bonding structures?

##### **Level Two**

1. Crystalline solids have definite patterns that repeat themselves throughout the structure of the crystalline solid. A unit cell is the smallest unit in the crystalline solid that represents this repeating pattern. Name the unit cells of the seven fundamental crystal lattice arrangements.
  2. Considering the types of bonds that each solid has, predict the following physical properties for each solid and explain your predictions:
    - a. melting point
    - b. electrical conductivity
    - c. thermal conductivity
    - d. malleability and ductility
    - e. hardness
  3. Explain how the subtractive method of three-dimensional construction could be used to model the bonding structure for a crystalline solid in clay.
- 

## Bond Types Determine Physical Properties

**List the four bond types, starting with the weakest and ending with the strongest.**

- From weakest to strongest, the four solid bonding types are molecular, metallic, ionic, and covalent network.

In marital bonds, the stronger the bond, the better the marriage. In chemical bonds, the stronger the bond, the higher the melting point. There is a similarity here. A strong bond results in a stable structure. Of the four types of bonding structures in a solid-covalent network (ionic, metallic, molecular, and covalent), covalent network solids have the highest melting points and molecular solids have the lowest. Most ionic solids have higher melting points than metallic solids. A high melting point means strong bonds. In the case of crystalline solids, the bonds are between the structural units.

**Discuss physical properties as related to chemical bond types.**

- The stronger the bond, the higher the melting point of a substance.
- Even though ionic solids are poor electrical conductors in the solid phase, they become good electrical conductors when dissolved in water.
- Water molecules are polar and can attract charged ions bonded in a crystalline lattice. Bonds between the ions break, and a water solution results.
- Free electrons promote electrical conductivity. When molecular solids dissolve in water, molecules are separated intact from the crystalline lattice, and no free electrons result. Therefore, molecular solid solutions are nonconductors of electricity.

- Metallic solids are good electrical conductors, since free electrons in the solid structure are available.

The nature of the bonds between the structural units of crystalline solids impart other physical properties to these solids. Metals are good conductors of electricity because metallic bonds allow a free flow of electrons. Covalent network, molecular, and ionic solids do not conduct electricity because their bonds do not provide for mobile electrons. Remember, however, that ionic solids in a water solution have free electrons and are good conductors of electricity. Metallic solids are malleable and ductile; covalent network solids are brittle and hard. These differences in physical properties are caused by the chemical bonds between the units: It is all in the bonds!

## THREE-DIMENSIONAL CONSTRUCTION: FORMING THE CLAY OBJECT

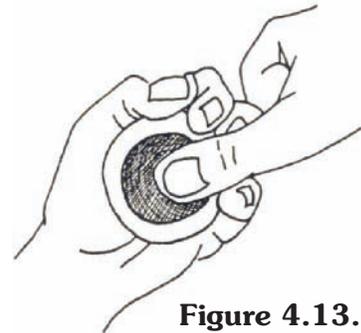
### Many Ways with Clay

Just as crystalline solids are bonded in many ways, clay artwork may be constructed in a variety of ways. Many construction techniques are available, several of which are noted here. These methods may be used alone or combined, allowing the artist to create an endless variety of forms.

#### How is a clay piece produced using the pinch pot method?

- In the pinch pot method, a ball of clay is pressed, pulled, and squeezed until an object is created.

**Pinch Pot: Press and Squeeze.** This is the oldest and most basic method of producing a clay piece. A ball of clay is placed in the palm of the hand. With the other hand, the clay is pressed and squeezed between the fingers and thumb to produce a small vessel or container, usually with curved sides. The thickness of the walls of the piece is regulated and made uniform with the fingers. (See Figure 4.13.)



**Figure 4.13.**

#### Describe the coil method of clay object construction.

- Coiling is a method for making a thin, hollow form. The artist rolls out ropelike strands of clay and then coils them one on the other. The coils are joined together and can be smoothed out or left as a ridged surface.
- The native tribes from the southwestern United States made large, finely shaped pots by the coiling method.

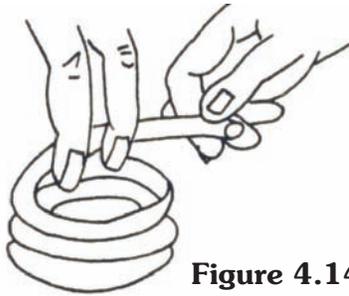


Figure 4.14.

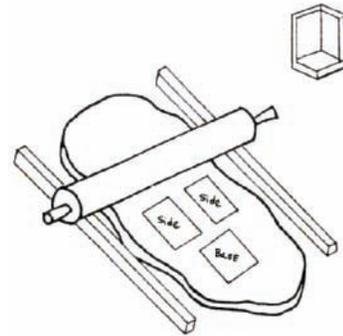
- In the twentieth century, a famous Pueblo potter, Maria Martinez, made beautiful black-on-black jars using the coil method.

**Coil Method: Roll, Press, and Smooth.** In this construction technique, the clay is first rolled into a sausagelike string, which is then coiled and attached upon itself. The layers formed by the coiled clay are smoothed together, either inside or outside the piece, to hold the coil together. (See Figure 4.14.)

**Describe the slab method of clay object construction.**

- In this method, clay is rolled into a sheet, or slab, that can be cut into pieces, curled into a cylinder, draped over a mold, or shaped into free-form sculptural configurations.
- The slab method is the best choice for forming rectilinear pieces.

**Slab Method: Roll and Cut.** In the slab method, the clay is rolled into a flat sheet using a rolling pin, the thickness being regulated with guide sticks. Pieces are cut from the sheet and assembled. (See Figure 4.15.)



1. roll out
2. cut out pieces
3. assemble

Figure 4.15.

**How can a mold be used to construct a clay piece?**

- A mold is a form containing a hollow, negative shape.
- Clay designed for use with molds is not primarily plastic. Molding clay is a liquid suspension of clay in water.
- The clay suspension must flow readily and smoothly and remain in suspension without settling within a mold. It must be designed so it can be pulled free from the mold without sticking, which can cause cracking and warping.
- The clay can either be pressed into the mold or draped around the mold.

**Forming in or on a Mold: Press and Form.** In this method, wet clay is shaped over or pressed into a mold made of a material such as plaster. This is often done to duplicate a preexisting shape. (See Figure 4.16.)

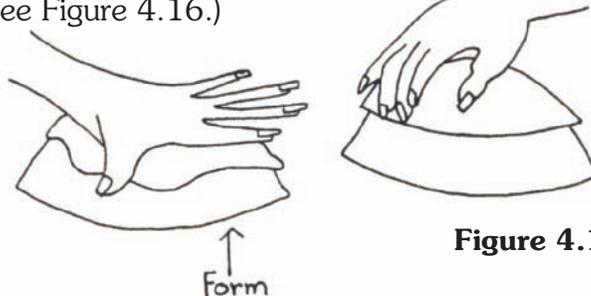


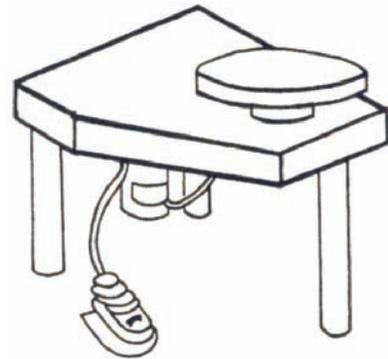
Figure 4.16.

**Describe how clay is formed on a potter's wheel.**

- Using a potter's wheel requires strength and control. As the potter's wheel spins, clay is pulled up by a potter into a predetermined shape. The type of clay, along with the potter's skills, determines the range of possible shapes for resulting pieces.
- A good throwing clay should not take on too much water while being worked and should stand well and hold its shape even when soft and thin.
- A good throwing clay is dense, highly plastic, and cohesive, with just enough rough material to aid the clay in standing while remaining wet and soft at the end of the throwing operation.

**Throwing or Forming on a Potter's Wheel:**

**Pulling Up.** A lump of clay can be formed or thrown on a potter's wheel. The wheel, whether manual or electric, consists of a flat, revolving, circular surface attached to a base. The revolution is controlled by a foot pedal or pump. Once the clay is centered on the wheel and the wheel is revolving, the clay can be pulled up with the hands and formed into a variety of shapes. This technique of forming clay, however, requires patience and practice and should not be attempted without first experiencing the other methods. (See Figure 4.17.)



**Figure 4.17. Electric Potter's Wheel.**

**Resources for Student Viewing**

The following films explain the many techniques of clay construction:

*Daughters of the Anasazi.* 28 min. Albuquerque, NM: 1990. Videocassette.

Hopper, Robin. *Beginning to Throw on the Potter's Wheel.* 60 min. Para Productions, 2003. potteryvideos.com. DVD.

*Native American Pottery Maker, Maria Martinez, Pueblo.* 27 min. native-americans.org, n.d. DVD.

Peeler, Mary, and Richard Peeler. *Peeler-Handbuilding Methods, 4 Methods.* 68 min. Ceramic Art Films, 2006. axner.com. 2 DVDs.

**TEXTURE AS AN ELEMENT OF DESIGN IN CERAMICS**

**What are some similarities between the construction of a ceramic artwork and the growth of a crystalline solid or the forging of a glass object?**

- A ceramic work of art is constructed by hand and formed into a predetermined shape. A crystalline solid grows to assume a predetermined shape. Aluminum atoms always pack into a face-centered cubic unit.
- Glass objects are forged by glass artists into carefully planned pieces.

- Dale Chihuly, a glass artist who designs and assembles large and small scale magnificent glass creations, creates glass bowls, flowers, and sea creatures that are planned to the last detail.

In this chapter we have considered three-dimensional ceramic constructions and nature's three-dimensional crystalline structures and glasses. There are many similarities between the construction of a ceramic work of art and the construction of a crystalline solid or glass. In both cases, units are built into a structure. The units are bonded together in a variety of ways. Both can result in pleasing works for the viewer to enjoy. A quartz crystal, made of silicon dioxide ( $\text{SiO}_2$ ), can be just as beautiful as a carefully crafted ceramic piece. Particular elements of design make these objects beautiful. When considering ceramic pieces and natural crystals, texture is an important element.

## How Does It Feel and Look?

### What is texture?

- Some textures are actual or tactile. We experience them through our sense of touch. The greater the differences in a surface elevation, the rougher the texture.
- Sometimes we cannot touch objects, but we can understand their texture by remembering similar objects that we have touched.
- Visual texture depends on the look of something. A zebra exudes visual texture.

Texture can be seen all around us. *Texture* is the feel and the look of things. How does something feel? Soft, rough, and smooth are all examples of one type of texture called *actual texture*, or the actual surface of something. A second type of texture is *visual texture*, or the look of something. Dots, zigzag lines, and stripes, as well as many other designs, can be arranged into patterns of visual texture.

Show students examples of visual and actual textures in two and three dimensions while discussing the following questions: Which examples have actual texture? Which examples have visual texture? What would be the result if visual textures were removed from the examples? How would you feel about the piece without its original texture? Which examples have both visual and actual textures? How do artists use visual and actual textures in their work? Can a sculpture have only visual texture? Why?

Examples of textures in two and three dimensions include the following artwork:

Lamp by Louis Comfort Tiffany, early twentieth century

Painting by Gustav Klimt, early twentieth century

Detail of cast-iron ornament from Carson Pirie Scott building (located on State Street, Chicago), Louis Sullivan, 1903–1904

Architecture: Church of Sagrada Familia (Barcelona, Spain), Antoni Gaudi, 1883–1926

Painting by Henri Rousseau, early nineteenth century

Painting by Henri Matisse, early twentieth century

Sculpture by Constantin Brancusi, early twentieth century

Sculpture by Edgar Degas, early twentieth century

Wallpaper by William Morris, late nineteenth century

Architecture: Eiffel Tower, Gustave Eiffel, 1889

Acoma Native American pottery

San Dominico Native American pottery

**ACTIVITY**

## 4.6

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### *Experimenting with Actual Textures*

#### **Objectives**

1. Students will create a variety of actual textures on clay using a variety of tools.

#### **Materials**

Water-based clay; rolling pin; variety of objects for pressing or scratching clay (paperclip; stick; pin; comb; burlap fabric; lace; string; Popsicle stick; pencil; etc.).

#### **Time**

30 minutes

#### **Procedure**

1. Roll out the clay using a rolling pin or pat it flat with your hands.
  2. Use the tools provided to scratch or press a variety of textures into the clay. Try repeating patterns as well as overall textures.
- 

**ACTIVITY**

## 4.7

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### *Making Pinch Pots Using Actual Textures*

#### **Objectives**

1. Students will create a three-dimensional clay form using the pinch pot method of construction.
2. Students will apply appropriate actual textures based on experimentation in Activity 4.6.

#### **Level One: Simple Pinch Pot**

#### **Materials**

Water-based clay; sponge; various tools for making textures (see Activity 4.6); water; student prepared glaze from Activity 4.3); flat stick for smoothing clay; kiln.

### Time

150 minutes for construction; two to three days' drying time; one day firing time; a second firing day after glazing

### Procedure

1. Wedge a ball of clay to remove the air bubbles. The clay ball should be a size that can be easily held in one hand, no larger than a tennis ball.
2. Hold the ball of clay in one hand and press into it with the thumb of the other hand, gradually making the opening larger by pressing with the thumb and fingers until a desired size and shape are achieved. Try to keep the walls of the piece about  $\frac{1}{4}$  in. thick.
3. Smooth the walls with a stick and a damp sponge.
4. Apply the texture at this point if appropriate, or allow the piece to become leather-hard before applying the texture.
5. Allow the piece to dry thoroughly (to greenware state).
6. The teacher should fire the piece in a kiln.
7. Apply a glaze prepared in Activity 4.3 to the bisque ware.
8. The teacher should fire the piece in the kiln a second time.

### Level Two: Combination Pinch Pots

#### Materials

Same as Level One.

#### Time

250 minutes for construction; remainder of time same as level one

#### Procedure

1. Follow steps 1–3 from the procedure in Level One, making two or three separate pinch pots. Try to vary the size of the pots.
2. Assemble the pinch pots to form a group (see Figure 4.18). Wet all surfaces (both surfaces) that will touch, and use a stick to score these areas with crosshatch marks. Press the pots together and add a small amount of wet clay to the outside of the joints for reinforcement.
3. Follow steps 4–8 from the procedure in Level One.



Figure 4.18.

### How is clay important in your life?

- Most people use clay objects on a daily basis.
- Clay is a simple material that is abundant, cheap, versatile, and easily acquired and prepared.
- Since clay objects were created by primitive people, the remains of these objects give us insights into the past.
- Clay has no value until it is transformed into valuable objects.
- Imagine a life without clay objects: no ceramic dishes, bricks, or flower pots. In addition, we would have no beautiful ceramic art objects to enjoy. Our lives are richer because someone realized that a material found in the ground could be fashioned into functional and beautiful objects.

Clay is one of the most important building materials conceived by humanity. Without clay, little from our past would remain preserved. Without clay, we would have fewer beautiful works of art to enjoy; we would not have useful electrical insulators and other modern-day appliances. Recently, “high”-temperature (90°K or –183°C) ceramic superconducting materials have been developed. Ceramic materials are used to make heat shields for space vehicles, such as the space shuttle. Clay is a material of the past and of the future. We will always be playing with clay.

### NOTES

1. Lorenzo Camusso and Sandro Bortone, *Ceramics of the World* (New York: Harry N. Abrams, 1991), 18.
2. Ruth Lee, *Exploring the World of Pottery* (Chicago: Children’s Press, 1967), 34.
3. *Ibid.*, 25.
4. Steven S. Zumdahl, *Chemistry*, 2nd ed. (Lexington, MA: D.C. Heath, 1989), 438.

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Zumdall, Steven S., et al. *World of Chemistry*. Evanston, IL: McDougal Littell, a Houghton Mifflin Co., 2002. (Chapters 6 and 12.)

## FILM

*Introduction to Throwing on the Potter's Wheel*. 53 min. Geneva, FL: Thoughtful Productions, 1993.

*The World of Chemistry: 08 Chemical Bonds*. 30 min. University of Maryland and the Educational Film Center, 1990.

*The World of Chemistry: 11 The Mole*. 30 min. University of Maryland and the Educational Film Center, 1990.



## ANSWERS TO ACTIVITY AND DEMONSTRATION QUESTIONS AND CONCLUSIONS

### Activity 4.1 Atomic, Ionic, and Molecular Crystalline Structures: Three-Dimensional Works of Art

#### Level One

1. Metals such as copper, silver, gold, magnesium, and zinc form atomic crystalline solids. Salts such as sodium chloride, potassium sulfate, calcium chloride, and ammonium phosphate form ionic crystalline solids. Hydrogen, oxygen, iodine, water, carbon dioxide, methane, and methyl alcohol form molecular crystalline solids. Ionic crystalline solids are often cubic in shape. Molecular crystalline solids come in a variety of shapes. Water solidifies to form a six-sided crystal that can be observed in snowflakes. There are seven crystalline systems that are built from unit cells, the smallest repeating unit that has all of the symmetry characteristics of the way the atoms are arranged. These systems are labeled cubic, tetragonal, orthorhombic, trigonal, hexagonal, monoclinic, and triclinic.
2. The models appear to be massive depending on how long the toothpicks are. Long toothpicks can make the unit cell appear massive and linear.
3. There is no regularity in the atomic or ionic structure of a glass. Every time a glass solidifies, it can assume a different shape. When nonglass substances solidify, they form into a regular, predictable lattice.

#### Level Two

1. Different metal atoms are different sizes. Different size atoms can pack into different crystalline structures. Try packing small marbles and then large tennis balls. Also, atomic electron configuration affects atom packing. Metallic solids bond through electrostatic attraction among metal ions and electrons.
2. Representing atomic packing arrangements, Charles Howard Hinton in 1912 created “Hypercube”, an arrangement of cubes in the shape of a three dimensional cross. In the same vein, in 1528 Albrecht Dürer created *Template for a Cube*. In 2000 Joseph Albers created *Homage to the Square* and *Section Through the Colour Solid of Wilhelm Ostwald*, the former resembling cubic crystalline solids and the latter resembling the crystalline structure of water.
3. Atomic solids are often more dense than ionic solids. In ionic solids, ions of different sizes must be packed together. In this packing, spaces between ions make the solid less dense than atomic solids, where the atoms are uniform in size.

4. In a glass the structural particles are irregularly scattered throughout the solid. A glass cracks along these irregular lines. In a crystal, the particles are regularly arranged, and a crack occurs along these lines.
5. The laboratory prepared crystals may be more regular than the store bought crystals because the laboratory crystals grew slowly without disturbance. The store bought crystals are processed where damaging can occur.

### **Demonstration 4.1 The Difference Between Crystalline-Solid Formation and Glass Formation**

#### **Level One**

1. The glass globules should not have the same shape. Glasses have a random atomic structure. As a glass globule cools, it can assume any shape.
2. All silver crystals have the same geometric shape. Therefore, the crystalline shape of a metallic solid is a function of the size of the metal solid atoms and their electron configuration. Each metal has its own geometric crystalline shape. Aluminum atoms pack into a face-centered cubic cell. Iron's solid structure is body-centered cubic.
3. Copper plus silver nitrate yields copper II nitrate and silver.
4. Glass melting and solidifying.
5. When copper metal atoms react with silver and nitrate ions, the copper atoms lose electrons and become copper ions. The copper atoms undergo oxidation. The silver ions gain electrons and undergo reduction. The nitrate ions are spectator ions.

#### **Level Two**

1. In crystalline solids, the particles are in a highly ordered, repeating pattern. Substances that solidify slowly tend to form crystalline solids. The most important substance in glass is silicon dioxide. When solid glass melts and then cools, the molecular structure of the original solid is not reestablished. This can occur because liquid glass cools rapidly.
2.  $2\text{AgNO}_{3(\text{aq})} + \text{Cu}_{(\text{s})} \rightarrow \text{Cu}(\text{NO}_3)_{2(\text{aq})} + 2\text{Ag}_{(\text{s})}$   
Class: metallic single replacement (see Chapter 3).
3. Metallic copper atoms change to blue copper ions. Electrons are transferred from the copper atoms to the silver ions which change into silver atoms.
4. The oxidizing agent gains electrons. The silver ions are oxidizing agents. The reducing agent loses electrons. The copper metal is the reducing agent.

## Activity 4.2 Glazing Pottery: Calculations Needed to Prepare a Glaze

### Level One

1.  $6.02 \times 10^{23}$  molecules.
2. If each paper is one mm thick, then the stack would be  $6.02 \times 10^{23}$  mm or  $6.02 \times 10^{20}$  meters high.

### Level Two

1. The mass of one mole of MgO is 40.3 and the mass of one mole of CaO is 56.1. This is because the relative mass of one MgO molecule is less than the relative mass of one CaO molecule.
2. When the clay piece is fired, the glaze clay and the piece clay become one. This causes the glaze to tightly adhere to the clay piece. Also, the clay helps to keep the glaze ingredients in suspension. The clay thickens a glaze so it can be evenly applied to a clay piece. Most of the aluminum oxide called for in a glaze is supplied by clay. The theoretical composition of kaolin is  $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ .
3. Copper oxide added to highly basic glaze compositions will produce turquoise blues. In lead-based glazes, copper oxide will produce soft greens. In barium-based glazes, copper oxide produced a greenish-blue of great depth and intensity. In a reduction-fired glaze, copper carbonate produces a red glaze.

## Activity 4.3 Preparing Glazes and Clay Slabs and Testing the Glazes on the Clay Slabs

### Level One

1. Silicon dioxide is the body of the glaze. It is the fundamental oxide of glass. It has a low coefficient of expansion. It does not affect glaze colorants. Copper oxide along with copper carbonate provides blue-green glazes. Aluminum oxide is used in small amounts in glazes. It makes the glaze more viscous. It prevents recrystallization during glaze cooling. Also, it adds to the hardness, durability, and tensile strength of glazes. Because of its high melting point, 2040°F, it lends opaqueness and roughness to a glaze.
2. A glaze that is too thick may not harden totally. Also, it may not adhere to a clay piece. It can crack easily. If the glaze is too thin, it may also not adhere to a clay piece surface and may crack. A thin glaze may run off a piece in a kiln and unintentionally glaze it.
3. When the glaze cracks, it cracks in an irregular pattern. There are no flat planes in the resulting pieces. This indicates a lack of atomic crystalline structure.

## Activity 4.4 Construction of a Three-Dimensional Periodic Table

### Level One

2. Elements 110 to 118 would appear in the seventh row of the periodic table. Element 110 would fall under platinum and element 118 below radon.
3. Mainly linear. If the periodic table is transformed into a spiral sculpture, it would be mainly solid. If a mobile periodic table is created, a linear, three-dimensional work of art would result. Famous artworks that resemble a mobile periodic table are the Alexander Calder mobiles. A good example is *Untitled* at the National Gallery of Art in Washington, D.C. Two red metal pieces represent the s elements, and six black metal pieces represent the p elements.

### Level Two

1. The greatest advantage of a three-dimensional periodic table is the correct placement of the f elements. In addition, a three-dimensional periodic table is compact and easy to read. A disadvantage of the spiral three-dimensional periodic table is the location of the rows. Since the spiral is continuous, numbers are needed to identify the rows. Also, the elements in a spiral periodic table must be rotated in order to see all of them.
2. Hydrogen can be at the peak of a spiral periodic table. In a mobile periodic table, hydrogen hangs by itself at the mobile top. In a sample of water, 99.9844% of the hydrogen atoms have no neutrons. Hydrogen is the only element having atoms without nuclear neutrons. Most of the remaining 0.0156% have one neutron. Hydrogen can act like a metal or nonmetal. It can lose one electron to form a positive ion acting like a metal, or gain an electron to form a negative ion acting like a nonmetal. Two hydrogen atoms can share electrons to form a stable hydrogen molecule. Hydrogen has the physical properties of a nonmetal. It is a colorless, odorless gas at room temperature.
3. A spiral periodic table can easily add new elements at the spiral bottom.
4. Whether the periodic table is two- or three-dimensional, physical and chemical properties of the elements *repeat* (i.e., recur periodically) as one looks across a row or down a column.
5. The three-dimensional periodic table can be a solid spiral sculpture or a functional mobile. The families or rows provide ideal components for an attractive mobile.

## Activity 4.5 Solid Bonding and Clay Construction

### Level One

1. For molecular solids, the structural units are atoms or molecules. They are bonded by hydrogen bonds or dipole-dipole dispersion forces. Dipole-dipole

dispersion forces are attractions between oppositely charged permanent dipoles. Permanent dipoles are molecules that have a small positive charge at one end of the molecule and a small, equal negative charge at the other end. For ionic solids, the structural units are positive and negative ions. The electrostatic attraction between these ions bonds them together. For metallic solids, atoms are the structural units. Metallic bonds, positive metal atom ions surrounded by a sea of electrons, bond the ions together. For covalent network solids, the structural units are atoms. Covalent bonds hold these solids together.

- Organic substances such as methane, naphthalene, and sucrose, and inorganic substances such as iodine, sulfur trioxide, carbon dioxide, and ice are molecular solids. Salts such as sodium chloride, potassium nitrate, and magnesium sulfate have ionic bonding structures. All metal elements, such as copper, silver, and iron, have metallic bonds. Examples of covalent network solids are diamond, graphite, and silicon dioxide.

### **Level Two**

- The seven units cells are cubic, tetragonal, monoclinic, triclinic, orthorhombic, rhombohedral, and hexagonal.

- | <b>Type of Solid</b>           | Molecular              | Metallic     | Ionic | Covalent Network |
|--------------------------------|------------------------|--------------|-------|------------------|
| <b>Melting Point</b>           | Low to moderately high | Low to high  | High  | Very high        |
| <b>Electrical Conductivity</b> | Poor                   | Excellent    | Poor  | Poor             |
| <b>Thermal Conductivity</b>    | Poor                   | Excellent    | Poor  | Poor             |
| <b>Malleability/Ductility</b>  | Poor                   | Excellent    | Poor  | Poor             |
| <b>Hardness</b>                | Soft                   | Soft to Hard | Hard  | Very Hard        |

Covalent network solids have the highest melting points because it takes a great deal of energy to break the covalent bonds between atoms arranged in a strong network pattern. Metallic solids have the best electrical conductivity because the metal atoms have valence electrons that are free to move from place to place. Metallic solids also have the highest thermal conductivity because these mobile electrons can transmit heat energy. Metallic solids are the most malleable and ductile of the four solids. Malleability is the ability to be pounded into thin sheets. When metals are pounded, they hold together because the valence electrons can shift to bond in new positions. Ductility is the ability to be drawn into a wire. In this case, the valence electrons also move into new positions and form new bonds. Covalent network solids are

very hard because the network of atoms held together with strong covalent bonds results in a strong substance.

3. The subtractive method involves removing portions of a sculpting material. Clay can be removed around crystalline solid structural units to leave the unit cell lattice points and bonds connecting these points. M. C. Escher, a Dutch artist who was a lover of visual puzzles, painted a work entitled *Cubic Space Division*, which depicted three-dimensional space created by stacking many cubes, each cube being a unit cell of the whole. This work can be modeled in clay using the subtractive method. In Escher's works, the negative space (the area where the clay is removed) is just as important as the positive space.



# Sculpture and Organic Chemistry

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## *Macroscopic and Microscopic Sculpture*



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: Most compounds obtained from living organisms contain carbon. What would happen if most living organisms were composed of compounds that contained silicon atoms rather than carbon atoms?**

## INTRODUCTION

*Organic chemistry* is the study of compounds that contain carbon (C). Carbon atoms have a strong affinity for each other. Like children playing “crack the whip,” during which they hold hands to bond in an endless variety of kinetic shapes, carbon atoms bond together in long chains to form an endless variety of organic molecules. We would expect the other members of the carbon family, such as silicon (Si), to form long-chain molecules by bonding with each other. However, silicon atoms are larger than carbon atoms and fit better into a silicon-oxygen bond arrangement than a silicon-silicon bonded molecule. Silicon atoms bond with oxygen (O) atoms in a network arrangement to form silicates.

### **What features make carbon atoms ideal components for living organism compounds?**

- Carbon atoms form strong covalent bonds to other carbon atoms and also strong bonds to oxygen, hydrogen, sulfur, and nitrogen atoms.
- Carbon atoms can form a vast number and variety of molecules necessary for living organisms.

In Chapter 4 we learned how silicates give clay its plastic properties. In this chapter we will see how carbon atoms bond in chain arrangements to produce organic compounds that can have the plastic properties of clay. We will study sculpture and describe molecular forms as sculptures. Finally, we will see how organic molecules, microscopic sculptures, have the same properties as macroscopic sculptures, which are visible to the naked eye.

## MACROSCOPIC SCULPTURE

### Sculpture: Form in the Round

Everyone has seen sculpture. It is all around us, in the park or as part of the front of a building, in an art museum, on a table in a living room, in the lobby of an office building, or for sale in a department store or art gallery. Even if it is as small as a piece of jewelry or as large as Mt. Rushmore, we can see it. We are also surrounded by invisible sculpture. Organic compounds made of chains of carbon atoms form the unseen sculptures that are the molecules of living objects. These microscopic sculptures express the same elements of design as the macroscopic sculptures that we see all around us.

### It's Sculpture: But What Is It?

Macroscopic sculpture, the sculpture we see around us, can be realistic or representational, like paintings and drawings, meaning it is similar to or resembles an observed subject. It may also be nonobjective, a piece not based on any observed subject matter. It may be *abstract*, a term used to describe forms created by the artist based on actual subject matter, but altered or distorted in some way. Sometimes in an abstract work there is little resemblance to the original subject, causing the viewer to ask, "What is it?" Microscopic sculptures, organic compounds, may be nonobjective, representing only their atomic arrangement (determined by their atom types and their bonds types), or abstract, resembling actual subject matter. However, abstract microsculptures are not meant to resemble an observed subject. They represent a composition of matter. Finally, some macrosculptures are called *kinetic* because they have moving parts. All microsculptures are kinetic because molecules are always in motion, unless they are reduced to a temperature of absolute zero, a state at which, theoretically, all molecular motion stops.

### How is a sculpture different from a two-dimensional painting?

- Whether it be a macroscopic or a microscopic sculpture, a sculpture exists in space like a molecule or a tree or a mountain or a human being.
- A sculpture takes the viewer through space. The sculpture can be seen, touched, and even walked around. A two-dimensional painting can only cover a flat area.

### Challenge Activity

Construct a kinetic sculpture depicting an organic molecule such as methane or a longer, branched hydrocarbon. Use Styrofoam balls for atoms and springs or toothpicks for bonds between atoms. Color the Styrofoam balls to represent atom types. Find a way to show atomic vibrations and molecular rotations and translations. Your kinetic sculpture should be in constant motion.

### **Examples of Sculpture by Professional Artists**

- Any African sculpture (abstract)
- Any work of Henry Moore (abstract), twentieth century
- Any Native American totem pole (wood, abstract)
- Any Italian Renaissance sculpture (realistic)
- Greek Parthenon frieze (marble relief, realistic), fifth century
- Statue of Liberty (copper sheet over steel frame, realistic), nineteenth century (steel frame—Gustave Eiffel, artist—Frederic Bartholdi)
- Any nonobjective mobile by Alexander Calder (kinetic), twentieth century
- Any sculpture by David Smith (nonobjective), twentieth century
- Life Death* (neon, abstract, kinetic), Bruce Nauman, 1983
- Any piece of jewelry by Salvador Dali (abstract), twentieth century

## **THE ELEMENTS OF SCULPTURE**

### **The Shape of Things: Shape as an Element of Design**

#### **How does the element of shape make a sculpture unique to an artist's work?**

- In *Moses*, Michelangelo shaped Moses's head so that every angle has a stern, religious, and charismatic look.
- Greek sculptors discovered beauty in the fluted forms depicted in draped garments.

Most forms of sculpture have shape as a common element of their construction. Shapes appear in all forms of art. Paintings and drawings contain shape as an element of their composition. Shapes describe subject matter. Shapes, whether realistic, abstract, or nonobjective, can be curvilinear, angular, organic-based, based on natural forms (free-form), or geometric. Shapes can express movement, direction, emotion, or mood. The following examples of art contain shape expressing movement, direction, emotion, or mood:

#### **Two-Dimensional Shapes**

- The Red Horseman*, Roy Lichtenstein, 1974
- Composition in White, Black and Red*, Piet Mondrian, 1936
- Guernica*, Pablo Picasso, 1937
- The Harlequin Carnival*, Joan Miró, 1924–1925
- Nude Descending the Staircase*, Marcel Duchamp, 1912
- The Starry Night*, Vincent van Gogh, 1889

#### **Three-Dimensional Shapes**

- The Bird*, Constantin Brancusi, 1914
- Black Beast*, Alexander Calder, 1940

#### **In sculpture, what is positive and negative space?**

- Positive space is the place where the sculpture is located.

- Negative space is the place around the sculpture. A sculpture makes negative space come alive.

**ACTIVITY****5.1*****Exploration of Shape*****Objectives**

1. Students will identify organic and geometric shapes.
2. Students will compare and contrast the characteristics of various types of shapes.

**Level One: Organic and Geometric Shapes****Materials**

Reproductions of the example artwork listed above (or other reproductions with shapes expressing movement, direction, mood, and emotion).

**Time**

30 minutes

**Procedure**

1. Have students view reproductions of artwork examples in the list above and answer the following questions for each:
  - a. Describe the shapes you see in the piece. What feelings or emotions do they suggest?
  - b. Are the shapes organic (free-form) or geometric?
  - c. If the organic shapes were changed to geometric and the geometric shapes were changed to organic, how would this affect the intent of the work?
  - d. Do you think the artists are successful in expressing their ideas through the use of the shapes? Explain.

**Level Two: Organic to Geometric****Materials**

4-x-24-in. drawing paper; ruler; pencil; magazines or original drawings by students.

**Time**

50 minutes

### Procedure

1. Have students choose a realistic image from a magazine or an original drawing. The image should be an organic shape (e.g., an animal or a plant).
2. Have students orient the paper so the long edge is horizontal and divide the sheet into six 4-x-4-in. squares.
3. Draw the realistic image in the leftmost rectangle (see Figure 5.1).



Figure 5.1.

4. Choose a geometric shape and draw it in the rightmost rectangle. This geometric shape should be very different from the shape in the leftmost rectangle.
5. Use the three remaining rectangles to transform the realistic, organic image in the leftmost rectangle into the geometric shape in the rightmost rectangle. Each drawing should gradually change the subject from a realistic, organic image to a geometric image.

## MICROSCOPIC SCULPTURES: ORGANIC MOLECULES AND SCULPTURE ELEMENTS

*Organic molecules* are minute, nonobjective sculptures, or are considered abstract when they resemble familiar, identifiable objects. They have shapes that are curvilinear, angular, or geometric (or a combination). Just as in macroscopic sculptures, these shapes can express movement and direction. If one considers organic molecules to be amazing tiny sculptures of the stuff of which matter is made, such a microsculpture can evoke an emotion or set a mood in the same way that a macrosculpture evokes emotions and sets moods.

### Challenge Activity

Pick a hydrocarbon molecule such as methane,  $\text{CH}_4$ , benzene,  $\text{C}_6\text{H}_6$ , or octane,  $\text{C}_8\text{H}_{18}$ . These molecules are discussed below. Make a model of your molecule using Styrofoam balls and toothpicks. Now you have created a microsculpture that represents a geometric shape. Identify the shape of your model. (Methane is a tetrahedral, benzene is a ring, and octane is a cylinder.) Looking at this geometric shape microsculpture, create a realistic image sculpture. This can be made of Styrofoam balls and toothpicks or clay. Are hydrocarbon molecules abstract sculptures?

## THE NAMES AND SHAPES OF ORGANIC MOLECULES

### Count the Carbon Atoms

The simplest class of organic compounds are hydrocarbons. As the name implies, these are carbon molecules that contain carbon (C) atoms and hydrogen (H) atoms. In Chapter 4 we learned that carbon atoms form covalent bonds with other carbon atoms. Carbon atoms have four outermost electrons and, therefore, four bonding sites. A carbon atom can share its four electrons with four other atoms. Remember, eight is great! Atoms are comfortable with eight outermost electrons. In hydrocarbons, carbon atoms will bond with each other to form chain and/or cyclic molecules. Then hydrogen atoms step into the remaining, unoccupied bonding sites.

#### What makes carbon bonding so unique?

- Eight outermost electrons make an atom very stable.
- In addition, a carbon atom is relatively small, so its outermost negative electrons are close to its positively charged nucleus. The shorter the distance between these particles, the stronger their attractive force. This allows carbon to form strong, short covalent bonds.

Carbon atoms can bond in an infinite number of arrangements. They can bond in straight chains. They can add branches to these straight chains. They can bond in cyclic arrangements. Hydrocarbons can have only single bonds; they can have double bonds in which two pairs of electrons are shared; and they can even have triple bonds—sharing of three pairs of electrons is possible. With all these possible arrangements, it is necessary to have a simple hydrocarbon naming system.

**Essential Question: If two oxygen atoms bond to form a stable O<sub>2</sub> molecule and two nitrogen atoms bond to form a stable N<sub>2</sub> molecule, why do two carbon atoms not bond to form a stable C<sub>2</sub> molecule?**

To discern how many carbon atoms are in a straight chain or branch of a carbon compound, prefixes are used. If all the carbon-carbon bonds are single bonds, the hydrocarbon name ends in *-ane*. These molecules are called *alkanes*. If there is a double carbon-carbon bond, the name ends in *-ene*. These molecules are called *alkenes*. If there is a triple carbon-carbon bond, the name ends in *-yne*. These molecules are called *alkynes*.

Table 5.1 lists the names and formulas of the first 10 unbranched (sometimes called *normal*) alkanes, alkenes, and alkynes. Photocopy and distribute this table to students. As students study this table, they should look for relationships between the number of carbon atoms and the number of hydrogen atoms in the various hydrocarbons. They will soon discover that the general formula for alkanes is  $C_nH_{2n+2}$ , the general formula for alkenes is  $C_nH_{2n}$ , and the general formula for the alkynes is  $C_nH_{2n-2}$ .

**Table 5.1**  
**Names and Formulas of Alkanes, Alkenes, and Alkynes**

Alkanes		Alkenes		Alkynes	
Name	Formula	Name	Formula	Name	Formula
Methane	CH <sub>4</sub>	None		None	
Ethane	C <sub>2</sub> H <sub>6</sub>	Ethene	C <sub>2</sub> H <sub>4</sub>	Ethyne	C <sub>2</sub> H <sub>2</sub>
Propane	C <sub>3</sub> H <sub>8</sub>	Propene	C <sub>3</sub> H <sub>6</sub>	Propyne	C <sub>3</sub> H <sub>4</sub>
Butane	C <sub>4</sub> H <sub>10</sub>	Butene	C <sub>4</sub> H <sub>8</sub>	Butyne	C <sub>4</sub> H <sub>6</sub>
Pentane	C <sub>5</sub> H <sub>12</sub>	Pentene	C <sub>5</sub> H <sub>10</sub>	Pentyne	C <sub>5</sub> H <sub>8</sub>
Hexane	C <sub>6</sub> H <sub>14</sub>	Hexene	C <sub>6</sub> H <sub>12</sub>	Hexyne	C <sub>6</sub> H <sub>10</sub>
Heptane	C <sub>7</sub> H <sub>16</sub>	Heptene	C <sub>7</sub> H <sub>14</sub>	Heptyne	C <sub>7</sub> H <sub>12</sub>
Octane	C <sub>8</sub> H <sub>18</sub>	Octene	C <sub>8</sub> H <sub>16</sub>	Octyne	C <sub>8</sub> H <sub>14</sub>
Nonane	C <sub>9</sub> H <sub>20</sub>	Nonene	C <sub>9</sub> H <sub>18</sub>	Nonyne	C <sub>9</sub> H <sub>16</sub>
Decane	C <sub>10</sub> H <sub>22</sub>	Decene	C <sub>10</sub> H <sub>20</sub>	Decyne	C <sub>10</sub> H <sub>18</sub>

### Challenge Activity

Write a play. The play should feature a family of hydrocarbon molecules. The father can be Octane, the mother Pentane, and the children Propane and Methane. There can be a complex cousin, 3-Methyl Heptane, and a twisted uncle, Benzene. The characters have personalities dictated by their hydrocarbon properties. Make the setting appropriate for hydrocarbon characters in a sculpture garden. Have the characters bond. Use your imagination. Produce the play for your class.

### Hydrocarbons Are Shapely Molecules

As discussed previously, each carbon atom in a hydrocarbon has four bonding sites. This is because the four outermost carbon atom electrons are seeking four additional electrons to have the comfortable arrangement of eight outermost electrons. Hydrogen atoms are the ideal companions for carbon atoms. Each hydrogen atom can offer one electron to a carbon atom. If one carbon atom bonds with four hydrogen atoms, methane (CH<sub>4</sub>) is formed. The angle between each of the bonds in the carbon atom is 109.5 degrees, which results in the formation of a tetrahedral-shaped molecule. When carbon atoms bond to each other, they form zigzag chains. If hydrogen atoms are bonded to the carbon atoms, they will project from the carbon atoms and form a molecule shaped like a caterpillar with projections. In alkenes, with one double bond, and alkynes, with one triple bond, the zigzag carbon chain shape becomes distorted.

In Activity 5.2, students will build models of various alkanes, alkenes, and alkynes and view these molecules as sculptures that exist in nature on a microscopic level. They will consider these shapes as an element of sculpture design.

**ACTIVITY****5.2*****Modeling Hydrocarbon Molecules:  
Microscopic Sculptures*****Objectives**

1. Students will model hydrocarbon molecules and observe their shapes.
2. Students will describe how the molecular models represent chemical formulas.
3. Students will discuss the rules for naming simple (normal) hydrocarbons.
4. Students will view the molecular models as microscopic sculptures and explain why they are either abstract or nonobjective.

**Materials**

Ball-and-stick molecular-model building kit; protractor; drawing paper; colored pencils.

**Time**

100 minutes

**Procedure**

1. Work in groups to research the chemical formulas for and build models of the following molecules: methane, propyne, pentene, butane, ethyne (acetylene). The chemical formulas are methane,  $\text{CH}_4$ ; propyne,  $\text{C}_3\text{H}_4$ ; pentene,  $\text{C}_5\text{H}_{10}$ ; butane,  $\text{C}_4\text{H}_{10}$ ; ethyne,  $\text{C}_2\text{H}_2$ .

Use a four-hole ball with the holes equally spaced to represent a carbon atom, and use a one-hole ball to represent a hydrogen atom. Use sticks for single bonds, and springs for double or triple bonds. Measure the bonding angle between the carbon and hydrogen atom in the methane molecule.

2. Label each model as either a nonobjective or an abstract sculpture.
3. Using colored pencils, draw each model.
4. With colored pencils, make either a nonobjective or an abstract drawing using at least one molecular model.

**Questions and Conclusions****Level One**

1. Explain how to write a chemical formula using a hydrocarbon name (see Table 5.1, p. 207). In the explanation, describe the general formulas and rules for naming alkanes, alkenes, and alkynes.

2. Explain why a four-hole ball is used to represent a carbon atom, and why a one-hole ball is used to represent a hydrogen atom.
3. What is the bond angle between the carbon atom and a hydrogen atom in the methane molecule? Is this angle the same for all the carbon-hydrogen bonds in methane?
4. What is the shape of the methane molecule?
5. How does the shape of a chain of carbon atoms change when a molecule has one double bond and one triple bond? Why are springs used to represent double and triple bonds?
6. For each of the molecular models studied in Activity 5.2, explain your choice for labeling it as a nonobjective or abstract sculpture. For each of your drawings, explain why it is a nonobjective or abstract work of art.
7. Explain how the shapes in your artwork show movement, direction, emotion, or mood.

#### **Level Two**

1. Write the chemical formulas for an alkane, an alkene, and an alkyne, each containing 25 carbon atoms, and explain how you derived the formulas.
  2. Considering the tetrahedral shape of methane, construct a multiple-methane-molecule sculpture, or draw a picture of such an arrangement. Explain why the sculpture or drawing is abstract or nonobjective. How do the shapes in the sculpture or drawing evoke a mood or emotion? How do the shapes show direction or movement?
  3. Considering the length of a chain of carbon atoms in a hydrocarbon molecule, theorize how the length of a carbon chain might influence hydrocarbon physical properties such as boiling point, melting point, and density.
- 

## **SHAPE IN MACROSCULPTURES AND MICROSCULPTURES**

### **Shape Can Determine Properties**

Just as shape is a common and essential element in the construction of a sculpture, the shape of a molecule is extremely important in determining the physical and chemical properties of a substance. For the alkanes, as the number of carbon atoms in the molecule increases, thereby increasing the molecular weight, the boiling point and the melting point of the substances increase. This would indicate that intermolecular forces, the attractive forces between molecules, increase as the number of carbon atoms and the molecular weight of the alkane molecules increase.

**How can molecular shape effect a chemical change?**

- An *enzyme* is a protein molecule that speeds up a chemical reaction.
- To be effective, an enzyme must have a particular shape. This enzyme shape allows the enzyme to fit into a certain accepting molecule, like a lock accepts only a certain key.
- After the catalyzed reaction is completed, the enzyme and accepting molecule separate.

**Weak Intermolecular Forces: London, Dipole-Dipole, and Van der Waals**

Because unbranched alkanes are neutral, nonpolar molecules, it is difficult to explain the existing intermolecular force between such alkanes that increases as the alkane molecules become larger. We will see that this attractive force is weak and tenuous. These molecules do not become overly friendly with each other. In theory, as atoms within one alkane molecule approach the atoms of another alkane molecule, the electrons around these atoms, for an instant, arrange themselves asymmetrically around the atoms so that instant dipoles are formed—the positive side of one atom attracts the negative side of another atom. This weak intermolecular attractive force is called a *London Force*. When there is a weak intermolecular attractive force between polar molecules, the force is called a *dipole-dipole force*. Together, London forces and dipole-dipole forces are called *Van der Waals forces*.

Another theory explaining an increase in boiling and melting points with increases in alkane molecular weight caused by the addition of carbon atoms is that the longer-chain molecules intertwine like strands of spaghetti. Additional energy is needed to untangle these long-chain alkane molecules and allow melting and boiling to take place.

**Normal, Straight, or Unbranched Chains; Branched Chains or Cyclic Molecules: Microscopic Sculptures Have a Variety of Shapes**

Our discussion has centered around hydrocarbon molecules that consist of carbon atoms bonded to each other in long chains. These chains are called normal, straight, or unbranched. The chains may have only single bonds (alkanes), double bonds (alkenes), or triple bonds (alkynes). Hydrocarbons with only single bonds are called *saturated*; hydrocarbons with double or triple bonds are called *unsaturated*. Not all hydrocarbons want to form straight chains. After all, who among us wants to be straight and serious all the time? Some of us will always be comedians. In the world of hydrocarbon molecules, the comedians are the branched and cyclic molecules.

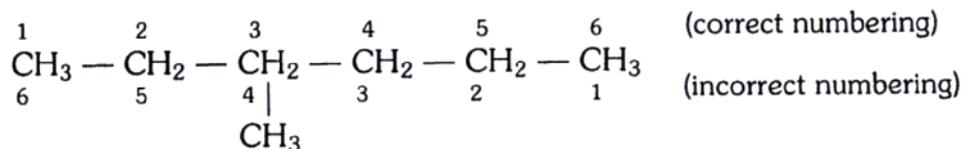
### Challenge Activity

Make a model of a DNA molecule. (Usually biology classrooms have model kits available for this purpose.) A DNA molecule has three components: a nitrogen-containing base; combinations of cytosine, adenine, thymine and guanine, and ribose (a five-carbon sugar); and a phosphate group. What is the shape of this molecule? How is the activity of the DNA molecule explained by its shape?

### Naming the Straight Hydrocarbons and the Comedians

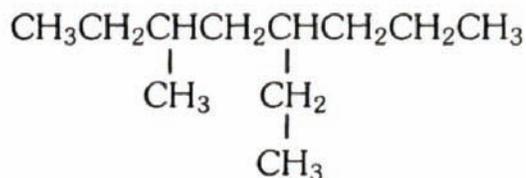
In a straight-chain hydrocarbon, the name of the hydrocarbon prefix indicates the number of carbon atoms in the chain; the suffix indicates the kind of bonds—single, double, or triple—in the chain. For a branched hydrocarbon molecule, the location of the branch is indicated by a number, then a word ending in *-yl* indicates how many carbon atoms are in the branch (the prefixes to indicate number of carbon atoms are, in order from one through ten: meth-, eth-, prop-, but-, pent-, hex-, hept-, oct-, non-, dec-), then the remaining straight chain is named as if it were a straight-chain molecule without a branch. Sounds simple, right? This is why we call branched molecules comedians. However, it is not as confusing as it sounds. Just one more rule: Carbon atoms in the straight chain, the longest unbranched chain of carbon atoms, are numbered to give the branch the lowest possible number.

The best way to learn to name branched hydrocarbon molecules is to apply the rules to an example molecule:



The correct numbering shows us that the branch comes from the third carbon atom in the straight chain. Therefore, the hydrocarbon name begins with the number 3. There is one carbon atom in the branch, so the branch name begins with *meth-* and ends in *-yl*—methyl. The straight chain has six carbon atoms (*hex-*) with only single bonds (*-ane*), so it is named hexane. Put it all together and we have 3-methylhexane.

When a hydrocarbon has more than one branch, the branches are named as indicated above, beginning with the branch of smallest number. For example:



This hydrocarbon is named 3-methyl 5-ethyloctane. In this octane molecule, if both branches were methyl branches, the name would be 3,5 dimethyl octane.

Cyclic (or ringed) hydrocarbons are simply named with the prefix *cyclo-* followed by an ending that is determined by how many carbon atoms are in the molecule. For example, a ringed hydrocarbon molecule containing five carbon atoms and only single bonds would be named cyclopentane. If the same molecule had a double bond between two carbon atoms in the ring, the name would be cyclopentene.

### Hydrocarbon Molecules: An Infinite Number of Microsculptures

An endless variety of hydrocarbon molecules can be constructed. Each molecule will have different physical and chemical properties. For example, gasoline is made of hydrocarbon molecules having from five to ten carbon atoms. When smaller-chain hydrocarbon molecules and branched hydrocarbon molecules are added to the gasoline, a car engine works more smoothly. Each hydrocarbon molecule has unique properties and a unique structure. We can consider a hydrocarbon molecule as a microsculpture having a unique shape. We will examine shape further and understand the relationship between shape and branched and cyclic hydrocarbon molecules. (See Figure 5.2.)

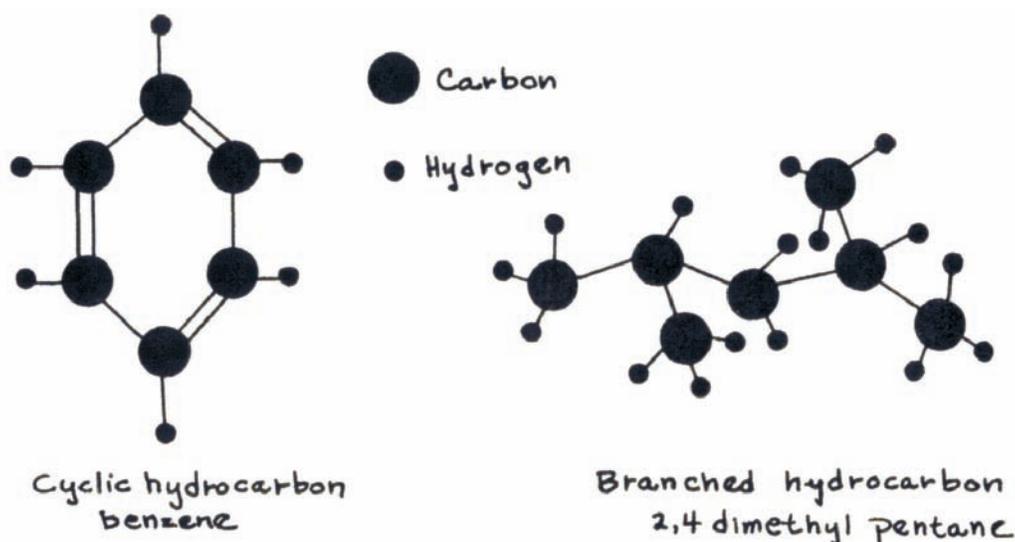
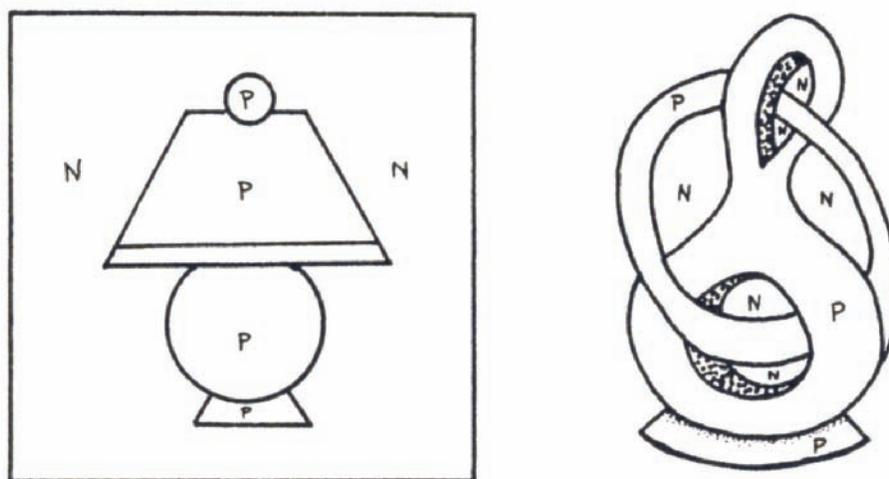


Figure 5.2.

### When Is Shape Not a Shape? Positive and Negative Shapes

The shapes of objects in a work of art are considered positive shapes. These are the shapes drawn, painted, or sculpted by the artist as the subject of the work. However, works of art have other shapes that are of great importance to the success of a composition.

In Chapter 1, a discussion of composition included both positive and negative shapes. In a two-dimensional picture, the negative shapes are the spaces remaining around the subject. In a sculpture, the negative space is the space surrounded by the sculpture material. Negative space, as well as positive space, should be interesting in size and shape. The negative space, however, should not overpower the positive space. (See Figure 5.3.)



**Figure 5.3. Negative (N) and Positive (P) Space.**

### **How can outdoor sculpture gardens maximize negative space?**

- In outdoor gardens, the surrounding landscape provides intriguing negative space for the installed sculptures.
- Laumeier Park in St. Louis provides rolling hills and groves of trees for sculpture negative space.
- The Yorkshire Sculpture Park north of London uses the English countryside as an environment for sculptures.
- Dale Chihuly installs brilliant glass sculptures in botanical gardens, where the surrounding negative space plantings intertwine with his organic glass sculptures.

The following artwork exhibits positive and negative space:

#### **Two-Dimensional Artwork**

*The Old Guitarist*, Pablo Picasso, 1903

*Eight Bells*, Winslow Homer, 1886

*Whaam*, Roy Lichtenstein, 1963

*Boy in Red Vest*, Paul Cezanne, 1890–1895

*A Ballet Seen from an Opera Box*, Edgar Degas, 1885

*The Card Players*, Paul Cezanne, 1892

#### **Three-Dimensional Artwork**

*Walking*, Alexander Archipenko, 1912

*The Three Shades*, Auguste Rodin, 1880

*King and Queen*, Henry Moore, 1952–1953

*Statuette: Dressed Ballerina*, Edgar Degas, 1922

Activity 5.3 will acquaint students with positive and negative space in macrosculptures (two- and three-dimensional works of art) and in microsculptures (unbranched, branched, and cyclic hydrocarbon molecules).

**ACTIVITY****5.3*****Examination of Negative and Positive Shapes in Macrosculptures and Microsculptures*****Objectives**

1. Students will identify positive and negative shapes in two- and three-dimensional works of art (macrosculptures) and in unbranched, branched, and cyclic hydrocarbon molecules (microsculptures).
2. Students will list ways in which negative space can enhance a two-dimensional work of art.
3. Students will construct models of hydrocarbon molecules (three-dimensional microsculptures) and describe the negative space that surrounds these sculptures in terms of size, shape, and relationship to positive space.

**Materials**

Pencil; tracing paper; magazines; reproductions of two-dimensional artwork using positive and negative space; ruler; ball-and-stick molecular-model building kit. (Comment: Don't use Styrofoam balls—correct bond angle holes are needed for tetrahedral shape.)

**Time**

60 minutes

**Procedure**

1. Point out positive and negative shapes in the examples and answer the following questions:
  - a. Is the negative space interesting? Why or why not?
  - b. Is there too much or too little negative space? Explain your answer.
  - c. Do the positive shapes fill the space successfully? Explain your answer.
2. Choose an example or a picture from a magazine and place a sheet of tracing paper over it.
3. Draw the perimeter of the picture on the tracing paper.
4. Trace the outline of positive shapes in the picture.
5. Using pencil, darken in the negative spaces, leaving the positive shapes white.
6. Observe the arrangement of the positive shapes and negative shapes.

7. Build ball-and-stick models of the following molecules: unbranched—methane ( $\text{CH}_4$ ), branched—2-methyl 4-ethylhexane ( $\text{C}_9\text{H}_{20}$ ), and cyclic—cyclohexane ( $\text{C}_6\text{H}_{12}$ ), and identify positive and negative space.

### Questions and Conclusions

1. How can negative space enhance a sculpture? How can negative space overpower a sculpture?
  2. Explain the qualities of the negative space in the molecular models constructed (in terms of size, shape, and relationship to positive space) and arrange the models as a microsculpture, making good use of the negative space.
- 

## PRINCIPLES OF GOOD COMPOSITION IN THREE-DIMENSIONAL SCULPTURE

### What Makes It Work?

Regardless of the subject matter, a successful three-dimensional sculpture should have the following characteristics:

**Variety.** The sculpture should possess an interesting silhouette and interesting interior negative space.

**Unity.** As the negative space is viewed from various angles, there should be a continuity of design. The eye should move easily from view to view.

**Interest.** The sculpture should be interesting from all angles.

**Truth in Materials.** The piece should be appropriate in design for the material from which it is made. A piece designed for stone would not work well in wire. The material should fit the idea.

### Catalysts and Negative Space

A *catalyst* is a special chemical substance that, when viewed as a microsculpture, has many of the characteristics of a successful three-dimensional sculpture, mainly variety, unity, and interest. A catalyst is a chemical substance that accelerates the rate of a chemical reaction but is not itself changed into a product. The catalyst is not consumed in the chemical change. If the catalyst is viewed as a microsculpture, it is the negative space of this microsculpture that is involved in the catalyst mechanism for changing the rate of a chemical reaction. This can be illustrated with either heterogeneous or homogeneous catalysts.

*Heterogeneous catalysts* are catalysts present in a phase, solid, liquid, or gas, different from the phase of the reactants, and *homogeneous catalysts* are present in the same phase as the phase of the reactants. Both heterogeneous and homogeneous

catalysts operate on the same principle: A reactant particle, a molecule atom or ion, bonds with a catalyst particle similar to a key fitting into a lock. When the door is open, the key is removed. (The bond breaks.) Some homogeneous catalyst systems involve large, complex, organic molecules. In the case of such homogeneous catalyst molecules, the catalysts are called *enzymes* and the reactants are called *substrates*. The enzymes bind with the substrates and form complexes. Referring to the lock-key analogy, the key represents the positive space of the substrate and the lock (keyhole) represents the negative space of the enzyme. For most catalysts, how they affect the reaction rate of the reactants depends on the geometry of the reactants. Most catalysts operate in a lock-and-key manner.

### How is a vitamin related to an enzyme?

- Vitamins are coenzymes. They get enzymes started.
- Vitamins prevent diseases such as scurvy.

**Essential Question: What would happen to living organisms if catalysts were not available to speed up chemical reactions?**

### Locks and Keys: Catalysts and Positive and Negative Space

When a heterogeneous catalyst is considered, platinum (Pt) often comes to mind. The platinum surface provides the right geometry for particular molecules to adhere to and easily react with other molecules. The platinum surface is a microsculpture in which the negative space is filled with reactant substances, and reaction rate is accelerated. The following examples show specifically how platinum works as a catalyst.

Sulfur dioxide ( $\text{SO}_2$ ) is oxidized to sulfur trioxide ( $\text{SO}_3$ ) when sulfuric acid ( $\text{H}_2\text{SO}_4$ ) is prepared. This process would be very slow without the use of a platinum catalyst. When the platinum catalyst is used, oxygen molecules are adsorbed on the platinum surface, where they dissociate into very reactive oxygen (O) atoms. The oxygen atoms are situated on the platinum-surface negative space, from which an  $\text{SO}_2$  molecule can pluck an oxygen atom and escape as an  $\text{SO}_3$  molecule (see Figure 5.4). The following chemical change has occurred [<sub>(g)</sub> denotes “gas”]:  $2\text{SO}_2\text{(g)} + \text{O}_2\text{(g)} \rightarrow 2\text{SO}_3\text{(g)}$ . An intermediate step involves the oxygen ( $\text{O}_2$ ) dissociating into separate oxygen atoms with the aid of the platinum surface. The reactants and product are in the gas phase and the catalyst is a solid, thus making the platinum a heterogeneous catalyst. If we consider the catalyst, the platinum, as being a microsculpture metal surface having an attractive shape and size, the shape and geometry of the microsculpture’s negative space is essential to the catalyst in enhancing the reaction rate. Considering the lock-and-key principle of catalyst operation, the platinum is the lock (keyhole) and the reactant  $\text{O}_2$  molecule is the key. The platinum catalyst’s negative space is invaded by the  $\text{O}_2$  reactant, providing a new, simple pathway to the formation of products. An uncatalyzed reaction pathway would be more complex and therefore take longer.

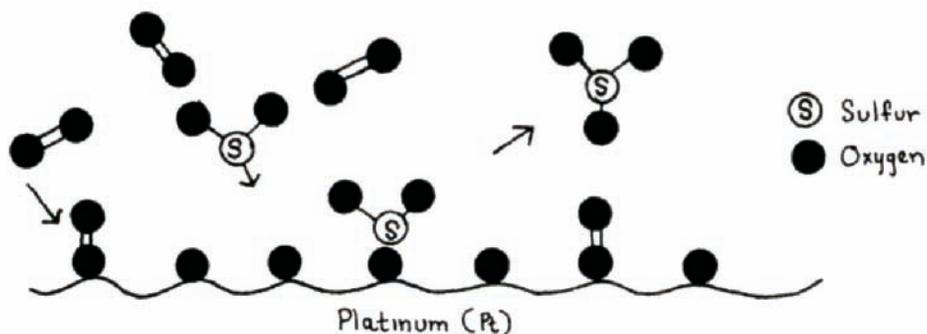


Figure 5.4. Using Platinum to Catalyze the Formation of  $\text{SO}_3$ .

## WHAT IS MATERIAL TO THE SCULPTURE?

### Truth in Materials

An important consideration for a three-dimensional macrosculpture is selecting the material from which the sculpture will be made. For example, the Statue of Liberty would not be effective as a wire sculpture. The function of the Statue of Liberty is to welcome travelers to the New York harbor as a gateway to the United States. In wire, the statue would be missed entirely by travelers. The materials used in a sculpture can determine its success or failure as a work of art. In Activity 5.4, students will be instructed about the use of plaster, sometimes called *plaster of Paris*, as a medium for three-dimensional macrosculpture. The preparation of plaster of Paris and the chemical changes that occur during preparation are discussed.

## ACTIVITY

### 5.4

## ***Plaster Three-Dimensional Macrosculpture***

### Objectives

1. Students will create three-dimensional macrosculptures appropriate for the plaster medium.
2. Students will use principles of good three-dimensional composition (variety, unity, interest, truth in materials).
3. Students will write chemical equations for the formation of plaster of Paris from gypsum from plaster.
4. Students will distinguish between exothermic and endothermic chemical reactions.
5. Students will work with nonobjective volume and mass in planning and executing a macrosculpture.

### Level One: Simple Free-Form, Nonobjective Plaster Form

#### Materials

Plaster of Paris; heavy-duty aluminum foil; X-ACTO<sup>®</sup> knife; plaster files; sandpaper; soft cloth or towel; spoon.

#### Time

90 minutes for steps 1 through 4; three days' drying time before step 5

#### Procedure

1. Use your hands to bend or crumple a segment of aluminum foil into a nonobjective depression deep enough to hold plaster. The foil may be depressed with a spoon to create smoother areas. Place a soft cloth or towel beneath the foil to avoid breaking it.
2. Prepare the plaster and pour it into the depression.
3. Allow the plaster to become hard but still damp, then remove the foil from the plaster.
4. While the form is still damp, use an X-ACTO knife to gently refine the piece and define the shape. Some areas may need to be removed to create a more pleasing silhouette for the piece. Try to incorporate negative space into the piece.
5. When dry, use files and then sandpaper to create a smooth finish for desired areas.

### Level Two: Sculpture Carved from a Block of Plaster

#### Materials

Plaster of Paris; paper cup or half-gallon milk or juice carton; sandpaper; plaster files; X-ACTO knife; kitchen knife.

#### Time

150 minutes for steps 1–4; three to five days drying time before step 5.

#### Procedure (see Figure 5.5)

1. If using milk or juice cartons, have students remove the tops.
2. Prepare the plaster and pour it into the cup or carton.
3. Allow the plaster to become hard but still damp, then remove the cup or carton from the plaster.

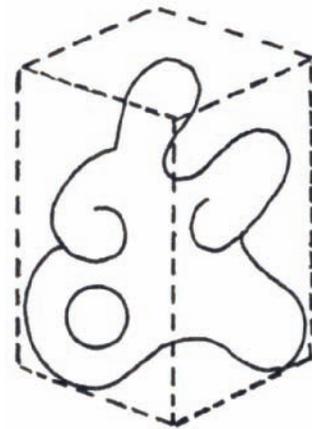


Figure 5.5.

4. Choose a realistic, abstract, or nonobjective subject, or a picture of a sculpture to use as a subject, and begin carving the plaster while it is still damp, using X-ACTO and kitchen knives. Try to incorporate negative space into the piece.
5. After carving a general, rough design, allow the piece to dry completely. This may take several days.
6. When dry, use files and then sandpaper to refine the form.

### Level Three: Hand-Held Plaster Sculpture

#### Materials

Same as level two, but omit the cup or carton.

#### Time

200 minutes steps 1–4; three to five days drying time before step 5

#### Procedure

1. Mix the plaster to a thick, creamy, smooth consistency.
2. Cup your hands to receive a blob of plaster. Hold the plaster in your hands until it begins to set. (See Figure 5.6.)

#### ■ Warning!

**You should not dig your fingers into the plaster because it may be difficult to remove them as the plaster sets.**

3. Remove your hands and allow the plaster to set until it hardens but is still damp.
4. Use X-ACTO and kitchen knives and plaster files to refine the shape. It is best to create a nonobjective piece. The shape is dictated by the plaster as it continues to harden. Try to incorporate negative space into the piece.
5. When dry, use sandpaper to refine the surface. (See Figure 5.6.)

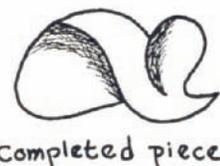


Figure 5.6.

#### Questions and Conclusions

1. Identify negative space in your plaster forms.
2. Explain how your plaster form illustrates the principles of a good three-dimensional sculpture: variety, unity, interest, and truth in material.
3. Write a chemical equation for the formation of plaster of Paris from gypsum.
4. Write a chemical equation for the formation of gypsum from plaster of Paris.

### **Examples of Professional Sculpture**

*Crouching Man* (stone), Andre Derain, 1907  
*The Newborn* (marble), Constantin Brancusi, 1915  
*Princess X* (marble), Constantin Brancusi, 1916  
*The Miracle* (marble), Constantin Brancusi, 1924  
*Joie de Vivre* (bronze), Jacques Lipchitz, 1927  
*Human Lunar Spectral* (bronze), Jean Arp, 1957  
*Reclining Figure* (stone), Henry Moore, 1929

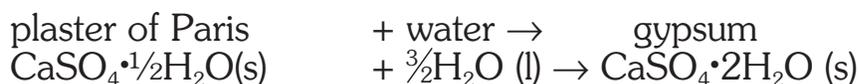
Resources for viewing these sculptures are in the “References” for this chapter.

### **Plaster of Paris: A Hot Item**

The plaster used in Activity 5.4, plaster of Paris ( $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ), has interesting chemical properties. It is derived from *gypsum* ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), which is used to make cement and pottery and, in a more purified form, chalkboard chalk. When gypsum is heated, it loses three-fourths of its water ( $\text{H}_2\text{O}$ ) content and becomes plaster powder. (Comment: *Liquid* refers to a pure substance in the liquid state. The water in the  $\text{CaSO}_4$  is loosely bonded to the  $\text{CaSO}_4$  to form a crystalline solid.)



In this reaction, water from the solid (s) gypsum is released in gas (g) form. It is an endothermic reaction (energy is absorbed). The reverse reaction, in which liquid (l) water is added to the plaster of Paris, is exothermic (energy is released):



While hydrating plaster of Paris, students feel heat—the energy being released by the hydration of the plaster.

### **How Much Heat Is Released?**

We can calculate just how much heat is released when plaster is mixed with water using a concept called *heat of reaction*. Symbolized  $\Delta H$ , it is derived from the heat of formation,  $\Delta H_f$ , of the reactants and products in a chemical change. Heats of formation values ( $\Delta H_f$ ), are compiled on special thermodynamic tables and expressed using the unit kilojoules per mole (kJ/mole). The heats of formation of plaster of Paris, gypsum, and water are  $-1575.2$  kJ/mole,  $-2021.1$  kJ/mole, and  $-285.8$  kJ/mole, respectively. To find the heat of the reaction, it is necessary to subtract the heat of formation of the reactants from the heat of formation of the products:

$$\Delta H = \sum \Delta H_f \text{ Products} - \sum \Delta H_f \text{ Reactants}$$

For the formation of plaster of Paris, the calculation would be:

$$\Delta H = (-2021.1) - (-1575.2 - 428.7)$$

$$\Delta H = -17.2 \text{ kJ/mole}$$

From the equation for the formation of plaster of Paris— $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}_{(s)} \rightarrow \text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}_{(s)} + \frac{3}{2}\text{H}_2\text{O}_{(g)}$ —it can be seen that  $\frac{3}{2}$  mole of  $\text{H}_2\text{O}$  is produced. Since  $\Delta H$  (f) values are given in kJ/mole, the value for water (-285.8) must be multiplied by  $\frac{3}{2}$  before the  $\Delta H$  value for the formation of plaster of Paris is calculated.

### How does a reaction become exothermic or endothermic?

- In a chemical change, when bonds break energy is required.
- When bonds form, energy is released.
- In an exothermic reaction, the energy released is greater than the energy required.
- In an endothermic reaction, the energy required is greater than the energy release.

When  $\Delta H$  is negative, the reaction is *exothermic*. When  $\Delta H$  is positive, the reaction is *endothermic*. In the formation of plaster of Paris, the reaction is exothermic. 17.2 kJ/mole plaster of Paris are released. There is enough energy released for students to feel the heat.

### Other Macrosculpture Materials: Plastic Possibilities

Chemists have been combining small, simple hydrocarbon molecules into long-chain complex molecules for many years. The process is called *polymerization*, and the resulting product is called a *plastic*. When a simple, small hydrocarbon molecule like ethene ( $\text{C}_2\text{H}_4$ ) is polymerized, polyethylene results:  $=\text{CH}_2=\text{CH}_2= \rightarrow \text{CH}_3(\text{CH}_2)_n \text{CH}_3$ . (Comment: The two horizontal bars denote a double bond between the carbon atoms.) This is the product that is used to make transparent wrap, flexible bottles, and thousands of other products. In addition, polyethylene makes an outstanding macrosculpture material. It can be molded into an endless variety of interesting shapes. It can be colored or left clear.

### What is the molecular weight of a useful polyethylene chain?

- A polyethylene chain should have a molecular weight of 1,000,000 to be useful.
- This translates into slightly over 60,000 carbon atoms bonded together into a polyethylene chain.

Polyethylene is formed by addition of  $\text{C}_2\text{H}_4$  molecules, which are merely linked together without the elimination of any reactant atoms. When other polymers are formed, molecules are linked together, and particular atoms break loose to form additional products. When water ( $\text{H}_2\text{O}$ ) is the additional product, the reaction is called a *condensation reaction*. Often the reactants are not simple hydrocarbons but are more complex organic molecules. The formation of nylon is a condensation polymerization reaction. In Activity 5.5 students will prepare a condensation polymer and use it to create a macrosculpture.

**ACTIVITY****5.5****Preparation of a Polymer****■ Warning!**

**Due to the toxicity of some reactants, this activity should be performed by a teacher with student assistance.**

**Objectives**

1. Students will learn how to prepare a plastic substance.
2. Students will write and explain the equation for the formation of nylon, a condensation polymer.

**Materials**

250 ml beaker; 50 ml beaker; 25 ml graduated cylinder; tweezers; cardboard; bare thread spool; seven pellets NaOH (sodium hydroxide); 1.3 g (25 drops) (hexamethylene diamine); 1.0 ml (sebacoyl chloride); 50.0 ml  $\text{CCl}_4$  (carbon tetrachloride); distilled water; eye dropper; food coloring.

**Time**

120 minutes

**Procedure**

The teacher should prepare nylon, a condensation polymer:

1. Form groups of four or five students. Each group can make a cardboard form in a shape to be used for a nylon thread sculpture (the nylon thread will be wrapped around the shape). The shape should be interesting and have a variety of negative space. It may be objective or nonobjective.
2. Place seven pellets NaOH into 50.0 ml distilled water in a 50 ml beaker.
3. Add 1.3 g (25 drops) of hexamethylene diamine and a drop of food coloring.
4. Place 1.0 ml of sebacoyl chloride in 50.0 ml of carbon tetrachloride in a 250 ml beaker.
5. Slowly pour the water solution into the carbon tetrachloride solution. Pour it along the side of the larger beaker.
6. Using tweezers, grasp the center of the film (nylon) that forms at the interface of the two solutions. **SLOWLY AND STEADILY** pull the nylon from the beaker. You can take turns and assist by pulling out the nylon thread after observing the teacher.
7. A student from each group can wrap the nylon thread around the cardboard form to make a sculpture. Thoroughly wash the sculpture.

8. Additional nylon thread should be wrapped around a bare thread spool, washed, and saved for Activity 5.6.
9. If more thread is needed, the above procedure can be repeated.

### Questions and Conclusions

#### Level One

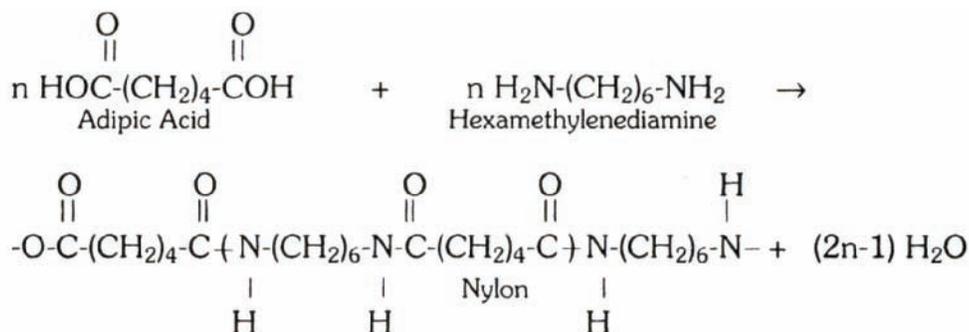
1. Write a word equation for the formation of nylon. Why is this reaction called a condensation reaction?
2. In the preparation of polyethylene, ethene molecules (C<sub>2</sub>H<sub>4</sub>) are bonded together to form a long carbon chain, with two hydrogen atoms bonded to each internal carbon atom and three hydrogen atoms bonded to the end carbon atoms. Draw polyethylene and explain why the formation of polyethylene is an addition reaction.
3. Explain how your nylon thread sculpture incorporates the elements of good three-dimensional composition (variety, unity, interest, truth in materials).

#### Level Two

1. Using a chemical equation for the formation of nylon from the reactants adipic acid and hexamethylene diamine, explain why this is a condensation reaction (see the next section, "Formation of Nylon").
2. Unsaturated hydrocarbons are more likely to form polymers by addition reactions than are saturated hydrocarbons. Explain why.
3. Describe how threads such as nylon can be used to create a three-dimensional work of art.
4. Describe a design for a sculpture in which nylon would be the appropriate material to use.

### Formation of Nylon

The formation of nylon using adipic acid and hexamethylenediamine takes place as follows:



In Activity 5.5, we condensed hexamethylene diamine with sebacoyl chloride, another way of producing nylon. In the polymerization using adipic acid, it can be seen that we no longer have hydrocarbon molecules. Nitrogen (N) and oxygen (O) appear in the molecules combined. When we add nitrogen and oxygen atoms to hydrocarbon molecules, we create molecules with an immense number of different properties, both physical and chemical. When combined with hydrocarbon chains, the following groups of atoms, called *functional groups*, produce familiar substances (R represents a hydrocarbon chain of any length):

**Table 5.2**  
**Functional Groups**

Functional Group Structure	Family Name	Examples
R-OH	Alcohol	Methanol: For rubbing.
$\begin{array}{c} \text{O} \\    \\ \text{R-C-OH} \end{array}$	Carboxylic Acid	Acetic Acid: Vinegar
R-O-R'	Ether	Diethyl Ether: Anesthetic
$\begin{array}{c} \text{O} \\    \\ \text{R-C-H} \end{array}$	Aldehyde	Formaldehyde: Preservative
$\begin{array}{c} \text{O} \\    \\ \text{R-C-R}' \end{array}$	Ketone	Acetone: Solvent
$\begin{array}{c} \text{O} \\    \\ \text{R-C-O-R}' \end{array}$	Ester	Pentyl Acetate: Banana odor
$\begin{array}{ccc} \text{H} & \text{R}' & \text{R}'' \\    &    &    \\ \text{R-N-H} & \text{R-N-H} & \text{R-N-R}' \end{array}$	Amine	Methylamine: Organic base

## EXPANDING ON ORGANIC MOLECULES: FUNCTIONAL GROUPS MAKE A DIFFERENCE

### What is a functional group?

- A functional group is an atom or group of atoms that has a predictable chemical behavior.
- Hydrocarbons containing functional groups, hydrocarbon derivatives, have properties that are a consequence of the hydrocarbon derivative's functional group.
- Many alcohols are volatile and flammable.
- Most esters have pleasant odors and tastes.

Organic molecules have a wide variety of structures that can result in innumerable sizes, shapes, and varieties of microsculptures. Each functional group presents a new shape and size to a molecule, and within each family are endless opportunities for molecular types. For each functional group, a change in the number of carbon atoms in the hydrocarbon chain will affect the physical and chemical properties of the resulting substances. For example, methanol ( $\text{CH}_3\text{OH}$ ), an alcohol with one carbon atom, is used for external purposes such as rubbing on the skin but is extremely poisonous if taken internally. Ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), however, an alcohol with two carbon atoms, can be enjoyed, in moderation, as a beverage. What a world of difference one carbon atom makes. Just as the addition of one atom in a molecule changes the physical and chemical properties of a substance, the addition of one element in a macrosculpture changes the mass, volume, size, balance, and unity of the artwork.

## THE KINETIC WORLD OF MOBILES AND MOLECULES: KINETIC SCULPTURE

**Essential Question: What would happen to our planet if all molecular motion stopped?**

The type of sculpture that incorporates motion and change into the artistic expression is called *kinetic sculpture*. We call some kinetic sculptures mobiles; the works of Alexander Calder immediately come to mind. Some of his mobiles are constructed of geometric and organic shapes connected by wires so that a slight breeze will move the shapes into an endless variety of positive and negative space relationships. Like a Calder mobile, molecules are in constant motion (except at absolute zero, a temperature at which, theoretically, all molecular motion ceases), behaving like microscopic mobile parts. In the solid state, they vibrate. In the liquid state, they rotate. In the gaseous state, they translate, moving from place to place while rotating and vibrating. Molecular motion represents nature's kinetic sculpture. In Activity 5.6 students will make a mobile that exhibits movement and balance, with a theme to provide unity.

### ACTIVITY

## 5.6

### *Mobile Making*

#### Objectives

1. Students will construct a mobile sculpture that exhibits the principles of good three-dimensional composition (variety, unity, interest, and truth in materials) using prepared nylon thread.

## Materials

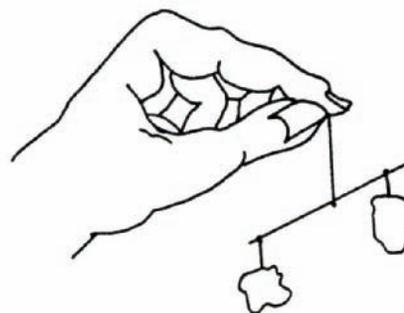
Large, colored glass or plastic beads; colored posterboard; X-ACTO knife; rigid 12- or 14-gauge wire; nylon sewing thread (prepared in Activity 5.5) or fishing line; examples of mobiles pictured in art books (see list at the end of this chapter); craft glue; needle nose pliers, wire cutters; ruler.

## Time

150 minutes

## Procedure

1. Use colored glass or plastic beads and cut additional shapes from colored posterboard to create several mobile pieces.
2. Look at examples of mobiles pictured in art books (Alexander Calder mobiles are engaging examples). If additional ideas are needed, visit a local library to find books about mobile construction.
3. Draw a picture of the mobile to be constructed. Show enough detail that construction will be possible using the drawing as a reference.
4. Cut rigid 12- or 14-gauge wire into lengths about 2 cm longer than necessary to construct the planned mobile. Make a loop at each end of each wire.
5. Using nylon sewing thread (prepared thread in Activity 5.5) or fishing line, tie pieces made from posterboard and colored beads to each loop and secure with a dot of glue.
6. Attach nylon thread or fishing line to the middle of each wire and move it back and forth to find the center of balance. Secure the thread to the wire at this point with a dot of glue.
7. Construct a balanced mobile, following the drawing (see Figure 5.7). It is easiest to begin at the lowest section of the mobile, balance that section, and then work toward the top, balancing each additional section as it is added.



**Figure 5.7.**

## Questions and Conclusions

1. Discuss each of the elements of good composition in a three-dimensional sculpture (variety, unity, interest, and truth in materials) as it applies to your mobile.
2. Explain the new relationships in space that are created as your mobile moves. Consider positive and negative space.

3. Is a kinetic sculpture more complex than a motionless three-dimensional sculpture? Explain your answer.
4. Explain how the three-dimensional periodic table constructed in Activity 4.4 is a kinetic sculpture.

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## LINE

### Line: A Dot Drawn Out

When a chemist looks at X-ray diffraction pictures of atoms, pictures in which X-rays are bounced off atoms, the chemist sees an array of dots in a definite pattern on an X-ray film. This indicates to the chemist that atoms, in a solid, are arranged in a precise order. When artists look at an X-ray diffraction film showing a precise arrangement of dots, they may recall a style of painting known as pointillism. In *pointillism*, an artist places tiny dots of many colors close together so that from a distance the viewer sees a merging of the dots into shapes and images in a variety of graduated colors. Lines are not used in such a work. The relationship between lines and dots is important to consider when the visual elements of a painting are examined. When is a line not a line? When it is a dot. By definition, a *line* is the path of a moving point, or *dot*. So a line is a mark made by a tool or instrument drawn across a surface.

### What important information has been made available through the use of X-ray diffraction?

- The number of atoms in a mole of a substance, Avogadro's number, can be determined by X-ray diffraction.
- The structure of the DNA molecule was determined by X-ray diffraction.

A line can represent the edge of something. In the case of a work by Georges Seurat, the edge of a set of dots represents a line. A line can be used to separate one area from another. Line is used to communicate information in many ways. We write our names or a note to a friend using line. Artists draw with pencil, pen, and paint, using lines to form objects and express ideas. Line does not exist in nature; it is an invention, an abstraction developed to represent what we see and what we want to communicate. The eye interprets line when it is actually the edge of the viewed object.

### The Personality of a Line

Line has personality, just like people. The personality of a line is expressed by its size, type, direction, location, and character. The character of the line can come from the medium. A charcoal line will be different in character from a wire line. Lines are short or long, wide or narrow, curved, straight, wavy, or jagged. They cross a painting's surface, move up and down, in and out, and back and forth. A line may unify or divide. Lines can show a variety of character, depending on the tool used to create them. A brushstroke line

is very different in character than one made with a pencil. Line can express emotion and feeling.

**ACTIVITY****5.7****An Examination of Line in Art****Objectives**

1. Students will identify different characteristics of line as seen in example reproductions of professional two- and three-dimensional artwork and in the film.

**Materials**

Film: *The Dot and the Line*. 9 min. Produced by MGM. DVD. Reproductions of the following examples of line artwork may be used in a discussion and examination of line:

**Two-Dimensional Artwork**

*Lavender Mist*, Jackson Pollock, 1950

*Big Painting*, Roy Lichtenstein, 1965

*The Red Tree*, Piet Mondrian, 1908

*The Jungle*, Henri Rousseau, 1908

Any drawing by Leonardo da Vinci

Any Japanese brush painting

Any woodcut by Albrecht Dürer

**Three-Dimensional Artwork**

*Linear Construction No. 2* (lucite and monofilament), Naum Gabo, 1970–1971

*Monument for V. Tatlin* (fluorescent tube), Dan Flavin, 1966–1969

*Man Walking III* (metal), Alberto Giacometti, 1960

*Spiral Jetty* (environmental sculpture, stone), Robert Smithson, 1970

*Linear Construction Variation* (plastic and nylon thread), Naum Gabo, 1942–1943

*Star Cage* (steel), David Smith, 1950

*1-2-3-4-5* (painted aluminum), Sol le Witt, 1980

*The Dot and the Line*. 9 min. MGM, 2005. DVD.

**Time**

60 minutes

**Procedure**

1. View reproductions of the suggested artwork or similar works.

2. The class should be divided in groups, each with an example reproduction of the film, and the members of each group should answer these questions:
  - a. Describe the lines used in terms of size, type, direction, location, and character.
  - b. What do you feel when looking at the lines in the work?
  - c. Discuss the types of shapes and lines seen in *The Dot and the Line*.
  - d. In *The Dot and the Line*, what feelings were expressed by the dot? By the line?

**ACTIVITY****5.8*****Descriptive Line*****Objectives**

1. Students will use paper and writing materials to draw colored lines that express particular emotions.

**Materials**

8½-x-11-in. paper; ruler; colored markers or colored pencils

**Time**

30 minutes

**Procedure**

1. Divide a sheet of paper into eight spaces. The spaces do not have to be equal in size or shape. Be creative!
2. Using the colors available, draw an expressive nonobjective line or lines to express these feelings: weariness, loneliness, happiness, fear, excitement, confusion, nervousness, and sadness.

**Questions and Conclusions**

1. How does color affect the emotion expressed by a line or lines?
2. How does the shape of a line or lines affect the emotion portrayed?
3. Look at one space on your paper. How did you use line to communicate a particular emotion?
4. How do the size and placement of a line or lines affect the emotion evoked?
5. Discuss how dots or contrasting colors can be used to suggest a line to the eye. Make a small sketch of a such a line.

## Lines Take Us into the Third Dimension: A Study in Depth on a Flat Surface

We have been examining line as a way to define space and describe emotion. There is an additional function that line can serve in artistic expression—allowing the artist to represent the third dimension on a flat surface. Depth on a flat surface can be achieved through the use of two systems, atmospheric perspective and linear perspective.

### Atmospheric Perspective

In atmospheric perspective, line is not used. Perspective, distance, or space is achieved on a flat surface using the following techniques:

1. Objects are portrayed to be overlapping one another. Overlapping objects appear closer to the viewer than overlapped objects.
2. More detail is used for objects that would appear closer to the viewer than for objects that would appear more distant.
3. Greater intensity of color is used for objects that would appear closer to the viewer than for similar objects that would appear more distant.
4. Larger size is used for objects that would appear closer to the viewer than for objects that would appear more distant.

Examples of pictures illustrating these techniques can be found in magazines or may be demonstrated on a chalkboard or with the use of an overhead projector.

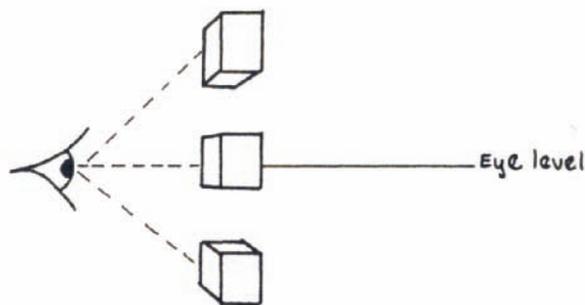
### Linear Perspective

As the word *linear* suggests, line is used in linear perspective, a mechanical system developed centuries ago during the Italian Renaissance. The following terms outline this system:

**Eye Level.** The position at which the viewer's eyes are located in relationship to the subject viewed. Objects directly in front of the viewer are at the eye level of the viewer. Some objects are above eye level; others are below eye level. (See Figure 5.8.)

**Horizon Line.** The place in the distance where the sky and the earth appear to meet.

**Vanishing Point.** The point or points on the horizon line at which an object will disappear as it moves away from the viewer into the distance.



**Figure 5.8. Objects Above, at,  
and Below Eye Level.**

In one-point linear perspective, the lines of vision come together at one point on the horizon line. In two-point linear perspective, the lines of vision come together at two points on the horizon line. (See Figure 5.9.)

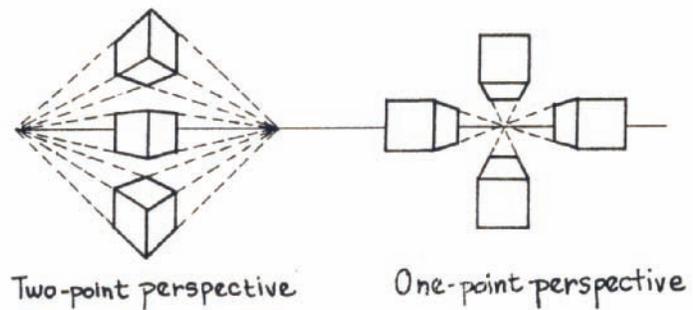


Figure 5.9.

## ACTIVITY

### 5.9

## ***One- and Two-Point Linear Perspective: Discussion and Exercise***

### **Objectives**

1. Students will observe the procedure for creating one- and two-point linear perspective.
2. Students will use the procedures for creating linear perspective.
3. Students will identify the use of one- and two-point perspective in works of art by well-known professional artists.
4. Students will draw the guidelines to the vanishing point or points for objects in one- and two-point perspective.

### **Materials**

Reproductions of artwork in one- and two-point perspective (see below); film about linear perspective or explaining how to draw in linear perspective (see list at the end of this chapter); 8½-x-11-in. paper; pencil; glue or tape; scissors; ruler; magazines.

### **Artwork in One-Point Perspective**

*The Parquet Layers*, Gustave Callebote, 1875

*The Last Supper*, Leonardo da Vinci, 1495–1498

*The Scream*, Edvard Munch, 1893

*Boulevard Monmartre Rainy Weather Afternoon*, Camille Pissarro, 1897

*Delivery of the Keys*, Pietro Perugeno, 1482

### **Artwork in Two-Point Perspective**

*The Letter*, Jan Vermeer, 1666

*The Glass of Absinthe*, Edgar Degas, 1876

*The Dancing Couple*, Jan Steen, 1663

*Pope Pius VII in the Sistine Chapel*, Jean Auguste Dominique Ingres, 1810

**Time**

150 minutes

**Procedure**

1. The teacher should show one of the films and discuss linear perspective.
  2. The teacher should show reproductions of artwork and ask the following questions:
    - a. Does this picture use one- or two-point perspective?
    - b. Where is the horizon line?
    - c. Where is the subject in relation to the horizon line?
    - d. Where is the vanishing point or points?
    - e. What is the effect of the perspective on the composition?
  3. Look through magazines to find a depiction of an object in one-point perspective and a depiction of an object in two-point perspective.
  4. Cut out and tape or glue the pictures to two separate sheets of paper.
  5. For each picture, use a ruler to draw a horizon line across the page in the proper position relative to the object depicted. The object will be above, at, or below the horizon line.
  6. For each picture, determine the vanishing point or points for the object and draw guidelines to the point or points for the object.
- 

**ACTIVITY**

**5.10**

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***Line as an Element of  
Three-Dimensional Sculpture***

**Objectives**

1. Students will use nylon thread to create a three-dimensional sculpture incorporating line as an element of design.
2. Students will combine nylon thread with other materials to create sculptures.
3. Students will observe the principles of good three-dimensional composition.

## Level One: Nonobjective Geometric Sculpture

### Materials

Various colors of posterboard; small hand-held hole punch; X-ACTO knife; illustration board; nylon thread prepared in Activity 5.5 (or purchased nylon thread); glue; scissors.

### Time

60 minutes

### Procedure

1. Choose a geometric shape and cut it from a piece of colored posterboard. The minimum size should be 6 x 6 in.
2. Using an X-ACTO knife, cut a second shape from the center of the first shape, leaving a negative space. Discard the smaller shape. The center negative opening should be considerably smaller than the original shape. For example, if the larger shape is 6 x 6 in., the smaller opening should be no larger than 3 x 3 in.
3. Using a hand-held hole punch, punch holes around the edge or edges of the negative space.
4. Using nylon thread, weave a linear design into the negative space by threading it through the punched holes and across the space. Glue the ends of the thread into place.
5. Cut a square of illustration board to use as a base. A new shape may be used for the base, or its shape may be a repetition of one of the shapes already used.
6. Cut a slit in the center of the base and insert the sculpture. (See Figure 5.10.)
7. Additional woven posterboard pieces may be added to create a more complex sculpture.

## Level Two: Modular Linear Sculpture

### Materials

Craft glue;  $\frac{1}{8}$ -square-in. strips of balsa wood; cardboard scraps; X-ACTO knife; colored posterboard; nylon thread prepared in Activity 5.5 (or purchased nylon thread).

### Time

200 minutes

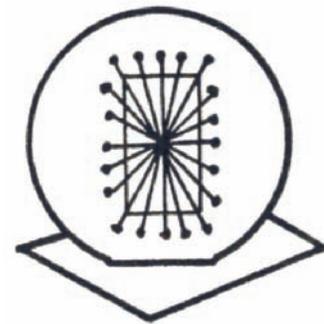
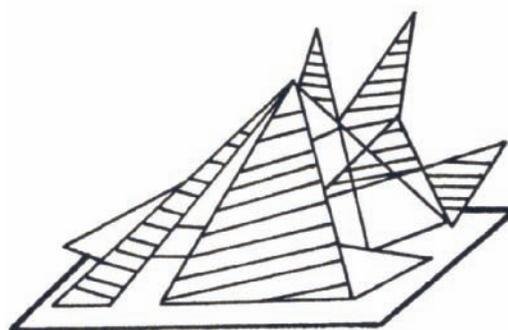


Figure 5.10.

### Procedure

1. Choose a module or shape as a theme (a rectangle, triangle, or square works well).
2. Using the theme shape as the basis for all the shapes to be used in the sculpture, create a series of units (suggested number is seven or nine) in a variety of sizes and proportions from strips of balsa wood glued together. The shapes should be linear. You should vary the size and proportion of the shapes, but all shapes should be variations of the theme shape.
3. Using craft glue, attach completed units to one another, creating a linear sculpture. (See Figure 5.11.)
4. Glue the sculpture to a base cut from colored posterboard.
5. To add a textured effect, choose three or more (but not all) of the units and wrap nylon thread around them, securing the thread with glue. Wrap the units in various directions. If preferred, shapes may be wrapped before the units are attached to one another.



**Figure 5.11.**

### Challenge Activity

Find a flowering plant that interests you. Look at the root formation, leaf shapes and how they are attached to the stem, and the shape of the flower. Draw these different shapes. Find molecules that resemble these different shapes. Remember that group 3A elements form trigonal planar shaped molecules, group 4A elements form tetrahedral shaped molecules, group 5A elements form pyramid shaped molecules and group 6A elements form bent shaped molecules. Carbon chains have a zigzag shape and the DNA molecule is a double helix. You will see that these molecular shapes are duplicated in natural objects. See how many molecular shapes you can find in an ordinary flower.

*Macrosulptures*, three-dimensional works of art, are found just about anywhere people congregate. They make our world a pleasant and interesting place. Not all sculptures are made by artists: Plants and geologic formations provide us with natural three-dimensional macroscopic sculptures. Atoms and molecules are viewed at the microscopic level. We have been referring to these sculptures as *microsulptures* because

they have never been viewed directly. We only see photographic imaging of refractive rays from these microsculptures—molecules, ions, and other combinations and forms of atoms—all of which have attributes of the visible macrosulptures: They provide interior negative as well as positive space for interesting viewing from every direction. They often show repetition and continuity of design. They are in constant motion, having kinetic properties of mobiles. Best of all, as chemical changes occur, these microsculptures change into new sculptures. Just imagine how a molecular microsculpture garden might appear to the human viewer: It certainly would not be boring!

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How to make one-point and two-point perspective drawings using boxes, landscapes, and buildings as subjects.

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## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 5.2 Modeling Hydrocarbon Molecules: Microscopic Sculptures

#### Level One

1. In a hydrocarbon name, the prefix tells how many carbon atoms are in the molecule, and the suffix tells how many carbon and hydrogen atoms are in the molecule. The general formula for alkanes is  $C_nH_{2n+2}$ , the general formula for alkenes is  $C_nH_{2n}$ , and the general formula for the alkynes is  $C_nH_{2n-2}$ .
2. Carbon atoms have four bonding sites; hydrogen atoms have one bonding site.
3. 109.5 degrees. Yes.
4. Tetrahedral.
5. The chain retains its zigzag shape except at the double bond site and triple bond site, where the chain straightens out. To form these bonds, carbon electrons must be stretched into new locations.
6. In a nonobjective work of art, the work is not based on any observed subject matter but only represents an atomic arrangement. An abstract work of art can represent actual subject matter.

#### Level Two

1. Alkane,  $C_{25}H_{52}$ ; alkene,  $C_{25}H_{50}$ ; alkyne,  $C_{25}H_{48}$ . The general formula for an alkane is  $C_nH_{2n+2}$ , the general formula for alkenes is  $C_nH_{2n}$ , and the general formula for the alkynes is  $C_nH_{2n-2}$ .
3. The longer the carbon chain, the higher the boiling point, the melting point, and the density.

### Activity 5.3 Examination of Negative and Positive Shapes in Macrosculptures and Microsculptures

1. Negative space can call attention to a sculpture. It can add interesting shapes to a sculpture. Negative space can detract from a sculpture by occupying a disproportionate amount of space. It must blend in with the sculpture.

### Activity 5.4 Plaster Three-Dimensional Macrosculpture

3.  $CaSO_4 \cdot 2H_2O (s) \rightarrow CaSO_4 \cdot \frac{1}{2}H_2O (s) + \frac{3}{2}H_2O (g)$
4.  $CaSO_4 \cdot \frac{1}{2}H_2O (s) + \frac{3}{2}H_2O (l) \rightarrow CaSO_4 \cdot 2H_2O (s)$

### Activity 5.5 Preparation of a Polymer

#### Level One

1. Adipic acid plus hexamethylenediamine yield nylon plus water. Water is a product.
2. In the formation of polyethylene, the double bond in the unsaturated monomer, ethene, breaks, and thousands of the resulting  $-\text{CH}_2-$  groups bond to form the polyethylene chain.

#### Level Two

1. This is a condensation reaction because water is a product.
2. Because weak double bond sites in unsaturated hydrocarbons are easily broken and ready for the addition of available carbon atoms.
3. Threads can be woven, braided, twisted, and wrapped around an infinite number of shapes to create a three-dimensional sculpture.

### Activity 5.6 Mobile Making

3. Either type of sculpture can be complex. If a sculpture is motionless, it can be constructed of many parts that are intricate and mysteriously joined together. In a kinetic sculpture, the element of motion leads to complexity. The sculpture must be arranged so the moving parts work together harmoniously.
4. If a student constructs a periodic table sculpture in the form of a mobile, then a kinetic sculpture is created. Families or groups can be separated and hung from rods that are balanced and in constant motion.

### Activity 5.8 Descriptive Line

1. Refer to Activity 1.2, The Psychology of Color (p. 7).
2. Jagged lines can suggest excitement and straight, or wavy lines can create calmness.
4. Large heavy lines can get the viewer's attention, while small, light lines are not especially noticed by the viewer. Lines placed very close together can sometimes evoke a sense of vibration.
5. Since a line is a dot drawn out, if dots are placed close together, from a distance a viewer will perceive a line.

# Jewelry

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## Heavy Metal



Answers to all activity and demonstration questions can be found at the end of the chapter.

**Essential Question: An alloy is a solid solution of two or more metals. Why do individual metal properties change when metals combine to form an alloy?**

## INTRODUCTION

We are in the midst of a frenzied jewelry-wearing revolution! The old rules for wearing jewelry are changing overnight. Men wear jewelry as conspicuously as women. Baseball players and other male athletes wear jewelry. Jewelry is often displayed by insertion into a wide variety of pierced body parts by both sexes. It is worn by men and women on all occasions and at any time of day or night.

### Sculpture in Miniature

Jewelry, or pieces of metal, stone, or other materials worn for ornamental purposes, has existed for centuries and represents one of the oldest crafts known to humanity. Jewelry is a form of sculpture in miniature. Many pieces, if enlarged, would be successful decorative pieces. For our purposes, we address jewelry made of metal, although many other materials, such as beads, feathers, fiber, stone, wood, clay, paper, leather, glass, and natural objects, are used to make a wide range of modern jewelry. The metals most suitable for jewelry are the heavy metals, metals of high density, such as gold, silver, and copper.

**What nonmetallic materials are best combined with metals to make unusual pieces of jewelry?**

- Wood, tortoise shell, ivory, bone, leather, cloth, and stone can be combined with metal to create decorative enhancements to metal jewelry.
- Close-grained hardwoods such as ebony or rosewood can be embedded with silver or gold wire to create imaginative pieces of jewelry.

## From the Beginning

Jewelry, in addition to being worn for ornamentation, has many other purposes. During early times, before the invention of the button and zipper, a brooch, pin, or buckle provided a means for attaching pieces of clothing. Jewelry held magical properties for ancient tribes. The earliest items date to the time of the Paleolithic peoples.<sup>1</sup> Many cultures of the ancient world, including those of Mesopotamia, Egypt, Greece, and Rome, created exquisite handmade pieces of gold and precious and semiprecious stones. In many cultures, jewelry represented status or wealth because of its rarity and value.

During the Middle Ages and into the Renaissance in Europe, jewelers became highly skilled in many jewelry-making techniques; they developed elaborate pieces of various metals, often set with a multitude of stones. Throughout the seventeenth and eighteenth centuries, jewelry was worn primarily by the rich and privileged. It was not until the early nineteenth century that techniques for electroplating base metals with a thin layer of gold or silver were developed. Improvements were also made in the quality of imitation stones.<sup>2</sup> This in turn led to the creation of inexpensive pieces of jewelry. By the late nineteenth century, all classes of people could afford inexpensive pieces of jewelry. Quality pieces, however, were still reserved for the privileged.

## METALS: A UNIQUE SET OF PHYSICAL AND CHEMICAL PROPERTIES

In Chapter 4 we learned that the known elements can generally be divided into two classes, metals and nonmetals. On the periodic table, the elements are arranged by increasing atomic number in rows and columns. As these rows and columns are generated, the elements with metallic properties fall on the left side of the table, and the elements without metallic properties fall on the right side of the table. In Activity 6.1, we will examine the physical and chemical properties of metals to understand why they are so often the material of choice in jewelry making.

### ACTIVITY

## 6.1

### *The Physical and Chemical Properties of Metals*

#### Objectives

1. Students will perform chemical experiments to discover and document the physical and chemical properties of various metals.
2. Students will find regularities in physical and chemical properties of metals as related to each metal's position on the periodic table, and then predict which metals might be useful for jewelry making.

## Materials

Small samples of copper (Cu) sheet and 18 gauge wire, silver (Ag) foil and 18 gauge wire, iron (Fe) sheet and 18 gauge wire, tin (Sn) foil, lead (Pb) sheet, aluminum (Al) foil, calcium (Ca) turnings, zinc (Zn) sheet, and magnesium (Mg) strips; (Wire samples should be about two inches long. Other pieces should be about one inch square except for calcium and magnesium.); emery cloth; wooden mallet; tongs; Bunsen burner or candle; matches; 0–300°C thermometer; 5 ml of 3.0 M HCl (hydrochloric acid); 50 ml graduated cylinder; centigram balance; thread; phenolphthalein solution; small test tubes; distilled water; eye dropper; a periodic table, needle nose pliers; Tables 6.1 and 6.2 (pages 244).

## Time

80 minutes

## Procedure

### Physical Properties

■ *Note:*

Use Table 6.1 to record physical properties.

- A. Color:
1. Remove oxides and other contaminants from all the metals by polishing them with emery cloth.
  2. Observe and record the color of each metal.
- B. Malleability: the ability to be beaten into thin sheets.
1. Hammer the copper, lead, zinc, magnesium, and iron pieces with a wooden mallet. (The aluminum, tin, and silver should already be in thin sheets.)
  2. Record the malleability of each metal.
- C. Ductility: the ability to be drawn into a wire.
1. Cut 2-in. pieces of copper, silver, and iron wire.
  2. Bend each wire piece back and forth until the wire breaks into two pieces. Count the number of bends required to break the wire. Record these numbers. (The greater the number of bends, the more ductile is the metal.)
  3. Use needle nose pliers to shape your wire pieces into forms that can be used to construct linear jewelry in Activity 6.1.
- D. Density:
1. Determine the density of tin, lead, copper, zinc, iron, silver, and aluminum metals as follows:
    - a. Mass to 0.10 g each metal sample. Record each mass.

- b. Fill a 50 ml graduated cylinder about one-third full with tap water. Record the volume of water in the cylinder to the 0.50 ml.
- c. Tie a thread around a metal sample. Carefully lower it into the graduated cylinder below the water level. Record the new volume of water. Repeat this process for each metal sample.
- d. Determine the volume of each metal by subtracting original water volume from final water volume. (This is a method for determining the volume of an irregular object by water displacement.)
- e. Calculate the density of each metal by dividing the metal's mass by the metal's volume.

### Chemical Properties

■ *Note:*

Use Table 6.2 to record chemical properties.

- A. Reaction of metal with oxygen:
  1. Using tongs, burn a small sample of each of the following metals in the flame of a Bunsen burner or candle for about one minute: copper, iron, aluminum, lead, silver, tin, and zinc.
  2. Record the color of the flame when each metal is heated.
- B. Reaction of metal with water:
  1. Place a small sample of each of the following metals into test tubes and add enough distilled water to cover each sample: copper, tin, lead, aluminum, calcium, zinc, magnesium, and iron. Let the test tubes stand over night. Record observations the next day.
  2. Add phenolphthalein solution to each metal-in-water solution and record results.
- C. Reaction of metal with acid:

■ **Warning!**

**Acids can be damaging to skin!**

  1. In small test tubes, react separately small pieces of copper, silver, tin, lead, aluminum, calcium, zinc, magnesium, and iron, each with 2 ml 3.0 M HCl. Record observations of these reactions.
- D. The alkali metals:
  1. Look up the physical and chemical properties of the alkali metals.
  2. Record alkali metal densities and reactions with water and acids.

### Questions and Conclusions

#### Level One

1. On the periodic table, find each metal tested and circle it.

2. For each metal tested, list the color, malleability, ductility, and density. State any relationship observed between the metal's position on the periodic table and the physical properties listed. Do metals in the same family have similar physical properties?
3. Research the physical properties of other elements in the same family as the tested metals and describe any trends in physical properties. Include information found concerning the alkali metals.
4. Which families of the periodic table have the most chemically active metals? Which are least reactive? Explain your answer.
5. What combinations of metal plus water turned phenolphthalein red? What products caused the phenolphthalein to turn red?
6. How is metal ductility related to wire breaking?
7. Considering the malleability and ductility of the metals tested, which metals would be good candidates for jewelry making? Why?
8. How would a metal's ability to react with oxygen, water, or an acid affect its use in jewelry making?

**Level Two**

1. Write symbol equations for the metal plus hydrochloric acid reactions (when a reaction occurred).
  2. When certain metals are heated in a flame, what causes the flame to change color?
  3. What area of the periodic table is home to the least reactive metals?
  4. When phenolphthalein turns red, a base is present. Explain how a metal plus water can produce a basic solution. Use symbol equations to explain your answer.
  5. Why is most jewelry made of alloys and not pure metals? What metal is most often combined with silver to make an alloy useful in making silver jewelry?
  6. Design on paper a piece of jewelry and then describe pure metals or alloys that should be used to construct this jewelry. Explain your choice of metals. Use your design when you make a piece of jewelry in Activity 6.1.
-

**Table 6.1**  
**Physical Properties of Metals**

<b>Metal</b>	<b>Color</b>	<b>Malleability</b>	<b>Ductility</b>	<b>Density</b>
Copper (Cu)				
Lead (Pb)			X	
Silver (Ag)		X		
Magnesium (Mg)			X	
Aluminum (Al)		X	X	
Zinc (Zn)			X	
Iron (Fe)				

**Table 6.2**  
**Chemical Properties of Metals**

<b>Metal</b>	<b>Reaction with H<sub>2</sub>O</b>	<b>Reaction with O<sub>2</sub></b>	<b>Reaction with HCl</b>
Copper (Cu)			
Silver (Ag)	X		
Iron (Fe)	X		X
Tin (Sn)			
Lead (Pb)			
Aluminum (Al)			
Calcium (Ca)		X	
Zinc (Zn)			
Magnesium (Mg)		X	

### **Challenge Activity**

Use your wire pieces from Activity 6.1. Also find pieces of string and twist-ties. Create an alien figure. Give your figure a metal name such as Silver Bullet, Copper Kid, or Iron Icon. Write a science fiction play starring your alien figure. Your play setting should be in a world where everything is made of metal. In your science fiction play, include as many metal elements as possible. Using your alien figure, act out your play for the class.

## The Physical and Chemical Properties of Metals Revisited

We now know that metals are shiny; conduct heat and electricity; are malleable; and react with oxygen, water, and acids. Because they possess these physical and chemical properties in varying degrees, we must examine in more detail how these properties make metals the material of choice in jewelry making.

### A Burning Bracelet

In Chapter 4 we learned that within a family on the periodic table, the elements have similar chemical and physical properties. From researching the alkali metals in Activity 6.1, we understand that alkali metals are very soft. They can be cut with a table knife. Also, they are very reactive. Sodium reacts violently with water to produce hydrogen gas, and in the process produces enough heat to ignite the hydrogen gas, as follows:  $2\text{Na}_{(s)} + 2\text{H}_2\text{O}_{(l)} \rightarrow 2\text{NaOH}_{(aq)} + \text{H}_{2(g)}$ . The sodium hydroxide (NaOH) is in the form of sodium ions ( $\text{Na}^+$ ) and hydroxide ions ( $\text{OH}^-$ ); the hydroxide ions are in excess and the solution is basic, as indicated by phenolphthalein turning red. Considering these physical and chemical properties of the alkali metals, we would not want a sodium bracelet. A bracelet that burns in air and reacts violently with water is not a desirable piece of jewelry. Jewelry made from alkali metals is not likely to become a popular commodity.

### Why is pure copper not the best metal for jewelry fabrication?

- As you observed in Activity 6.1, copper combines with oxygen to form blue copper oxide. The copper oxide can rub off on to skin.
- You also observed that copper is very malleable. Pure copper jewelry can bend at will. Copper can be alloyed with silver to create a nonreactive, hard metal perfect for jewelry construction.

### Other Reactive Metals: Alkaline Earth Metals

Alkaline earth metals are also improbable candidates for jewelry making. We see that calcium (Ca) forms a thick oxide crust in the presence of air, and also reacts with water to produce calcium hydroxide and hydrogen gas:  $\text{Ca}_{(s)} + 2\text{H}_2\text{O}_{(l)} \rightarrow \text{Ca}(\text{OH})_{2(aq)} + \text{H}_{2(g)}$ . In addition, calcium is rather brittle. We would not be wise to seek out alkaline earth metals to make jewelry.

### Transition Metals: Voted the Most Likely to Succeed

The alkali metals are too reactive, the alkaline earth metals are somewhat reactive, but the transition metals are just right. We have examined some of the transition metals and see that they have potential for jewelry making. Copper (Cu), iron (Fe), and zinc (Zn) are malleable. They can be pounded into myriad shapes and thicknesses. In addition, they are not very reactive with air (oxygen), water, or nonoxidizing acids, such as hydrochloric acid (HCl).

**Essential Question: Why is lead extremely malleable but difficult to draw into a wire?**

### **Two Miles of Gold Thread**

Because elaborate equipment is required to test metal ductility, we tested the ductility of the copper, silver, and iron wires in Activity 6.1 indirectly. Ductility is a physical property of metals that allows them to be drawn or stretched into thin threads without the metal breaking. Two of the most ductile metals are gold and silver. One gram of gold can be drawn into a thread two miles long!<sup>3</sup> Threads can be used as lines in art. We know that lines in art are used to communicate what we see and feel. A thread, used as a line, can enhance a sculpture or even serve as the sole material for the sculpture. Because many pieces of jewelry are sculptures in miniature, threads of gold and silver are excellent materials for creating attractive pieces of jewelry.

**Essential Question: The most ductile metals, in order of decreasing ductility, are gold, silver, platinum, iron, copper, aluminum, and nickel. Why are some metals more ductile than others?**

### **Metal Density and Jewelry Making**

The density of a substance is the mass of the substance in a particular volume, expressed as  $\text{g}/\text{cm}^3$  (grams per cubic centimeter). The more units, such as molecules, atoms, or ions, that exist in a given volume, the greater the density of a substance. A crafter designing a piece of metal jewelry will consider the density of the metal used. For example, a large earring of very dense metal would not fit comfortably in a small earlobe (in some African tribes, such as the Masai in Kenya, large, dense earrings are used to elongate earlobes). The densities of copper (Cu), iron (Fe), and zinc (Zn) are  $8.92 \text{ g}/\text{cm}^3$ ,  $7.86 \text{ g}/\text{cm}^3$ , and  $7.14 \text{ g}/\text{cm}^3$ , respectively.<sup>4</sup> We can see that the density of copper is somewhat higher than the density of iron, which is higher than the density of zinc. However, all these metals would have the same usefulness when metal weight is a consideration in the design of jewelry. Considering the two metals most often used in jewelry making, silver (Ag) and gold (Au), silver has almost the same density as copper, but gold has a density of  $19.32 \text{ g}/\text{cm}^3$ . Jewelry made of pure gold can be very heavy.

### **Acids, Metals, and Jewelry**

Acids are a part of our environment, present in food and in rain, and a component of skin moisture. It is necessary to consider the effect of acids on metals used to make jewelry. In Chapter 3 we learned that acids produce hydrogen ions ( $\text{H}^+$ ) in aqueous solutions. Metal atoms tend to be effective reducing agents, losing electrons to become more stable. Some metals are better reducing agents than others. For example, zinc atoms lose electrons more easily than iron atoms, which, in turn, lose electrons more easily than copper atoms.

Hydrogen ions will seize available electrons and convert to hydrogen gas ( $\text{H}_2$ ). The more effective the metal is as a reducing agent, losing electrons, the more reactive the metal will be with an acid. Also, the stronger the acid, the more likely it is to react with the metal.

### How can we tell if a metal will react with an acid?

Through chemical experimentation, activity series of metals have been made readily available. The series ranges from a list of the strongest metal-reducing agents to the weakest. The metals, as reducing agents, are compared to hydrogen,  $\text{H}_2$ , as a reducing agent. Those metals above hydrogen are stronger reducing agents than hydrogen. They react with acids and form metal ions and release hydrogen gas. Those below hydrogen cannot react with acids to release hydrogen gas. The following is a partial activity series of metals:

Metal	Metal Ion
Ca	$\text{Ca}^{2+}$
Na	$\text{Na}^+$
Mg	$\text{Mg}^{2+}$
Al	$\text{Al}^{3+}$
Zn	$\text{Zn}^{2+}$
Fe	$\text{Fe}^{2+}$
Ni	$\text{Ni}^{2+}$
Sn	$\text{Sn}^{2+}$
Pb	$\text{Pb}^{2+}$
$\text{H}_2$	$\text{H}^+$
Cu	$\text{Cu}^{2+}$
Ag	$\text{Ag}^+$
Au	$\text{Au}^{3+}$

Considering two strong acids, nitric acid ( $\text{HNO}_3$ ) and sulfuric acid ( $\text{H}_2\text{SO}_4$ ), nitric acid is stronger than sulfuric acid. It would follow that a nitrate ion ( $\text{NO}_3^-$ ) is a stronger oxidizing agent than a sulfate ion ( $\text{SO}_4^{2-}$ ). If we make a piece of jewelry from zinc and it comes in contact with nitric acid, too bad! The chemical reaction will permanently change the jewelry. However, copper metal, a weaker reducing agent than zinc, does not react with sulfuric acid. Copper can react with stronger acids such as nitric acid to produce nitrous oxide and water. If these acids are present on skin, copper ions ( $\text{Cu}^{2+}$ ) will form, turning the skin blue-green. In addition, if we had tested gold, we would have found that it is even a weaker reducing agent than copper and does not react with most acids. Also, we observed that silver, a weaker reducing agent than copper, did not even react with weak hydrochloric acid ( $\text{HCl}$ ). It is easy to understand why gold and silver are popular choices for precious jewelry. Not only are they not very chemically reactive, but they also can be polished to a radiant shine, have a beautiful luster, and can be textured in a variety of ways.

### Alloys: Metal Solutions and Mixtures

To make metals even more appropriate for jewelry making, we combine them to attain the most desirable physical properties of each. We melt two or more metals in specific proportions to form a metal solution or metal mixture, both called an *alloy*. Gold

(Au) and silver (Ag) in their pure states are very soft and usually unsuitable for jewelry, which requires a harder metal to resist wear and tear. Sterling silver is an alloy of silver (92.5%) and copper (7.5%). Gold is sometimes used in jewelry as pure gold, known as 24-carat gold. More frequently, though, jewelry is made of 18-carat and 14-carat gold, containing 75.0% and 58.3% gold, respectively. The remaining 25.0% and 41.7%, respectively, consist of metals such as silver and copper.

### **When is an alloy a solution, and when is it a mixture?**

- When a small amount of an element is added to a metal and the original metal crystalline structure remains the same, this alloy is called a *metal solution*.
- When an element is added to a metal and a new compound results, this alloy is called a *mixture*. An example of an alloy that is a mixture is a combination of iron with carbon to make steel, where  $\text{Fe}_3\text{C}$  is formed.

### **Alloys: New Colors and New Strength**

When a pure metal is changed to an alloy, new physical properties are imparted to the resulting alloy. Silver added to gold forms an alloy that appears greenish-gold, and copper alloyed with gold creates an alloy that is reddish-gold in color. “White” gold is an alloy of platinum (Pt) and gold. This combination is very durable and appropriate for delicate but strong settings for stones. Gold can also be alloyed with other metals to create additional colors, such as purple, gray, and blue-gold. Brass, often used in jewelry making, is an alloy of copper (Cu) and zinc (Zn). Depending on the amounts of copper and zinc, brass can have a yellow color or a reddish color. Nickel-silver contains no silver but is actually an alloy of copper, nickel (Ni), and zinc. Because of its strength and reasonable cost, nickel-silver is sometimes used for jewelry. Pewter is an alloy of copper and tin (Sn). Because of its low melting point and softness, it is not suitable for pieces such as rings, which require a more durable metal.

### **Why is a new alloy stronger than the original metal?**

- When new atoms are introduced into a metallic crystalline structure, the new atoms produce additional forces on surrounding atoms and cause some structural distortion due to their different size. The displaced atoms cannot slide along crystalline slip planes as easily as they did before.
- The new alloy is not only stronger than the original metal but also has more formability.

When making metal jewelry, the artisan is concerned with the melting point of a chosen metal, especially when he or she must solder together jewelry parts or melt the metal to pour it into a mold. Table 6.3 lists the melting points and approximate composition of various metals and alloys.

**Table 6.3**  
**Alloy and Metal Melting Points**

Metal or Alloy	Melting Point	Composition
Gold (Au)	1945°F/1063°C,	
Silver (Ag)	1761°F/961°C	
Sterling Silver (Ag, Cu) (Alloy)	1640°F/893°C	92.5% Silver, 7.5% Copper
Copper (Cu)	1980°F/1082°C	
Tin (Sn)	450°F/232°C	
Brass (Cu, Zn) (Alloy)	1503°F/817°C	79% Copper, 21% Zinc
Nickel Silver (Cu, Ni, Zn) (Alloy)	1959°F/1071°C	60% Copper, 20% Nickel, 20% Zinc
Pewter (Sn, Cu) (Alloy)	500°F/260°C	85% Tin, 15% Copper

In addition to the alloys listed in Table 6.3, bronze has been known since ancient times. Bronze is 70–95% copper, 1–25% zinc, and 1–18% tin. Bronze is not used extensively in jewelry, but it is used for casting sculptures and medals that must remain permanently in good condition. Another alloy, Wood's metal, made of 50% bismuth, 25% lead, 13% tin, and 12% cadmium, has such a low melting point, about 70°C, that it would not be suitable for jewelry use.<sup>5</sup>

### How Metal Atoms Mix

When some alloys are formed, atoms of one metal replace atoms of another metal. These alloys are classified as substitution alloys. When a substitution alloy is formed, the atoms of metals forming the alloy are about the same size. Therefore, one kind of atom can fit into a space vacated by another atom. In sterling silver, about 7% of the atoms are copper. These copper atoms are randomly dispersed throughout the metallic crystalline silver atoms. Pewter and brass are other examples of substitution alloys.

Alloys can also be formed when much smaller atoms are introduced into spaces between the metallic crystalline atoms. In steel, small carbon (C) atoms occupy spaces between larger iron (Fe) atoms. This type of alloy is called an *interstitial alloy*. The strength of the steel is much greater than the strength of the iron. Steel is used for posts in earrings because it is relatively nonreactive and very strong. For the same reasons, steel is used in the construction of decorative belt buckles.

### Metals and Electron Configuration

We know the physical properties of metals, that they are shiny, malleable, and ductile; have high densities; and are usually gray or silver (except in the case of copper and gold). We know some of the chemical properties of metals, that many are reactive in air (oxygen), forming oxides, and that some react with acids, forming hydrogen gas. Now we

will examine the electron configuration of metals to explain these chemical and physical properties of this unique material called metal.

### **Alkali Metals: Chemical Reactivity**

The alkali metals, as we have seen, are frisky little devils. If there is any doubt about this, watch potassium (K) burst into flame in the presence of air, or watch sodium (Na) react violently in water. As we learned in Chapter 4, there are some electron configurations that are very stable, mainly those having eight outermost electrons. The alkali metals have one outermost electron, which they are anxious to dispose of. These electrons are usually transferred to nonmetals, such as oxygen (O), chlorine (Cl), fluorine (F), and bromine (Br), with a release of energy that is predictable, pronounced, and unforgettable.

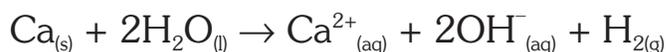
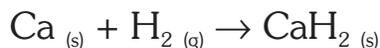
**When an alkali metal loses its outermost electron, will it have the same electron configuration as a noble gas?**

- Yes.
- Lithium becomes like helium, sodium like neon, potassium like argon, rubidium like krypton, cesium like xenon and francium like radon.

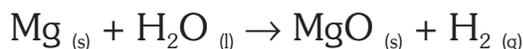
As we move down the family of alkali metals on the periodic table, metal chemical reactivity increases. This increase in reactivity corresponds to an increase in atomic size. As atomic size increases, the outermost electrons are farther from the atomic nucleus. The positively charged protons in the atomic nucleus are trying to attract the negatively charged outermost electrons, but attractive force decreases as distance increases. This is analogous to a mother trying to keep her children home while the children, as they become more energetic, wander farther away and often eventually leave home. A child can leave home more easily when already distanced from home. Therefore, cesium (Cs), in which the outermost electron is far from the positive nucleus and can easily leave home, is much more chemically reactive than lithium (Li), in which the outermost electron is close to home, the nucleus.

### **The Alkaline Earth Metals: Chemical Reactivity**

Though not as chemically reactive as the alkali metals, the alkaline earth metals lose or share two outermost electrons easily to obtain eight outermost electrons. Calcium (Ca) reacts with hydrogen gas (H<sub>2</sub>) to produce calcium hydride (CaH<sub>2</sub>), and with water (H<sub>2</sub>O) to produce calcium (Ca<sup>2+</sup>), hydroxide ions (OH<sup>-</sup>) and hydrogen gas (H<sub>2</sub>):



Magnesium (Mg) and beryllium (Be) are not nearly as reactive as calcium. Beryllium does not react in water, and magnesium reacts in hot water to produce hydrogen gas, as follows:



Our theory regarding atomic size and reactivity holds true for the alkaline earth metals. As we move down a group on the periodic table, as the atomic size increases, the chemical reactivity increases. Calcium is more reactive than beryllium and magnesium. Neither the alkali metals nor the alkaline earth metals would be good candidates for jewelry making. We would not want to wear metal jewelry that might react violently to oxygen or water vapor in the air.

### **The Transition Metals: Chemical Reactivity**

The transition metals are our premier metals for jewelry making. They have electron configurations that are different from the alkali metals and the alkaline earth metals. Therefore, transition metals exhibit different chemical and physical properties. It is necessary to determine just where electrons reside in transition-metal atoms so we can understand the properties of transition metals and how they bond. To understand these properties and manners of bonding, we must revisit the electron cloud atomic model.

## **The Electron Cloud Atomic Model**

In Chapter 1 we learned that electrons are outside the atomic nucleus in probability areas that resemble clouds. We do not know exactly where these electrons are because they are in constant motion. In 1927 Werner Heisenberg (1901–1976), a German physicist and one of the founders of quantum mechanics, told us that it is impossible to know simultaneously the speed and position of an electron. He called this the uncertainty principle. Even though we cannot determine the exact position of an electron or how the electron moves in an atom, we can place an electron in an area outside the atomic nucleus where it is highly likely to be found, called a *probability area*.

### **Probability Areas: Orbitals**

The first probability area, or orbital, is called an *s* orbital. It has a spherical shape and can hold two electrons. In fact, any single orbital can only hold two electrons (these electrons are spinning in opposite directions, however). Next we have *p* orbitals, of which there are three, holding a total of six electrons. Each *p* orbital has an elongated figure-eight shape. The *d* orbitals come next and have complex shapes. There are, as you might have guessed, five *d* orbitals, holding 10 electrons altogether. Finally, we have the *f* orbitals, seven of them, with 14 electrons. (See Figure 6.1.)



Figure 6.1.

## **Energy Levels**

The orbitals, as described, are placed in energy levels that denote the amount of energy in an electron. The greater the number of the energy level,  $n$ , the greater the energy of the electron and the farther the electron is from the nucleus. Therefore, when  $n$  for an electron is 1, the electron is closest to the nucleus and at its lowest energy level. Also, the first energy level has only one  $s$  orbital, with two electrons. The second energy level, farther from the nucleus, has one  $s$  and three  $p$  orbitals, each containing two electrons, for a total of eight electrons. The third energy level has one  $s$  orbital, three  $p$  orbitals, and five  $d$  orbitals, holding a total of 18 electrons. The fourth energy level has one  $s$  orbital, three  $p$  orbitals, five  $d$  orbitals, and seven  $f$  orbitals, holding a total of 32 electrons.

### **Challenge Activity**

Each student should do this activity. Make a paper target with four concentric circles extending from the target center. This should result in a central circle surrounded by three rings. Place the target on a magnetic metal surface and hang it on a wall. Stand 10 feet from the target. Using a magnetic dart, try to hit the target center. Do this 30 times. Be sure that each dart hit makes a mark or dent on the paper. Count the number of hits in the central circle and in each of the outside rings. The teacher will collect data from each student. Make a graph showing the distance of the hits from the target center as related to the number of hits. (The largest ring is the farthest from the center.) Your graph illustrates the probability of hitting the center of your target with a magnetic dart. This is analogous to the probability area for an electron location in a one  $s$  orbital. In Figure 6.1, probability areas for one  $s$  and two  $s$  orbitals are illustrated. The dots in the figure represent a probable position of the electron at a different instant in time.

## **Placing Electrons in Orbitals**

When the electrons in an atom are at their lowest possible energy levels, we call this the ground state: Electrons are placed into orbitals beginning at the first energy level, then the second energy level, next the third, and so on, until all the electrons in a particular atom are placed into orbitals. There is some variation in this pattern beginning at the third energy level, where electrons fill into the fourth energy level  $s$  orbital before they are placed into the third energy level  $d$  orbitals. When electrons are placed into the same orbitals at the same energy level, one electron is placed into each orbital and then the orbitals are filled with a second electron. For example, when five electrons are placed in the three  $p$  orbitals, one electron would be placed in each orbital and then the two remaining electrons would pair with a single electron, so two  $p$  orbitals would have two electrons and one  $p$  orbital would have one electron. Now we can place electrons in these orbitals and see how the electron placement affects bonding for and properties of the transition metals.

### How does the electron configuration of an element relate to the element's magnetic properties?

- When two electrons are in the same orbital at the same energy level, they spin in opposite directions.
- When one electron is assigned to an orbital in an atom, the electron can spin in either direction. In a magnetic field, this electron acts as a micromagnet and aligns with the magnetic field. An element with an unpaired electron is usually magnetic.
- Iron has four half filled *d* orbitals and is magnetic. Zinc has filled *d* orbitals and is not magnetic.

**Essential Question: What happens to *s* and *p* orbitals when atoms try to combine to form  $B_2$ ,  $C_2$ ,  $N_2$ ,  $O_2$ , and  $F_2$  molecules? (See molecular orbital theory.)**

### What Is Stable and What Is Unstable?

Particular electron configurations are very stable and others are not so stable. Helium (He) has only two electrons, which are in the first energy level in the *s* orbital, designated  $1s^2$ . This arrangement is quite stable. We know that helium is a nonreactive noble gas. We also know that eight is great! Eight outermost electrons make an atom or ion very stable. Considering the 10 electrons in neon (Ne), 2 are in the first energy level *s* orbital, 2 are in the second energy level *s* orbital, and 6 are in the second energy level *p* orbitals, or  $1s^2 2s^2 2p^6$ . Neon has eight outermost electrons and is nonreactive. All the noble gases, except helium, have eight outermost electrons, and all the noble gases are nonreactive. Therefore, one very stable electron configuration is filled outermost *s* and *p* orbitals. Another fairly stable arrangement is filled outermost *d* orbitals and half-filled *d* orbitals. Chromium (Cr) atoms should have four electrons in the *d* orbitals, but actually five electrons are one each in the five *d* orbitals, resulting in half-filled *d* orbitals. Manganese (Mn) atoms also have half-filled *d* orbitals, and copper (Cu), zinc (Zn), palladium (Pd), silver (Ag), and cadmium (Cd) have filled *d* orbitals—10 electrons in the five *d* orbitals. These elements having half-filled and filled *d* orbitals are among the least chemically reactive of all the known elements.

### What is molecular orbital theory?

- When two or more atoms bond, atomic orbitals can combine to produce molecular orbitals that are spread over two or more atoms. The number of molecular orbitals always equals the number of atomic orbitals contributed by the atoms that have combined.
- The *s* orbitals of two atoms can overlap to form two sigma bonding orbitals.
- When hydrogen atoms combine,  $1s$  orbitals overlap to form sigma bonding and sigma antibonding orbitals. The electrons are at a lower energy level in the sigma orbital than in either parent  $1s$  orbital, so a bond results and  $H_2$  is formed.

- When an attempt is made to combine helium atoms, the pair of electrons assigned to the sigma orbital stabilizes the molecule, but the pair of electrons in the antibonding orbital increases the molecular energy to an extent that prevents molecular formation.

### ***Alkali Metal and Alkaline Earth Metal Reactivity***

The alkali metals have one outermost electron in an s orbital. This is a very unstable electron configuration, so the alkali metals are very reactive. The alkaline earth metals have two outermost electrons in an s orbital, making them somewhat reactive because an arrangement with eight outermost electrons is the most stable. The larger alkaline earth metals, strontium (Sr) and barium (Ba), are very reactive because those two outermost electrons are far from the nucleus.

In summary, it appears that the chemical activity of the elements is based primarily on electron configuration and then on outermost electron distance from the nucleus. Mostly because of their electron configuration, the transition metals, in the middle of the periodic table (next to the noble gases), are the most stable elements. They are not very reactive with other elements. This is why these transition metals, the so-called heavy metals, make such good jewelry material. However, other important factors are their shiny luster, ductility, and malleability.

### **Metallic Bonds: A Sea of Electrons**

When we determined the crystalline structure of solids in Chapter 4, we noted that most transitional metals form crystals with atoms in a close-packed hexagonal structure, face-centered cubic structure, or body-centered cubic arrangement. In the body-centered cubic structure, the spheres take up almost as much space as in the close-packed hexagonal structure. Many of the metals used to make alloys used for jewelry, such as nickel, copper, zinc, silver, gold, platinum, and lead, have face-centered cubic crystalline structures. Perhaps their similar crystalline structures promote an ease in forming alloys. In sterling silver, an atom of copper can fit nicely beside an atom of silver in the crystalline structure.

### **What metals have close-packed hexagonal and body-centered cubic arrangements?**

- Beryllium, cobalt, magnesium, and zinc have close-packed hexagonal structures.
- Zirconium and titanium have close-packed hexagonal structures at room temperatures.
- Iron (at room temperature), titanium (at high temperatures), molybdenum, niobium, potassium, tungsten, and vanadium have body-centered cubic crystalline structures.

The crystalline structure of metals is often disturbed when metals are worked into pieces of jewelry. For example, the artisan might pound, pull, twist, bend, and cut a piece of gold to produce a single, unique bracelet or earring (students should examine jewelry that they are wearing to find evidence of metal manipulation). Metals can be annealed, heated, and then carefully cooled, to make them soft. Metals do not shatter when they are

pounded. There must be a particular bonding structure for metals that explains this behavior.

### How does the crystalline structure of a metal affect the physical properties of the metal?

- Close-packed hexagonal crystalline structure is a very brittle structure. It is found in metals that have little ductility. Examples of such metals are cadmium, cobalt, magnesium, titanium, beryllium, and zinc. These metals would not be desirable for jewelry fabrication.
- Metals with body-centered cubic and close-packed hexagonal structures bend much more easily than metals with close-packed hexagonal crystalline structure.
- Metals with body-centered and face-centered cubic structures are more ductile than other metals.

### Essential Question: How does annealing change the crystalline structure of a metal?

The electron sea model (see Figure 6.2) for metal bonding proposes a theory that explains observed metal properties. In this model, we can envision that metal bonds are formed when a uniform array of metal cations, positively charged metal ions, are surrounded by a sea of electrons. The electrons' attraction for the cations acts like a glue to keep the metal together even when it is pulled into a wire or pounded into a thin sheet. This electron-cation attraction is strong, and the bonding is nondirectional. Therefore, cations can easily be moved around when metals are worked. Metals have high melting points, which indicates a strong bonding system. Metals can conduct electricity and heat through their mobile electrons. The electron sea model provides good evidence for the physical properties of metal.

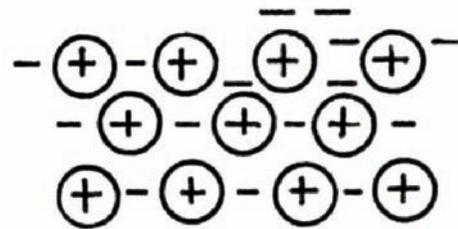


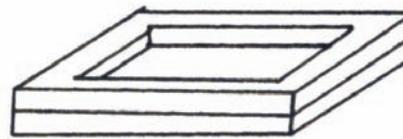
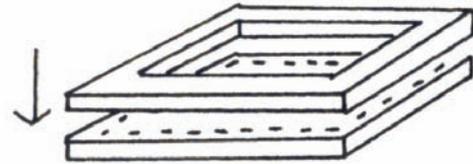
Figure 6.2. Electron Sea Model.

## METALWORKING TECHNIQUES

Metal for jewelry making comes in a variety of forms, including sheet, wire, ingot, and pellet. For handmade or fabricated pieces, made by sawing, pounding, twisting, bending, and soldering, sheet and wire forms are used. For casting or melting metal, which is then poured into a mold, ingot or pellets are the most common forms used. Sheet and wire forms can be obtained in various thicknesses, or gauges. The smaller the number of the gauge, the thicker the wire or sheet. Typical gauges for wire and sheet metal used in jewelry making range from 16 to 20.

## Two Basic Metalworking Techniques: How to Do It

**Fabrication.** Fabrication is a method of jewelry making that involves the uniting together of parts, either by soldering, linking, or intertwining. An example of a fabricated piece would be one in which layers of metal are attached by heating. Solder is placed between the layers. Because the solder has a lower melting point than the metal, the solder melts first and attaches the sections of metal. (See Figure 6.3.)



**Figure 6.3. Fabrication.**

**Casting.** Casting is a method of making jewelry that involves melting the metal and pouring, or pulling, it into a prepared mold. There are several methods of casting, including casting in molds made of plaster, sand, or other porous materials. A second method, the lost wax method, is not new, dating from 1000 B.C. It has been refined and updated over the years. The lost wax process is based on the principle that a model or pattern of the finished product is made in wax. This pattern is surrounded by a creamy investment plaster that hardens to form a mold. During the mold heating that follows, the wax pattern melts away and is “lost.” Metal is then cast into the cavity left by the lost wax, thus duplicating the original wax pattern. The mold is then destroyed to recover the casting. For more information on the lost wax method, see the film list at the end of this chapter. A casting method is used when it is necessary to make several identical shapes or when the piece is too difficult to model directly in metal using the fabrication method.

## Preliminary Preparation for Jewelry Making

### Basic Equipment for Jewelry Making

Jeweler’s saw and blades: 2/0, 1/0, and 1	Steel block
Pliers: flat, round, and needlenose	Propane torch
Needle files: round, semicircular, and flat	Charcoal block
Small vise	Fireproof working surface
Hammer	Easy silver solder (melts at 1325°F)
Scribe for scratching designs	Tweezers
Wooden or rawhide mallet	Scissors, for cutting solder
Ring mandrel (steel rod)	Flux
ntblBench pin and C-clamp	Flux brush
Wire cutters	Pickle solution
Punch and hand drill (small drill bits, nos. 53 and 57)	Copper tongs
Medium and fine emery paper or cloth	

## **Proper Precautions for Jewelry Making**

### ■ **Warning!**

**Be sure to take the precautions discussed below when making jewelry.**

When working with materials for jewelry making, the following precautions should be taken:

- Wear protective goggles.      Avoid breathing fumes.
- Wear a protective apron.      Use reasonable care in handling tools and materials
- Have proper ventilation.

## **ACTIVITY**

## **6.2**

### ***One-Piece Adjustable Ring with Interrelated Design***

#### **Objectives**

1. Students will design an adjustable ring so that a portion of an interrelated design appears at each end.
2. Students will saw, file, and prepare the adjustable ring for use in Activity 6.4.
3. Students will properly use jewelry making tools and equipment.
4. Students will exhibit a knowledge of good design in the creation of a jewelry piece.

#### **Materials**

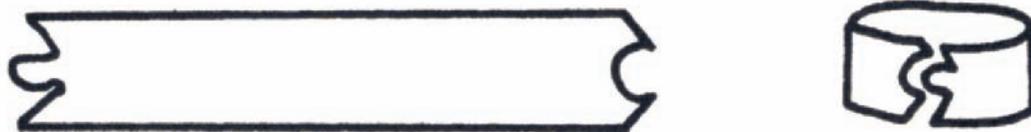
Paper; pencil; scissors; jeweler's saw and no. 1 blades; C-clamp; 16- or 18-gauge sheet copper; scribe; needle files; ring mandrel; mallet; medium and fine emery paper. (See equipment list above for more details.)

#### **Time**

200 minutes

#### **Procedure**

1. Make several patterns using paper and pencil based on the following design idea. One end of the ring will contain a first part of the design and the other end of the ring will contain a second part of the design. When the ring is bent into a circle, the parts of the design will become interlocked. The side edges of the ring design may be straight or may also have a design. (See the design sources under "Resources".)
2. Cut out the design and fit it around a finger, allowing enough negative space between the ends for adjustment. (See Figure 6.4, p. 260.)



**Figure 6.4. Adjustable Ring.**

3. Transfer the design to a sheet of copper using a scribe to scratch the outline into the metal.
4. Attach the saw blade to the frame of the saw at one end. The teeth of the blade must be facing down, toward the saw handle. Apply pressure to the frame to achieve tension on the blade before attaching the opposite end.
5. Secure the bench pin to the surface of a table with the C-clamp and place the area of the metal to be sawed across the *V* of the pin. Saw out the design shape using a vertical sawing motion. Notice that the blade cuts only on the down stroke. When turning a corner, move the saw up and down while slowly turning the metal.
6. Use needle files to smooth the rough edges. Use flat files for flat areas and outside curves, and use semicircular and round files for inside curves.
7. Polish the copper, first with medium emery cloth and then with fine emery cloth, to remove scratches and create a brushed finish.
8. Bend the ring around the ring mandrel and complete the form by gently tapping with a mallet. Adjust the ring to fit a finger.
9. Save this ring for Activity 6.4, in which the ring will be electroplated.

## **ELECTROCHEMISTRY: PROTECTIVE COATS FOR METALS**

### **Electrochemical Cells**

Batteries are electrochemical cells. Where would we be without batteries? A battery is needed to start a car. Batteries power flashlights, move toys, and make watches work. Jewelry with lightbulb designs can use tiny batteries. A battery provides an electric current through oxidation-reduction reactions in which the flow of electrons is directed through a wire. The force of the electrons through the wire is measured in volts.

Electrochemical cells are made of two conducting electrodes, called the *anode* and the *cathode*. The oxidation reaction takes place at the anode, where electrons are released to flow through a wire to the cathode. At the cathode, reduction takes place. For the oxidation and reduction reactions to occur, the electrodes must be in a conducting solution called an *electrolyte*. The electrochemical cell voltage depends on the types of materials, usually conducting metals, used as electrodes, and the concentration of the electrolyte solution. (See Figure 6.5.)

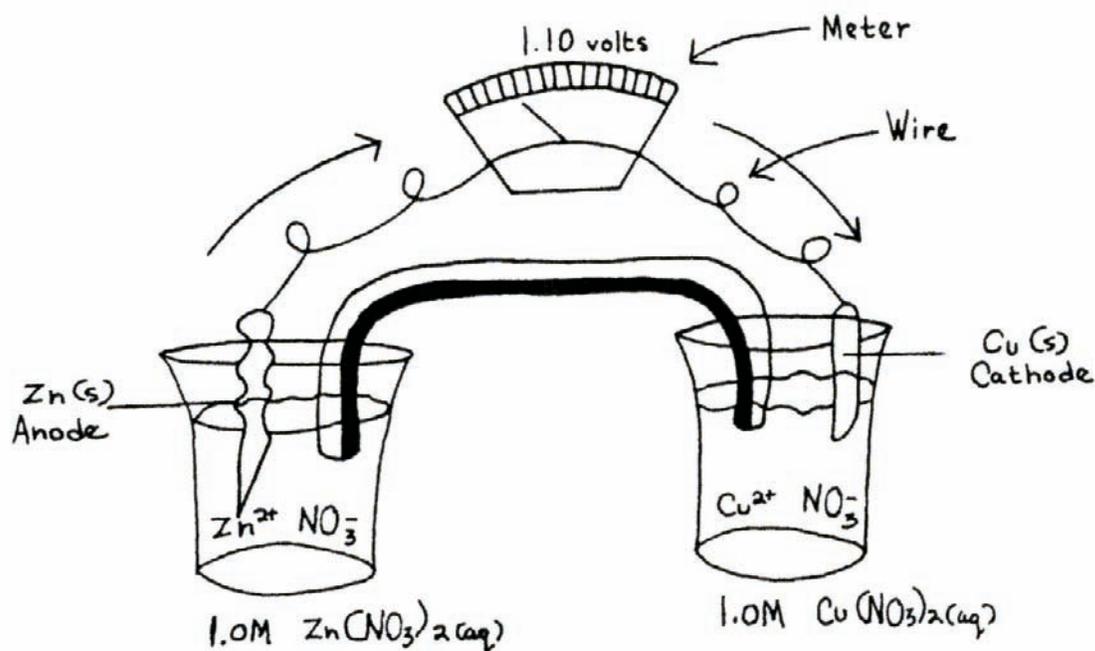


Figure 6.5. An Electrochemical Cell.

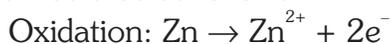
### Challenge Activity

Find used AA, AAA, C, D, and 9 volt batteries. Have someone with a power tool cut the batteries apart. In these batteries, identify the anode, cathode, and electrolyte. How do these electrochemical cells differ from the electrochemical cell that you construct in Activity 6.3?

Because the oxidation reaction and reduction reactions occur simultaneously in an electrochemical cell, it is difficult to find the voltage produced from just one of these reactions. If the voltage produced at a particular electrode could be known, it would be possible to predict the overall voltage for most electrochemical cells. A standard voltage,  $E^\circ$ , is determined for a reaction at one electrode by using a hydrogen electrode reaction assigned an  $E^\circ$  value of 0 as a comparison to all other reactions. A table of  $E^\circ$  values can be established experimentally by preparing an electrochemical cell with one hydrogen electrode (hydrogen gas is bubbled over platinum), and another electrode, zinc for example. The electrolyte solution has a 1 molar concentration. The cell voltage is read from a voltmeter. This entire voltage is assigned to the zinc reaction and, because oxidation occurs at the zinc electrode, the voltage is given a positive sign, +0.76 V. In this case, in a zinc electrode/hydrogen electrode cell, the voltage would be 0.76 V. A positive sign indicates that zinc loses electrons more easily than hydrogen.

## Half Reactions

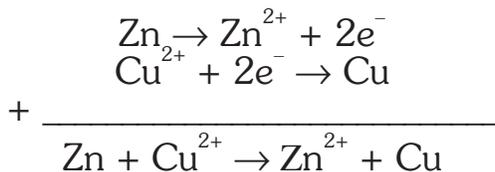
When  $E^\circ$  values are established for a number of substances, these values are placed in a table that shows an equation for the half reaction associated with each  $E^\circ$  value. Either the oxidation half reactions at the anodes or the reduction half reactions at the cathodes may be listed. For the zinc/hydrogen electrochemical cell described above, the half reactions would be as follows:



At the present time, tables of  $E^\circ$  values use reduction half reactions called *standard reduction potentials*. Because the value of  $E^\circ$  is affected by the concentration of the electrolyte solution, these values are given for 1 molar solutions. On a table of standard reduction potentials, we would find the  $E^\circ$  value for zinc to be  $-0.76 \text{ V}$ , the negative value resulting because the zinc oxidation half reaction must be reversed for a reduction potential table: When the half reaction is reversed, the sign must also be reversed. Some standard reduction potential half reactions include the following:



To calculate the  $E^\circ$ , the voltage, of an electrochemical cell, the voltage for the oxidation half reaction at the anode is added to the voltage for the reduction half reaction at the cathode:  $E^\circ_{\text{cell}} = E^\circ_{\text{oxid.react.}} + E^\circ_{\text{red.react.}}$ . For an electrochemical cell with zinc and copper electrodes,  $E^\circ = 0.76 + 0.34 = 1.10 \text{ V}$ , voltage equals  $0.76 + 0.34$ , which equals 1.10 volts. The sign for the zinc reduction potential half reaction is changed because the half reaction is reversed to show that oxidation occurs at the zinc electrode. The two half reactions can also be added to show the overall reaction in the electrochemical cell:



The zinc anode is eroded as zinc metal changes to zinc ions, and the copper cathode gains mass as copper ions convert to copper metal, which is deposited on the copper cathode. The oxidation and reduction reactions, sometimes called *redox reactions*, in the electrochemical cell are spontaneous. The electrode most likely to lose electrons, the most effective reducing agent, which is zinc, becomes the anode, and the strongest oxidizing agent, which are the copper ions, is the cathode. In theory, a copper bracelet or earrings could be the cathode of this cell, so that a copper coat could be deposited on the bracelet or earrings. In Activity 6.3 we will make an electrochemical cell, and in Activity 6.4 we will observe the results when a piece of jewelry is coated with copper.

**ACTIVITY****6.3*****Making an Electrochemical Cell*****Objectives**

1. Students will construct an electrochemical cell and identify the anode, cathode, electrolyte, direction of current flow, and direction of ion flow.
2. Students will write balanced chemical half reactions and an overall redox reaction for the reaction that takes place in the electrochemical cell.
3. Students will discuss the pros and cons of coating a piece of jewelry in an electrochemical cell.
4. Students will calculate the voltage for their electrochemical cell and determine if their calculated voltage is the observed voltage. They will explain any differences between the two voltages.

**Materials**

For each group: Two 250 ml beakers; 200 ml 1.0 M  $\text{Cu}(\text{NO}_3)_2$  (copper nitrate); 200 ml 1.0 M  $\text{Zn}(\text{NO}_3)_2$  (zinc nitrate); zinc metal for an electrode; copper metal for an electrode; U-tube; cotton plugs; two conducting wires with alligator clips at both ends; 100 ml 1.0 M  $\text{NaNO}_3$  (sodium nitrate); voltmeter.

**Time**

50 minutes

**Procedure**

1. Place 200 ml 1.0 M  $\text{Cu}(\text{NO}_3)_2$  solution in a 250 ml beaker.
2. Place 200 ml 1.0 M  $\text{Zn}(\text{NO}_3)_2$  solution in another 250 ml beaker.
3. Fill the U-tube entirely with 1.0 M  $\text{NaNO}_3$  and plug the ends with cotton so that there are no air bubbles in the solution.
4. Invert the U-tube into the beakers so that one arm is in one beaker and the other arm is in the other beaker.
5. Place a copper electrode in the  $\text{Cu}(\text{NO}_3)_2$  solution.
6. Place a zinc electrode in the  $\text{Zn}(\text{NO}_3)_2$  solution.
7. Clip a conducting wire onto each electrode.
8. Connect the other ends of the conducting wires to a voltmeter.
9. Read the voltage generated by the electrochemical cell and record this voltage.

10. After the cell has been connected for several minutes, observe any changes in the solution colors and record these changes.
11. Wait several minutes, disconnect a wire, and remove the copper and zinc electrodes. Carefully observe the electrode surfaces and record any changes in color and texture. Look for changes in electrode size. Record all observations.
12. Remove the zinc electrode and record any changes in its appearance.

## Questions and Conclusions

### Level One

1. Which electrode is the anode? Which electrode is the cathode?
2. Which electrode loses mass? Which electrode gains mass?
3. Write the half reaction at the anode. Write the half reaction at the cathode. Add these reactions together to find the overall reaction. Be sure that you have written balanced equations for all the reactions.
4. After examining the electrodes, explain why an electrochemical cell would be a good way to coat metal and why it would be a bad way to do that.

### Level Two

1. Using half reactions and  $E^\circ$  values, calculate the expected voltage for the cell that you constructed. If the observed voltage is different from the calculated voltage, explain this difference.
2. Explain the change in color in the  $\text{Cu}(\text{NO}_3)_2$  (copper nitrate) electrolyte solution.
3. The Statue of Liberty was made of sheets of copper attached to an iron framework. Explain why the iron framework corroded so badly that the Statue of Liberty almost collapsed. How would you remodel the Statue of Liberty so that the metals would not corrode?

## How can a car battery supply 12 volts of electricity?

- A car battery contains six electrochemical cells.
- Each electrochemical cell has a porous lead anode and a compressed insoluble lead (IV) cathode. The anode and cathode are submersed in a sulfuric acid electrolyte.
- Each electrochemical cell produces 2.041 volts. The overall oxidation reduction reaction is  $\text{Pb}_{(s)} + \text{PbO}_{2(s)} + 2\text{H}_2\text{SO}_{4(aq)} \longrightarrow 2\text{PbSO}_{4(s)} + 2\text{H}_2\text{O}_{(l)}$
- In the car battery, the six anodes are connected and the six cathodes are connected, to make one electrochemical cell that produces six times 2.041 volts, or approximately 12 volts of electricity.

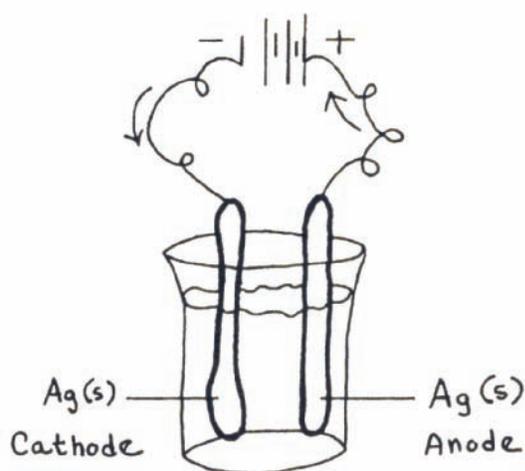
## Challenge Activity

Design a sculpture or a piece of jewelry that incorporates batteries. The batteries can make the object move or turn on a light. Old jewelry can be used to make a sculpture or new jewelry creation. The batteries can be part of the sculpture or jewelry or external to the object. A switch can be added to turn the batteries off and on. Demonstrate your object for your classmates.

## Electrolytic Cells

The plating of jewelry in an electrochemical cell is not very satisfactory. Because the reaction is spontaneous, there is not much control over the rate of plating. Metal is deposited unevenly. Also, often the metal does not adhere to the jewelry being coated and will flake off, leaving a mottled appearance. A better way to coat jewelry is in an electrolytic cell.

### A Nonspontaneous Reaction



**Figure 6.6. An Electrolytic Cell.**

In the electrolytic cell (see Figure 6.6), electricity is added to the cell from an outside source. This outside source of current can be from direct-current sources, such as a battery or generator. The hookup of the current source to the electrolytic cell electrodes determines which electrode will be the anode and which electrode will be the cathode. The electrode, where electrons flow into the electrolytic cell from the current source, is the cathode. At the cathode, ions or molecules undergo reduction. If metal ions are present in an electrolyte solution surrounding the cathode, they will gain electrons and deposit on the cathode as a metal coating or plating. Meanwhile, at the anode, electrons are produced when ions or molecules are losing electrons. If the anode is metallic, the metal

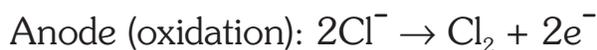
atoms will leave the surface of the anode and convert to metal ions, which become part of the electrolyte solution. As the cell operates in this manner, the anode gradually erodes.

Except for its source of outside current, the electrolytic cell has the same elements as the electrochemical cell: an anode and a cathode placed in an electrolyte in which cations (positive ions) move toward the cathode, and anions (negative ions) move toward the anode. The oxidation half reaction at the anode and the reduction half reaction at the cathode can be added together to find the overall redox reaction for the cell. The process is called *electrolysis*. If a coating of silver metal is desired on a piece of silver jewelry, electrolysis can be performed to coat or plate the silver jewelry in an electrolytic cell. The electrolyte silver nitrate ( $\text{AgNO}_3$ ) solution supplies a source of silver ions ( $\text{Ag}^+$ ). The cathode is the silver jewelry, from which silver ions are reduced to silver metal. The anode

is a silver metal strip that is oxidized to produce silver ions. The oxidation half reaction is the reverse of the reduction half reaction.

### ***Electrolysis of Molten Sodium Chloride***

An electrolysis reaction in which the oxidation reaction is not the reverse of the reduction reaction is the electrolysis of molten sodium chloride. Molten sodium chloride (NaCl), with calcium chloride ( $\text{CaCl}_2$ ) added to decrease the melting point, is electrolyzed in a Downs cell, in which the sodium and chlorine products are separated so that sodium chloride does not reform. The following reactions occur:



This is an example of how electrolysis is performed in an important industrial process.

### **When is a nickel cadmium battery an electrolytic cell?**

- When any rechargeable battery is recharging, it is receiving an electrical charge from an outside source. Electrical energy is driving a nonspontaneous reaction. This describes an electrolytic cell.
- In a nickel cadmium battery, nickel is the anode and  $\text{NiO(OH)}$  is the cathode.
- When a nickel cadmium battery recharges, the net reaction is as follows:  $\text{Cd(OH)}_{2(s)} + 2\text{Ni(OH)}_{2(s)} \rightarrow \text{Cd}_{(s)} + 2\text{NiO(OH)}_{(s)} + 2\text{H}_2\text{O}_{(l)}$
- Think of all of the electronic device batteries that you recharge daily (cell phone and computer batteries are examples.) Most of those devices are powered by nickel cadmium batteries.

## **ACTIVITY**

### **6.4**

## ***Electroplating a Copper Ring***

### **Objectives**

1. Students will prepare a system for the electrolysis of a copper ring.
2. Students will identify the parts of the electrolysis system and explain the function of each part.
3. Students will operate their electrolysis system to plate a copper ring.
4. From experimental data, students will determine and explain what conditions should exist for ideal jewelry electroplating.

### **Materials**

For each group: 100 ml 1.0 M  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  (copper sulfate); 100 ml 5% solution  $\text{H}_2\text{SO}_4$  (sulfuric acid); copper rings made in Activity 6.2; strips of

18-gauge copper metal; 250 ml beaker; wax; source of 12-volt direct current; ammeter; three wires with alligator clips at both ends; fine emery cloth; hot plate.

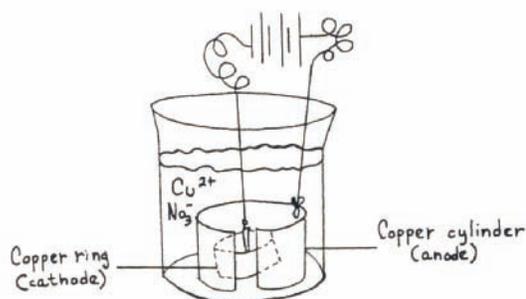
## Time

60 minutes

## Procedure

### A. Electroplating a metal object with copper:

1. Pour approximately 100 ml 1.0 M  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  and approximately 100 ml (5%)  $\text{H}_2\text{SO}_4$  into a 250 ml beaker.
2. Take a strip of copper and form it into an incomplete cylinder that can surround the object to be plated.
3. With wax, cover the areas on the copper ring that are not to be plated.
4. Using a wire with clips, clip the copper cylinder to the positive electrode of the current source and clip the copper ring to the negative electrode of the current source. Connect the ammeter to the current source.
5. Place the copper cylinder and copper ring in the beaker containing the solutions. Be sure that both the cylinder and the bracelet are covered with the solutions. (See Figure 6.7.)
6. Adjust the voltage to 6 volts and the ammeter to 0.5 amps.
7. Allow the electrolysis to proceed until the desired coating of copper is achieved. Record the amount of time it takes.
8. Examine the appearance of the copper plating and record observations.
9. Remove the wax by placing the ring in warm water and wiping off the wax. Using fine emery cloth, polish the ring.



**Figure 6.7. Copper Ring Electrolysis**

### B. Perform the electrolysis in part A with the copper sulfate electrolyte heated to about 40°C.

## Questions and Conclusions

### Level One

1. Identify the anode, cathode, anions, and cations in the electrolysis performed in this activity.
2. Write the reduction half reaction and the oxidation half reaction for this electrolysis.

3. Which electrode should always have the piece of jewelry to be plated? Why?

**Level Two**

1. In writing, compare the appearance of the objects plated at room temperature to those plated at a higher temperature. Discuss evenness, color, distribution of the copper, and any other observed properties.
2. Using this activity, predict the ideal temperature for electroplating a piece of jewelry with copper.

Electroplating is commonly performed to enhance the appearance of a piece of jewelry. Silver and gold are often plated onto cheaper metals to produce inexpensive jewelry that resembles more expensive varieties. The average person can spend less money and look great.

### WIREWORK: LINE IN METAL

Because the bonding structure of metals consists of electrons in a sea of protons, in which the electrons act like glue to hold onto the protons, metals are malleable and ductile enough to be shaped into many forms, such as sheets and wires. Jewelry can be made from these and other forms of metal. Wire is one of the more popular forms for jewelry construction. With a minimum of tools, wire can be flattened, twisted, and woven into a variety of interesting pieces.

Wire for jewelry making can be purchased in a variety of metals and in a variety of thicknesses, or gauges. For jewelry making, 16-, 18-, 20-, 22-, and 24-gauge wires are most often used. Silver wire can be purchased in half-round, square, and round shapes.

**ACTIVITY****6.5*****Linear Jewelry*****Objectives**

1. Students will experiment with bending, twisting, and flattening wire.
2. Students will create a piece of linear jewelry using wire in various forms.
3. Students will learn to properly use tools to form wire pieces.
4. Students will employ good design in the creation of wire jewelry.

**■ Note:**

See the design resources under “Resources” for design ideas.

## Level One: A Simple Pendant

### Materials

Pencil; paper; pliers (round; flat; and needle nose); wire cutters; hammer; steel block; hand drill; vice and eye screw for twisting wire; propane torch; emery paper; copper wire in various gauges from 16 to 24.

### Time

90 minutes

### Procedure

1. Experiment with a short length of 16- or 18-gauge wire, bending the wire with pliers to form curves and angles.
2. Flatten segments of the wire using the hammer and steel block.
3. Twist two or more wires together, using the drill and hook to hold one end of the wires and the vise to hold the other end. Allow extra length for twisting. (See Figure 6.8.)

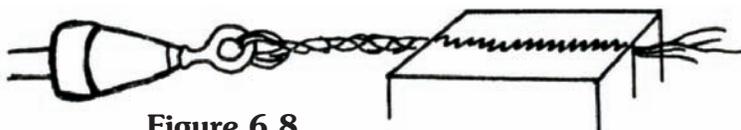


Figure 6.8.

#### ■ Note:

Twisting can make wire brittle, so care should be taken. To soften brittle, twisted wire so that it can be bent without breaking, the wire must be annealed. Annealing involves heating the wire to a dull red and plunging it into water. Twisted wire should not be pounded to flatten it. Annealing is also used to soften pounded wire that is brittle.

4. Sketch several chemistry-related ideas for a simple pendant design using one continuous piece of wire.
5. Create a piece of jewelry from one continuous piece of wire, following the ideas sketched in step 4. A means of attachment to the chain or cord can be made by forming a loop at the top of the piece and binding it with a piece of 22- or 24-gauge wire. (See Figure 6.9.)



Figure 6.9

## Level Two: Pendant Using Several Individual Pieces Joined Together

### Materials

Same as level one, with the addition of glass, clay, or wooden beads.

### Time

100 minutes

### Procedure

1. Proceed with steps 1–3 from the procedure in Level One.
2. Sketch several ideas for a pendant based on having several separate pieces of wire joined together, allowing for movement of the parts. Try to incorporate round pieces of wire as well as flattened and twisted variations. Incorporate beads for accent.
3. Create a piece of jewelry using various gauges of wires and various methods, such as twisting, flattening, and pounding, following the ideas sketched in step 2. (See Figure 6.10.)



Figure 6.10

## REVISITING FABRICATION: SOLDERING AND COLORING

### Soldering: One Plus One Equals One

Soldering is a procedure used to join two pieces of metal together using heat. This process is referred to as hard soldering and requires a much higher temperature than soft soldering. The solder used is made from an alloy of metals—tin-lead alloys for soft soldering at low temperatures and copper-zinc alloys for hard soldering at high temperatures. It is necessary that the solder melt at a lower temperature than the metals being soldered. Silver solder is typically used to solder most metals. Solder is cut into very small pieces because not much is needed to make a strong connection. (*Note:* When purchasing solder, make sure it is cadmium free. Cadmium vapor is toxic.)

Flux is a protective coating applied to a piece before soldering to help the solder flow and to prevent oxides from forming on the surface of the pieces to be soldered. Flux

separates the surface of the piece from the air (oxygen). The solder is melted by applying heat from a propane torch or other source of intense heat. After the solder has melted onto the piece, it is placed in an acid solution, called *pickle*, to convert any oxides formed during soldering to soluble substances that can be easily removed. The commercial name of one pickle solution is Sparex. Heating the pickle solution in a heat-proof glass container will speed the cleaning process.

■ *Note:*

An appropriate film that describes the processes of jewelry making is *Basic Jewelry* (see “Resources”).

**DEMONSTRATION**

## 6.1

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### Soldering

#### Objectives

1. Students will observe the proper preparation of a piece for soldering.
2. Students will observe a proper soldering procedure.

#### Materials

Copper sheet metal; easy silver solder; scissors; propane torch; charcoal block; fireproof surface for soldering; flux; brush; pickle solution; copper tongs; tweezers. (See the list of basic equipment for jewelry making on page 256 for details.)

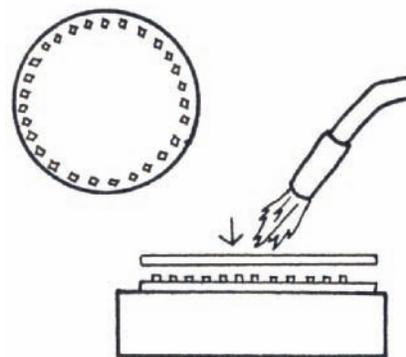
#### Time

50 minutes

#### Procedure

1. The teacher should place a charcoal block on a fireproof surface.
2. Prepare two pieces of flat copper by cleaning them with emery paper. Do not touch the flat surfaces after they are cleaned.
3. Place the bottom copper piece on the charcoal block and apply flux with a brush to the top surface of this piece.
4. Clean the solder with emery paper and cut it into small pieces, about  $\frac{1}{16}$  in. wide. Place them on the fluxed piece surface along the edges.
5. With a brush, apply flux to the top and bottom surface of another copper piece and place this piece over the bottom piece.
6. Light a propane torch and rotate the flame around the outside of the piece. Keep rotating it until the flux turns white. At this point, direct heat can be applied to the solder areas. (See Figure 6.11, page 270.)

7. Continue heating until the top piece appears to drop down. This indicates that the solder has begun to melt. A bright seam of metal can be seen around the edges. This means that the solder has flowed.
8. When the solder has flowed, remove the heat, grasp the piece with tweezers, and drop it into the pickle solution to clean it. Remove the soldered piece with copper tongs and rinse with water.



**Figure 6.11. Solder Setup**

## COLORING METALS: A PLEASANT PATINA

When a piece of jewelry is fabricated, solder is the glue that holds together the individual pieces. After the object is assembled, a surface color may be desired. This surface color, or *patina*, may develop naturally upon exposure to the atmosphere or may be produced as the result of an anticipated chemical change. Usually, the patina will make the piece of jewelry more attractive than it was originally.

After metals are fabricated into jewelry pieces, a patina may be added by the artisan. The patina is usually considered ornamental and not protective. However, the chemical reactions to produce patinas are similar to those reactions that cause metals to form protective coats. These are oxidation-reduction reactions in which the metal atoms change to ions by losing electrons: They undergo oxidation. These metal ions can react with available anions, such as carbonates ( $\text{CO}_3^{2-}$ ), oxides ( $\text{O}^{2-}$ ), sulfides ( $\text{S}^{2-}$ ), and sulfates ( $\text{SO}_4^{2-}$ ), to form colored compounds that, in small amounts, give the metal an attractive patina and, in larger amounts, provide a protective coating to the metal. However, if the oxidation proceeds to erode a large portion of the metal, the design of the original piece of jewelry is not protected but will be destroyed. We call this process *corrosion*.

### What are some examples of chemical combinations that produce metal patinas?

- For an antique green patina, combine 5 g of ammonium chloride ( $\text{NH}_4\text{Cl}$ ) with 42 g of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , in one liter of distilled water. Heat this solution to  $68^\circ\text{C}$ . Heat the metal object to be plated to  $79^\circ\text{C}$ . Wash the metal with cool water until it reaches a temperature of around  $23^\circ\text{C}$ , about room temperature. Wash the coloring solution over the metal surface. Let it dry. Repeat this process until the desired shade of green is achieved.
- For a golden yellow patina, combine 7 g of sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ ), with 56 g of iron III nitrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ), in 1 L of distilled water. Bring to a boil. Dip the object to be colored in this solution.

## Patinas, Protective Coatings, and Corrosion

### Patinas

Patinas add color and interest to works of art on public display, along with those items, such as jewelry, that are kept in a more controlled environment. Henry Moore's bronze *Reclining Figure* (1963–1965), displayed in front of the Center for Performing Arts in New York City, is a beautiful blue color because the copper combines with sulfate to form copper sulfate ( $\text{CuSO}_4$ ). The blue-green color of the Statue of Liberty comes from brochantite [ $\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$ ] and antlerite [ $\text{CuSO}_4 \cdot 2\text{Cu}(\text{OH})_2$ ]. Copper can form a black patina as copper oxide ( $\text{CuO}$ ) and also as copper sulfide ( $\text{Cu}_2\text{S}$ ), and can form an olive-green patina as copper chloride ( $\text{CuCl}_2$ ). In ornate silver jewelry, black silver sulfide ( $\text{Ag}_2\text{S}$ ) can form in crevices in the design. This can delineate and emphasize the design, adding to the beauty of the jewelry.

### Protective Coatings

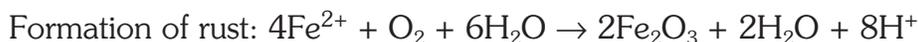
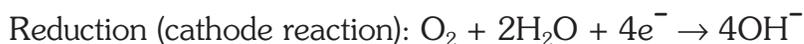
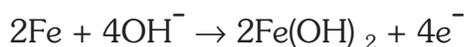
Upon exposure to air, most metals tend to form an oxide coating. If colored, this oxide coating acts as a patina to enhance the appearance of the metal. The oxide coating can also act as protection against further chemical change with internal metal atoms. Particular types of steel are protected from rust formation by a coating of metal oxide. Aluminum forms aluminum oxide ( $\text{Al}_2\text{O}_3$ ) or  $[\text{Al}_2(\text{OH})_6]$ , which provides a protective coating.

### Corrosion

The corrosion of metals is an electrochemical process involving oxidation-reduction, or redox, reactions. When corrosion is addressed, it is often in the context of structural materials for buildings, bridges, and transportation vehicles, such as steel, an alloy of iron (Fe) and carbon (C). However, steel is also used for necklace and bracelet findings, such as clasps, and is often used for the posts in earring. When corrosion of iron occurs, the iron atoms are oxidized to iron ions ( $\text{Fe}^{2+}$ ), and electrons are released. In a reduction reaction, the released electrons react with oxygen and water to form hydroxide ions ( $\text{OH}^-$ ). Another oxidation reaction can occur when iron atoms react with hydroxide ions, producing iron (II) hydroxide ( $\text{Fe}(\text{OH})_2$ ) and releasing electrons. Finally, iron ions can react with oxygen and water to produce iron oxide ( $\text{Fe}_2\text{O}_3$ ), commonly known as rust. The following equations describe these pathways to the corrosion of iron in steel:



or

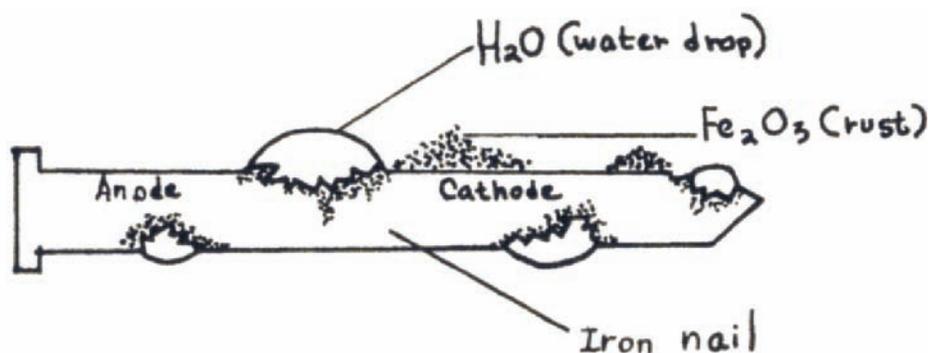


### What is the composition of steel?

- All steel contains iron and carbon. Sometimes other elements such as chromium, nickel, and molybdenum are added.
- The percentage of carbon in steel ranges from just above 0% to 2%.
- Steel with less carbon is more flexible but weaker than steel with more carbon.

### The Sacrificial Anode

When it is desirable to prevent corrosion of iron, a new anode, such as a zinc (Zn) or magnesium (Mg) strip, is connected to the surface of the iron. These metals are stronger reducing agents than iron and will be more easily oxidized. As oxidation occurs, the zinc or magnesium, rather than the iron, will furnish electrons. These “sacrificial anodes” will erode instead of the iron. They must be replaced periodically, but the iron will remain intact. (See Figure 6.12.)



**Figure 6.12. The Rusting Process.**

In a piece of jewelry, such as an earring, the steel post is often placed into a silver or gold earring design. When the earring is worn, body fluids come into contact with the steel. *Voila!* We have a small electrochemical cell. The iron in the steel acts as the anode, the silver (Ag) or gold (Au) is the cathode, and the body fluids act as an electrolyte. Oxidation at the anode results in iron atoms converting to iron ions and releasing electrons. The anode is eroded. Some iron ions will travel to the gold or silver cathode region through skin moisture and react with oxygen in a reduction reaction, resulting in the formation of rust (Fe<sub>2</sub>O<sub>3</sub>), which can deposit on the silver or gold. Our earrings would not be very pretty, nor would they be wearable. Fortunately, steel compositions have been formulated so that the iron is tightly bonded and not available to participate in redox reactions. Steel posts are ideal for earring construction.

### Coloring Metals: In Nature and in the Laboratory

Some metals will react with substances available in the environment, such as oxygen, sulfur, and water vapor, to form colors, highlights, and shadings that are attractive to the eye. However, a natural change in color can take years. We can speed the process by placing a piece of metal jewelry into an appropriate chemical solution that will cause a

chemical change resulting in a new color on the surface of the metal. There are hundreds of coloring chemicals, such as copper sulfate and ammonium sulfide.

## CASTING: THE PLOT THICKENS

Casting is used to produce jewelry that is too difficult or inappropriate for fabrication methods. There are two types of casting: vacuum casting, using a lost wax mold (described on page 256), and gravity mold casting, using pewter. In both methods, the metal is melted and poured into a prepared mold.

### Gravity Mold Casting: Gravity Pulls It Down

A gravity mold casting uses the force of gravity to produce the piece. A variety of materials can be used for the mold, including plaster, charcoal, and cuttlefish bone. Pewter is a metal often used in gravity mold casting. It is an alloy consisting of about 84% tin and about 16% of another metal, such as copper. The copper adds strength to the alloy. Pewter is an easy metal to work with because of its relatively low melting point (500°F, 260°C). It is available in casting ingots or sheets from supply houses.

## ACTIVITY

### 6.6

## *Plaster Gravity Mold Using Leaf Forms as Subject Matter*

### Objectives

1. Students will design a pendant using leaf forms, employing the principles of good composition.
2. Students will carve and assemble a plaster mold for casting.
3. Students will melt and pour pewter metal into the mold, producing a pendant.
4. Students will use proper techniques to finish a pewter piece.

### Materials

Paper; pencil; small (3-x-4-in.) cardboard box with lid; plaster of Paris or casting plaster; water; iron skimmer ladle; pewter in sheet or ingot form; wire (stove pipe); pliers; carving tools (simple knife; nail file; pencil; old dental tools; or anything that will carve plaster); wire cutters; propane torch; fireproof surface (casting container of sand); steel wool; jeweler's saw and blades; files; X-ACTO knife; C-clamp; leaves.

### Time

200 minutes

## Procedure

1. Mix plaster and pour it into the top and the bottom sections of the box to a depth of at least 1 in. Allow the plaster to set and dry. Each student will need two plaster pieces, one to carve and one for the back of a mold (see Figure 6.13).
- 
2. Remove the box top and bottom from the plaster pieces. This should be done several days in advance of carving to allow the plaster to dry thoroughly.
  3. Collect a variety of leaves in different sizes and types. Arrange several leaves in an overlapping fashion and draw a picture of this arrangement. It is important to have several layers created for carving in the plaster. Try several arrangements, using a variety of sizes and shapes.
  4. Transfer or draw the design on one of the plaster pieces. Allow a minimum of ½ in. as a border. Be sure the surface is completely flat.
  5. Using carving tools, carve the design into the plaster. Remember that the carved areas will become raised areas in the cast piece.
  6. Carve a sprue or channel from the piece to the outer edge of the plaster.
  7. Carve a sprue or channel in the flat side of the second piece. This channel will allow the metal to flow into the carved cavity. The sprue should be deep enough and long enough to touch the carved area of the first piece. Be sure that the sides that touch each other are completely flat to ensure a good cast. Secure the two sections with a C-clamp or wire.
  8. Place the plaster mold on end in a bed of sand in a metal pan.
  9. Place the pewter in the ladle and heat with a propane torch.
  10. Pour the liquid pewter into the sprue opening. Allow the pewter to cool.
  11. Remove the piece with pliers.
  12. Saw off the sprue with a jeweler's saw. If any metal has run beyond the mold, this too should be removed.
  13. File and polish the piece with fine steel wool.

**Figure 6.13**

## HEAVY METAL

Whether we are referring to music or high-density metals, heavy metal brings to mind a material that plays an essential role in almost every phase of our daily lives. We use metals not only for jewelry but as the structural material for transportation vehicles and most buildings and bridges, and as conductors of electricity and heat. Our entire infrastructure depends on metals.

Gold (Au), silver (Ag), and copper (Cu) can occur freely in nature. However, most metals are combined with other elements and occur as ores. If the ore has a low melting point, ion mobility will allow the electrolysis of the ore to produce a pure metal. Most ores do not have low melting points. Until a process for separating a metal from its ore was developed, the metal remained scarce. In 1855 the cost of aluminum was \$100,000 per pound. In 1890 the price dropped to \$2 per pound because the Hall-Heroult process for isolating aluminum from its ore had been discovered.<sup>6</sup> Today we take the availability of pure metals for granted. After working with heavy metals in jewelry making, we should give these metals proper respect.

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2. *Ibid.*, 33.
3. David Redu, *Jewelry Making: A Manual of Techniques* (Wittshire, England: Crowood Press, 1991), 36.
4. Steven S. Zumdahl, *Chemistry*, 2nd ed. (Lexington, MA: D.C. Heath, 1989), 897.
5. W. Masterton, E. Slowinski, and C. Stanitski, *Chemical Principles*, 6th ed. (Philadelphia: Saunders, 1985), 239.
6. Zumdahl, *Chemistry*, 810.

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Allcraft Tool and Supply Company, Inc.  
135 W. 29th St.  
New York, NY 10001

Sax Arts and Crafts  
2725 S. Moorland Rd.  
New Berlin, WI 53151

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- Potts, Nena Galloway. *Jewelry Making with Nena*. 122 min. Handy Craft Media Productions, 2005  
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- Werger, Paulette. *Basic Jewelry*. 26 min. Artsmart Video, 2007. Crystal Productions.com  
Demonstration of cutting, piercing, soldering, filing, and polishing techniques
- The World of Chemistry. 19 Metals*. 30 min. University of Maryland and the Educational Film Center, 1990.



## ANSWERS TO ACTIVITY AND DEMONSTRATION QUESTIONS AND CONCLUSIONS

### Activity 6.1 The Physical and Chemical Properties of Metals

#### Level One

2.

Metal	Color	Malleability	Ductility	Density (g/cm <sup>3</sup> )
Copper (Cu)	Brown	Good	Excellent	8.92
Silver (Ag)	Silver	Excellent	Excellent	10.5
Iron (Fe)	Gray	Good	Good	7.86
Tin (Sn)	Silver	n/a	n/a	7.28
Lead (Pb)	Gray	Good	n/a	11.3
Aluminum (Al)	Silver	Good	n/a	2.70
Calcium (Ca)	Gray	n/a	n/a	n/a
Zinc (Zn)	Gray	Fair	n/a	7.14
Magnesium (Mg)	Gray	Fair	n/a	n/a

There are some relationships between a metal's position on the periodic table and the physical properties studied. Magnesium and calcium, alkaline earth metals, are not very malleable or ductile. They have low densities: 1.74 g/cm<sup>3</sup> and 1.55 g/cm<sup>3</sup>, respectively. All of the other metals tested are transition metals. They exhibit a wide range of physical properties. Copper and silver are in the same family. They are both quite ductile and malleable. They have fairly high densities.

3. The alkali earth metals have very similar physical properties. They are soft, silver-white metals with low densities: sodium (Na) 0.97 g/cm<sup>3</sup>, potassium (K) 0.86 g/cm<sup>3</sup>, rubidium (Rb) g/cm<sup>3</sup>. They are kept under oil since they react violently with air (oxygen) and water.
4. The alkali metals are the most chemically active metals. Alkaline earth metals are second in reactivity. Elements in the same family have the same outermost electron configuration. Alkali metals have one outermost electron that is easily transferred to needy atoms. Alkaline earth metals have two outermost electrons to share or transfer. The transition metals are the least active.
5. Calcium and magnesium plus water will turn phenolphthalein red. Calcium hydroxide and magnesium hydroxide cause phenolphthalein to turn red.

6. When metals are drawn into a wire, their crystalline structure is distorted. The more ductile metals show crystalline structure distortion but still retain a stable crystalline structure. The more stable the crystalline structure, the harder it is to break the wire. The more ductile the wire, the harder it is to break.
7. Silver and copper are the best candidates for jewelry making. They are malleable and ductile and easily shaped into desired shapes. Silver is very chemically nonreactive. However, silver is very soft. Copper is harder but does react with oxygen and certain anions such as sulfate, nitrate, and phosphate. Therefore, an alloy of silver and copper is the best material for jewelry making.
8. A chemically reactive metal cannot be used for jewelry. Oxygen comprises about 20% of our air. Water and acid are components of perspiration. If metals that react with oxygen, water and acids are used for jewelry construction, the jewelry metals would change into new substances with different physical properties.

### **Level Two**

1. 
$$\begin{aligned} \text{Fe}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{FeCl}_{2(aq)} + \text{H}_{2(g)} \\ \text{Sn}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{SnCl}_{2(aq)} + \text{H}_{2(g)} \\ \text{Pb}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{PbCl}_{2(aq)} + \text{H}_{2(g)} \\ 2\text{Al}_{(s)} + 6\text{HCl}_{(aq)} &\longrightarrow 2\text{AlCl}_{3(aq)} + 3\text{H}_{2(g)} \\ \text{Ca}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{CaCl}_{2(aq)} + \text{H}_{2(g)} \\ \text{Zn}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{ZnCl}_{2(aq)} + \text{H}_{2(g)} \\ \text{Mg}_{(s)} + 2\text{HCl}_{(aq)} &\longrightarrow \text{MgCl}_{2(aq)} + \text{H}_{2(g)} \end{aligned}$$
2. When some metals are heated, their atoms lose electrons and ions are formed. These ions can be colored. Copper ions are blue-green, so heated copper metal produces a blue-green color.
3. The transition metals are the least reactive metals. Of those, group IB, copper, silver and gold, are the least reactive.
4. Bases that produce hydroxide ions in solution turn phenolphthalein red. Calcium and magnesium produce hydroxide ions in water. The following equations symbolize the reactions:
 
$$\begin{aligned} \text{Ca}_{(s)} + 2\text{H}_2\text{O}_{(l)} &\longrightarrow \text{Ca(OH)}_{2(aq)} + \text{H}_{2(g)} \\ \text{Mg}_{(s)} + 2\text{H}_2\text{O}_{(l)} &\longrightarrow \text{Mg(OH)}_{2(aq)} + \text{H}_{2(g)} \end{aligned}$$
5. When metals are combined to make alloys, the resulting alloy has a combination of the original metal properties. Copper is most often combined with silver to make jewelry. Pure silver is too soft to be used for jewelry. Copper metal in solution with the silver produces a hard product suitable for jewelry fabrication. Sterling silver consists of 925 parts silver and 75 parts copper. Jewelry with less than 90 parts silver cannot be labeled silver.

## Activity 6.3 Making an Electrochemical Cell

### Level One

1. Zn is the anode, Cu is the cathode.
2. The anode loses mass, the cathode gains mass.
3. At the anode:  $\text{Zn}_{(s)} \rightarrow \text{Zn}^{2+}_{(aq)} + 2e^{-}$ ; at the cathode:  $\text{Cu}^{2+}_{(aq)} + 2e^{-} \rightarrow \text{Cu}_{(s)}$ ; overall reaction:  $\text{Zn}_{(s)} + \text{Cu}^{2+}_{(aq)} \rightarrow \text{Zn}^{2+}_{(aq)} + \text{Cu}_{(s)}$ .
4. In an electrochemical cell, the oxidation reduction reactions initially proceed at a constant rate. Usually the reaction rate is appropriate for uniform conversion of metal ions to metal atoms at the cathode and even metal coating of an object to be plated. However, sometimes it is necessary to change the rate of metal atom deposit. This can only be accomplished in an electrolytic cell where an external voltage source controls metal atom deposit.

### Level Two

2. The  $\text{Cu}(\text{NO}_3)_2$  (copper nitrate) solution is blue due to the presence of blue  $\text{Cu}^{2+}$  (copper ions). The  $\text{Cu}^{2+}$  ions are converted to copper atoms, so with fewer  $\text{Cu}^{2+}$  ions present the solution becomes lighter blue.
3. The Statue of Liberty functioned as a large electrochemical cell. Sea water served as an electrolyte that allowed iron metal atoms to lose electrons and convert to iron ions, and copper ions to gain electrons and become copper atoms. The iron structural elements became weak. Eventually the Statue of Liberty would have collapsed.

## Activity 6.4 Electroplating a Copper Ring

### Level One

1. The copper cylinder is the anode. The copper ring is the cathode. Copper ions and hydronium ions ( $\text{H}_3\text{O}^+$ ) are cations and nitrate and sulfate ions are anions.
2. Reduction half reaction:  $\text{Cu}^{2+}_{(aq)} + 2e^{-} \rightarrow \text{Cu}_{(s)}$ . Oxidation half reaction:  
 $\text{Cu}_{(s)} \rightarrow \text{Cu}^{2+}_{(aq)} + 2e^{-}$ .
3. The cathode. At the cathode, reduction occurs. Cations gain electrons and become atoms. The atoms deposit on the object to be plated.



# Two- and Three-Dimensional Works of Art Revisited



## *Putting Together the Pieces of the Puzzle*

Answers to the questions and conclusions are found at the end of the chapter.

**Essential Question: Think of the Rosetta Stone as a relief sculpture. How would you prepare a Rosetta stone for future generations, explaining the meaning of each chemical symbol used to identify each element?**

## INTRODUCTION

In the preceding chapters, four of the five basics or elements of art were discussed in detail. You will remember the example of the jigsaw puzzle made up of many pieces of elements. When a jigsaw puzzle is assembled properly, a picture appears. So it is with the elements of art: color, line, shape, texture, and light and dark contrast. When properly composed, these elements make a successful work of art. The composition of the artwork, whether two- or three-dimensional, should contain an effective balance of these basic elements, along with an eye-catching center of interest, an arrangement that promotes movement of the eye through the work, an interesting arrangement of space (both positive and negative), and a feeling of unity and harmony of the parts. These are the tools artists use to turn their ideas into reality. Whether the medium is paint, clay, or stone, the structural tools are the same.

In this chapter, the last of the five elements, light and dark contrast, or value contrast, is examined in detail. Students will use value contrast, along with the other elements and principles of good composition, to create works of art that incorporate as subject matter molecular models depicting a variety of molecular geometric shapes. The artistic movements of fauvism, cubism, and surrealism will be explored and examined because their techniques are used to create “modern” art.

**■ Note:**

It would be helpful to review with students the elements of art and principles of composition as seen in reproductions of the artwork listed in Chapter 1 (beginning on page 21) or in reproductions of similar artwork.

**IT IS A RELIEF: BUT WHAT IS IT?**

We have been working in two dimensions with paper and pencil or paint, and in three dimensions, “in the round,” with clay and plaster. A three-dimensional piece can be seen from all angles, as we turn it or walk around it and study the play of light and shadow against its surfaces. In a mobile, the element of motion is added, allowing for an ever-changing combination of relationships between negative and positive space. Relief sculpture, unlike sculpture in the round, has a back and a front. The forms of the relief project into the third dimension from the front area. The surface may be a wall or a canvas or a piece of metal. The projection of shapes may be in low relief, raised only slightly from the main surface, or it may be in high relief, protruding considerably from the back surface

**What is the Rosetta Stone?**

- The Rosetta Stone is a dark gray-pinkish stone with writing on it in two languages, Egyptian and Greek, using three scripts, Hieroglyphic, Demotic Egyptian, and Greek.
- It was discovered by a Frenchman, Captain Pierre-Francois Bouchard, in the Egyptian port city of Rosetta on July 15, 1799. It is dated March 196 B.C.
- The stone writings contain priestly decrees. Since the decrees are repeated in the three scripts, the writings made clear that hieroglyphs not only had symbolic meaning but also represented a spoken language.
- The Rosetta stone is considered to be an ancient code book.

**How is the Rosetta Stone like a relief sculpture?**

- The Rosetta Stone has a front and a back.
- The languages carved on the front create positive and negative space.
- The elements of art are also present: color, line, texture, shape, and light and dark contrast.

Relief sculpture has been used since prehistoric times, and it is still popular today. It is frequently seen in architecture, where it is used as decoration on the exterior and interior walls of buildings. It is seen in ceramics and jewelry, and in many works of contemporary painting.

**Examples of Relief Sculpture in Various Media**

*Dying Lioness from Nineveh* (limestone; Iraq), 650 B.C.

*Frieze of the Parthenon* (marble, Athens), 440 B.C.

*Column of Trojan* (marble; Rome), A.D. 106–113

*Gates of Paradise* (bronze; door of the Baptistery, Florence, Italy), 1435

*Singing Angels* (marble), Luca Della Robbia, 1435

*Musical Instruments* (painted wood), Pablo Picasso, 1914  
*Target with Four Faces* (canvas and plaster), Jasper Johns, 1955  
*Radiant White 952* (cardboard and plywood), Robert Rauschenberg, 1971

As can be seen from the list above, relief subject matter can be almost anything. We have faces, musical instruments, singing angels, a dying lioness, and mythical themes. Now we will try something new. For our purposes, it is appropriate that we use a chemistry theme for our relief construction. The varied and sometimes unique shapes of molecules will provide unusual and interesting material for the subject matter of a relief sculpture.

## MOLECULAR SHAPES

When we studied organic molecules in Chapter 5, we realized that chains of carbon atoms with branches appear in a variety of shapes. Cyclic molecules were possible. Catalysts worked to change the rate of a chemical reaction because one molecule fit into another, like puzzle pieces. Catalysts worked because of the molecular shapes of the interacting molecules. Clearly, molecules have distinct shapes.

### How Molecular Shapes Can Be Predicted: Using the Periodic Table

In chemistry, as well as in art, we look for organizational systems to help us understand our subject matter. The five elements of art—color, line, shape, texture, and value contrast—are guidelines for evaluating a work of art. The periodic table is the means for assembling information about the chemical elements. It provides the basis for determining the molecular shape of many molecules.

All the elements of a group A family have the same number of bonds when a molecule is formed. In addition, these bonds all originate in the same orbitals. In Chapter 6 we learned the names of the orbitals where the outermost electrons reside. These orbitals are the places where bonds form with other atoms. The shape and orientation of these orbitals determine the geometric shape of resulting molecules when a group A atom bonds with other atoms. Before this information is summarized, it is necessary to consider how some orbitals combine to form hybrid orbitals when bonds are formed.

### **Hybridization of Orbitals; Hybridization of Corn**

Hybrid corn seed comes from corn plants that have particular properties worth preserving. One plant may produce sweet kernels; another may produce long ears. Cross-breeding of the two plants will produce seeds that grow sweet-kernel, long-eared corn. A better ear of corn is produced. When group IIA, IIIA, and IVA families bond, the  $s$  and  $p$  orbitals combine to form hybrid  $sp$  orbitals, where bonding occurs. The  $sp$  orbitals replace the individual  $s$  and  $p$  orbitals to provide more stable locations for the bonds and a more stable molecule. A better molecule is formed.

### **How Hybrid Orbitals Are Created**

For the group IIA elements, the two outermost electrons are in an  $s$  orbital. When a bond is forming, these two electrons move 180 degrees away from each other into two new, hybrid  $sp$  orbitals made of one  $s$  and one  $p$  orbital. These atoms now have two bonding sites. For the group IIIA elements, the two outermost electrons are in an  $s$  orbital and the other outermost electron is in a  $p$  orbital. Three hybrid orbitals,  $sp^2$  orbitals, are formed when bonding occurs. These  $sp^2$  orbitals are made of one  $s$  orbital and two  $p$  orbitals and provide three bonding sites, with a 120 degree angle between each bonding site pair. Finally, the group IVA elements bond in  $sp^3$  orbitals, which are made of one  $s$  and three  $p$  orbitals, providing four bonding sites, with a 109.5 degree angle between each bonding site pair. Molecules formed when atoms bond to IIA and IIIA elements are on a two-dimensional plane. When atoms bond to a IVA element, a three-dimensional molecule is formed.

#### **What orbitals remain unchanged after hybridization?**

- In IIA elements, two  $p$  orbitals remain unchanged. In IIIA elements, one  $p$  orbital remains unchanged.
- These empty  $p$  orbitals provide locations for additional bonding with other atoms.

### **Challenge Activity**

Assign a group A element to each student. Students can take turns bonding with other students to form molecules. When a molecule is formed, the students forming the molecule must state the names of the orbitals involved in the bonding. Students get credit for correctly stating the names of the bonding orbitals involved in creating their molecule. (See Table 7.1.)

**Table 7.1**  
**“A” Group Families: Bonding Orbitals and Shapes**

<b>Family</b>	<b>Bond Number</b>	<b>Bonding Orbitals</b>	<b>Sample Molecule</b>	<b>Molecular Shape</b>
IA (Alkali Metals)	1	$s$	LiH	Linear
IIA (Alkaline Earth Metals)	2	$sp$	MgH <sub>2</sub>	Linear
IIIA	3	$sp^2$	BH <sub>3</sub>	Triangular Planar
IVA	4	$sp^3$	CH <sub>4</sub>	Tetrahedral
VA	3	$p$	NH <sub>3</sub>	Pyramid
VIA	2	$p$	H <sub>2</sub> S	Bent
VIIA (Halogens)	1	$p$	Cl <sub>2</sub>	Linear

## **Molecular Polarity: The Shape of Groups of Molecules (Covalent, Ionic, and Polar Covalent Bonds)**

As we have seen, the orientation of atoms in a molecule, as determined by bonding orbitals, in turn determines the molecular shape. However, the type of bonds between atoms in a molecule, along with the molecular shape of the molecule, determines the polarity of a molecule. (A molecule is polar if it has a positive end and a negative end.) If a molecule is polar, it can attract other polar molecules to make a variety of structures including, but not limited to, chains, hexagons, and grids. Hydrogen fluoride molecules bond to form zigzag chains, water molecules bond to form open hexagons, and iodine chloride molecules bond to form grids. Bonded molecules make beautiful, three-dimensional structures that have all the elements of successful works of art.

In addition to molecular shape, intramolecular bond types also help to determine molecular polarity. Our discussion thus far has concerned covalent and polar covalent bonds. In covalent bonds, electrons are shared equally by both atoms forming the bond; in polar covalent bonds, electrons are shared unequally. Sharing an electron is like sharing a piece of pie. The piece of pie is either cut exactly down the middle—equal sharing, as in a covalent bond—or it is cut into one large and one small piece—unequal sharing, as in a polar covalent bond. In ionic bonds, electrons are pulled entirely to one atom; a bond results because the positive side of one atom attracts the negative side of another atom. The system for determining the type of bond that exists between two atoms depends on an atomic property called electronegativity.

### **Electronegativity**

The electronegativity of an atom describes its ability in a molecule to attract bonding electrons to itself. Linus Pauling, a Nobel Prize-winning American scientist, developed an electronegativity scale in which each element is assigned a number. The greater the number, the greater the ability of the atom to attract an electron. The periodic table shows electronegativity trends: Electronegativity values decrease down a column (a group, or family) and increase across a row (or period). For the group A elements, electronegativity correlates to atomic radius. As the atomic radius increases, the electronegativity decreases. Down a column, the atomic radius increases and electronegativity decreases. Across a row, atomic radius decreases and electronegativity increases. As an atom becomes larger and outermost electrons move farther from the nucleus, the atom becomes less able to attract those outermost electrons. Electronegativity values range from a high of 4.0 for fluorine (F) to a low of 0.7 for francium (Fr).

### **Electronegativity Values: What Is the Difference?**

The difference between the electronegativity values of the atoms forming a bond within a molecule is used to determine whether the bond is covalent, polar covalent, or ionic. Generally, an electronegativity difference from 0 to 0.4 indicates a covalent bond; a difference from 0.5 to 1.8 indicates a polar covalent bond; and a difference of 1.9 or greater indicates an ionic bond. For example, the electronegativity differences for the bonds Cl-Cl, H-O, and Na-Cl are 0, 1.4, and 2.1, respectively, indicating that the bond types are covalent, polar covalent, and ionic, respectively.

Intramolecular bonds (with molecular shape) determine molecular polarity. Molecular polarity, in turn, establishes whether or not one molecule will attract another molecule. If a IA or VIIA intramolecular bond is ionic, the molecule is polar. If a IA or VIIA intramolecular bond is covalent, the molecule is nonpolar. Polar molecules bond to each other (intermolecular bonds) to form an endless variety of geometric shapes that resemble beautiful three-dimensional sculptures. (See Figure 7.1.)

<table border="1" style="margin: auto;"> <tr> <td style="padding: 2px;">H 2.1</td> </tr> </table>							H 2.1
H 2.1							
Li 1.0	Be 1.5	B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	
Na 0.9	Mg 1.2	Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	
K 0.8	Ca 1.0	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	
Rb 0.8	Sr 1.0	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	
Cs 0.7	Ba 0.9	Tl 1.8	Pb 1.9	Bi 1.9	Po 2.0	At 2.2	
Fr 0.7	Ra 0.9						

Figure 7.1. Electronegativity Table.

**Essential Question: How are electronegativity values determined?**

### Orbital Orientation

In Chapter 6 we learned that, in an atom, there is a spherical-shaped  $s$  orbital at any energy level outside the nucleus. In addition, there are three  $p$  orbitals at every energy level, except the first level, and each  $p$  orbital is shaped like a figure eight, with the atomic nucleus between the two lobes of the figure eight. Because the  $s$  orbital is spherical in shape, there is no particular orientation for electrons in the  $s$  orbital. However, the three  $p$  orbitals have definite orientations in space. They appear at right angles to one another. One  $p$  orbital appears on an  $x$ -coordinate axis, one appears on a  $y$ -coordinate axis, and one appears on a  $z$ -coordinate axis. When electrons in the  $p$  orbitals are involved in forming bonds with other atoms, the orientation of the  $p$  orbitals determines the resulting molecular shape.

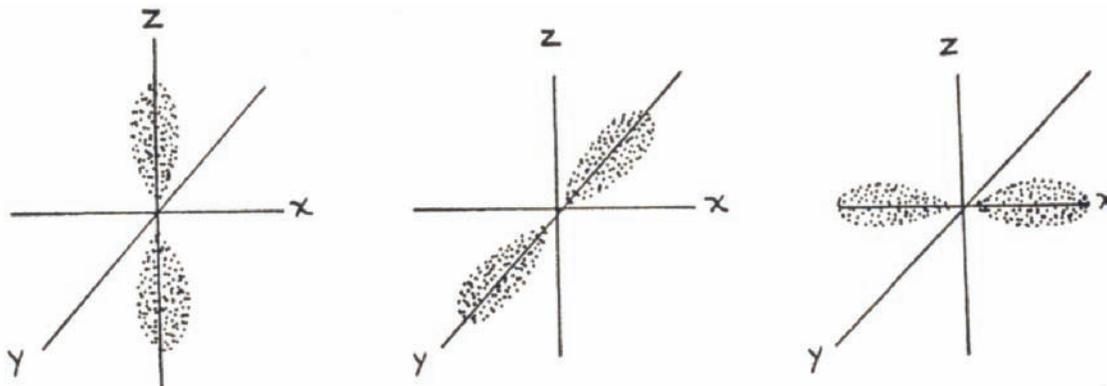


Figure 7.2. The Three  $p$  Orbitals.

### Challenge Activity

Create a board game called Orbital Orientation. Draw and cut out a two-dimensional representation of the  $x$ ,  $y$ , and  $z$   $p$  orbital orientations superimposed over each other in the center of your board. (See Figure 7.2.) Place a spinner in the center of the orbitals. Each player takes a turn and spins the spinner. When a player lands on or near a particular orbital, that player can place an electron into that orbital. It is assumed that the  $1s$  and  $2s$  orbitals are filled, each with two electrons. The purpose of the game is to attain the electron configurations of boron, carbon, nitrogen, oxygen, fluorine, and neon. The first player to do so wins. (Remember Pauli's exclusion principle: No atomic orbital can contain more than two electrons.) Also, each  $p$  orbital must contain one electron before a second electron can be added to a  $p$  orbital.

In an atom, the hybridization of  $s$  and  $p$  orbitals to form  $sp$  orbitals provides electron probability areas where bonds can form to make a molecule more stable than if the bonding had occurred in the individual  $s$  and  $p$  orbitals. The  $sp$  orbitals have one large lobe and one small lobe and are aligned along  $x$ ,  $y$ , and  $z$  coordinates so that four  $sp$  orbitals, called  $sp^3$  orbitals because they are made of one  $s$  and three  $p$  orbitals, result in a tetrahedral-shaped arrangement. When there are three  $sp$  orbitals, made of one  $s$  and two  $p$  orbitals, called  $sp^2$  orbitals, the molecular has a triangular-planar shape. If there is bonding in two  $sp$  orbitals, made of one  $s$  and one  $p$  orbital, a linear molecule results.

### **Hybridization: A Theory That Explains Molecular Structure**

When a group IIA atom bonds with two atoms to form a molecule, the molecular shape is linear. If a group VIA atom bonds with two atoms to form a molecule, the shape is bent. In each case, the molecule is made of three atoms. The different shapes result because the group IIA atom bonds in  $sp$  orbitals and the group VIA atom bonds in  $p$  orbitals. Group IIIA atoms bond with three atoms in  $sp^2$  orbitals to form triangular-planar molecules; group VA atoms bond with three atoms in  $p$  orbitals to form pyramid-shaped molecules. In each case, the resulting molecule is made of four atoms. Finally, group IVA atoms bond with four atoms in  $sp^3$  orbitals to form tetrahedral-shaped molecules. Hybridization is a useful theory to explain the known structures of many molecules.

### **Molecular Shapes: Relief Subject Matter**

Now we are ready to construct molecular models that will provide subject matter for a relief sculpture. The molecules can be arranged like pieces of a puzzle in a pleasing composition to form a unique work of art.

**ACTIVITY****7.1*****Making Molecular Models*****Objectives**

1. Students will predict molecular shapes and construct molecular models from molecular formulas.
2. Students will compare the bond angles and geometric shapes in their molecular models to actual angles and shapes.
3. Students will determine geometric shapes for their molecular models based on bonding orbitals.
4. Students will use electronegativity values to determine whether a bond is ionic, polar covalent, or covalent.
5. Students will arrange their molecular models into a composition to be used as the subject matter for a relief sculpture.

**Materials**

For each group: Ball-and-stick molecular-model building kit (the model building kit prepared in Activity 1.1 can be used); paper and pencil; protractor.

**Time**

50 minutes

**Procedure**

1. Review the following rules of bonding:
  - a. Group IA atoms have one bond; group IIA atoms have two bonds (180 degrees apart); group IIIA atoms have three bonds (120 degrees apart); group IVA atoms have four bonds (109.5 degrees apart); group VA atoms have three bonds (105 degrees apart); group VIA atoms have two bonds (105 degrees apart); group VIIA atoms have one bond.
  - b. Allow each atom the correct number of bonds; it might be necessary to have double and/or triple bonds in a molecule.
  - c. The central atom in a molecule having more than two atoms determines the shape of the molecule.
  - d. When bonding occurs in  $sp$  orbitals, the atoms surrounding the central atom are as far as possible from one another.
2. The teacher should make a list on the chalkboard of the following molecules:  $H_2$ ,  $NH_3$ ,  $CCl_4$ ,  $MgO$ ,  $AlCl_3$ ,  $H_2O$ ,  $CO_2$ ,  $N_2$ ,  $C_2H_6$ ,  $C_2H_2$ ,  $C_2H_5OH$ .

3. Use the molecular-model building kit constructed in Activity 1.1 to make ball-and-stick models of the molecules listed on the chalkboard. The balls represent atoms and the sticks represent bonds.
4. After the models have been prepared, prepare a table as follows: List the molecules in step 2 in a vertical column along the left side of a sheet of paper. Across the top of the paper, write "Drawing of Molecule," "Geometric Shape," and "Bond Angle Degrees." Draw lines to create boxes in which the indicated items will be recorded.
5. Complete the table, drawing each molecule and predicting each geometric shape. Use a protractor to measure the bond angles for each model. Discuss your answers; the teacher should provide correct answers.

## Questions and Conclusions

### Level One

1. Predict the shapes of the following molecules:  $\text{H}_2\text{S}$  (hydrogen sulfide),  $\text{CaCl}_2$  (calcium chloride),  $\text{CH}_4$  (methane),  $\text{BF}_3$  (boron trifluoride), and  $\text{KBr}$  (potassium bromide).
2. Which of the molecular models had double bonds and which had triple bonds? Why are double bonds and triple bonds necessary in particular molecules?
3. Explain why some four-atom molecules, such as  $\text{NH}_3$  (ammonia), have a pyramid shape, and other four-atom molecules, such as  $\text{AlCl}_3$  (aluminum chloride), have a triangular-planar shape.
4. What is the best way to arrange your molecular models to form a relief sculpture with interesting positive and negative space?

### Level Two

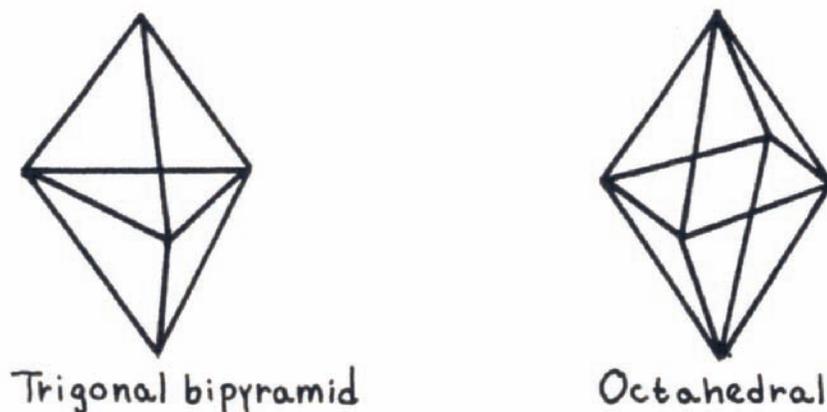
1. For each of the molecules  $\text{H}_2\text{S}$ ,  $\text{CaCl}_2$ ,  $\text{CH}_4$ ,  $\text{BF}_3$ , and  $\text{KBr}$ , name the bonding orbitals where intramolecular bonds are formed.
2. For each of the molecules  $\text{H}_2\text{S}$ ,  $\text{CaCl}_2$ ,  $\text{CH}_4$ ,  $\text{BF}_3$ , and  $\text{KBr}$ , use electronegativity values to determine the type of each intramolecular bond: ionic, polar covalent, or covalent. For each molecule, determine whether the molecule itself is polar or nonpolar, explaining your reasoning.
3. Explain why a molecule (such as  $\text{H}_2\text{O}$  [water]) that has two polar covalent bonds is polar.

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## Molecules and Relief Sculptures

The molecules we have been studying are composed of atoms that usually bond in  $s$ ,  $p$ , and  $sp$  orbitals. We can explain additional molecular shapes when we account for the hybridization of  $d$  orbitals with  $sp$  orbitals. In some molecules, such as phosphorus

pentachloride ( $\text{PCl}_5$ ), there are five  $sp^3d$  orbitals for bonding electrons. The  $\text{PCl}_5$  molecule has a trigonal-bipyramidal shape (see Figure 7.3). In other molecules, such as sulfur hexafluoride ( $\text{SF}_6$ ), the six bonding orbitals are  $sp^3d^2$ , and the molecular shape is octahedral. Have students make models of  $\text{PCl}_5$  and  $\text{SF}_6$  to use (in addition to the models constructed in Activity 7.1) as the subject matter for a relief sculpture in Activity 7.2.



**Figure 7.3. Trigonal-Bipyramidal and Octahedral Bonding Arrangements.**

### How are $d$ orbitals included in forming a hybrid orbital set?

- In  $\text{PF}_5$ , five  $sp^3d$  orbitals are needed to provide a trigonal-bipyramidal shaped molecule. The P (phosphorus) atom has a single electron in each of the five  $sp^3d$  orbitals ready to overlap a  $2p$  orbital in each of the five F (fluorine) atoms to form the molecule.
- In  $\text{SF}_6$ , six  $sp^3d^2$  orbitals are needed to provide an octahedral shaped molecule.
- In Armenia, the Noravank Monastery has a relief sculpture of Christ surrounded by Peter and Paul and a dome having an octahedral umbrella.<sup>1</sup> The artist and mathematician M. C. Escher used octahedral and trigonal-bipyramidal shapes in many of his works.

## ACTIVITY

### 7.2

## Relief Plaster Sculpture Using a Clay Mold

### Objectives

1. Students will design relief sculptures based on previously constructed molecular models, emphasizing interesting negative and positive space, visual movement through shape, and visual texture applied to positive shapes.
2. Students will construct clay molds and cast plaster to create relief sculptures.

## Level One: Relief Plaster Sculpture Emphasizing Interesting Positive and Negative Space

### Materials

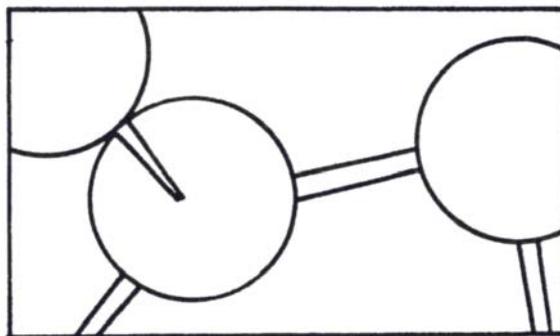
Pencil; paper; molecular models from Activity 7.1; nonhardening clay; clay tools; strips of cardboard to form a frame around a clay mold; cardboard for base; X-ACTO knife; ruler; tape; plaster of Paris; bowl; water.

### Time

150 minutes

### Procedure

1. Using a molecular model, draw a series of small preliminary sketches of the chosen model, emphasizing interesting positive and negative space. A sketch need not be completely contained by the edges of the paper; allow some parts of the drawing to touch the edge of the page, implying extension beyond the page. Try combining two or more models in one sketch. The typical shape for a sketch would be rectangular, but the outer shape might be square, circular, or triangular. (See Figure 7.4.)



**Figure 7.4**

2. Choose one of your sketches and prepare a clay mold:
  - a. Flatten the clay to a 2-in. thickness.
  - b. Cut a cardboard base in an appropriate shape and place the clay over it. Trim the clay and the base so that the edges are flush.

■ *Note:*

Feel free to use any desired size and shape for the mold. Recommended size for a rectangular shape is 5 x 8 in.

- c. Use clay tools or hands to make indentations in the clay. Do not remove so much clay that the base is exposed, and make some areas high relief and some areas low relief, for variety. The cast piece will be an inverted image of the mold: The deeper the carving in the mold, the higher the relief in the cast piece.
- d. Place cardboard strips around the outside of the mold, securing them with tape. The strips should rise at least 1 in. above the highest part of the clay. In the cast piece, this elevated portion will form the base. Secure the bottom edge of the outside of the mold with clay to prevent plaster leakage.

3. Mix plaster of Paris with water in the bowl and pour it into the mold. Allow the plaster to set completely.

■ *Note:*

The plaster may be colored, if desired, by adding a small amount of liquid tempera paint to the mixture.

4. Remove the frame and the cardboard bottom. Peel the clay off the mold. (The clay can be reused.)
5. Title your piece, using a variation or combination of the names of the molecules modeled.

**Level Two: Relief Plaster Sculpture Emphasizing Positive and Negative Space and Visual Movement**

**Materials**

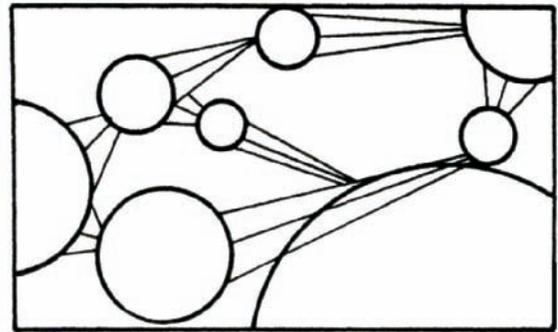
Same as Level One.

**Time**

150 minutes

**Procedure**

1. Draw preliminary sketches as in Level One. In addition to emphasizing interesting positive and negative space, try to create a sense of visual movement across, up, down, in, out, around, and so forth. This sense of movement can be intensified by exaggerating the components of the models (e.g., varying the sizes and shapes of their components). (See Figure 7.5.)



**Figure 7.5.**

2. Proceed with steps 2–5 from the procedure in Level One.

**Level Three: Relief Plaster Sculpture Emphasizing Positive and Negative Space, Visual Movement, and Visual Texture**

**Materials**

Same as Level One.

**Time**

150 minutes

### Procedure

1. Draw preliminary sketches as in Level Two, applying visual texture to the positive shapes in the composition. These textures should reinforce the movement of the positive shapes.
2. Proceed with steps 2–5 from the procedure in Level One. (See Figure 7.6.)

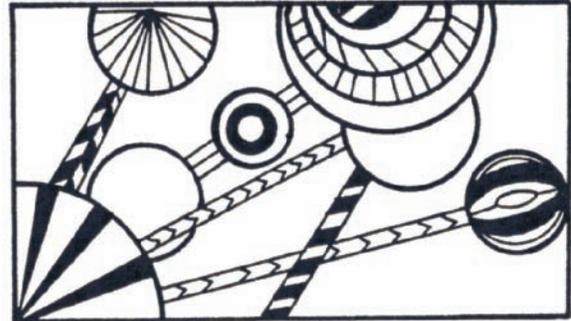


Figure 7.6.

**Essential Question: What important social and religious purposes have relief sculptures served?**

## THE LAST PIECE TO THE PUZZLE

### The Value of Contrast, the Contrast of Value

*Contrast of value* is an important tool of the artist. Without contrast, a work would lack definition. Whether the work is in color or in black and white, a contrast between light and dark helps the eye focus on particular areas. Contrast of value can be seen all around us: a dark-colored tree against a light-colored building; a white full moon against a black night sky; areas of a sculpture highlighted by a light source while other areas are plunged into darkness. Shapes are distinguished from each other by value.

In X-ray diffraction pictures, atomic nuclei reflect X-rays onto photographic film, resulting in a pattern of dark-colored spots against a light-colored background. This value contrast in the picture allows the scientist to determine the position of atoms in a crystal or in a molecule. There are many uses for light-dark contrast.

The use of light-dark contrast to suggest three dimensions was first successfully accomplished during the fifteenth century by Italian painters. The term often used to describe the effect of light colors against dark colors is the Italian word *chiaroscuro*, from *chiaro*, meaning “light,” and *oscuro*, meaning “dark.”

#### Well-Known Examples of Value Contrast

Any work by Rembrandt van Rijn, seventeenth century

Any work by Jan Vermeer, seventeenth century

*Death of Marat*, Jacques-Louis David, 1793

*The Bathers*, Georges Seurat, 1883–1884

*Anxiety*, Edvard Munch, 1896

*The Old Guitarist*, Pablo Picasso, 1903

*Melancholy and Mystery of a Street*, Giorgio de Chirico, 1914

*Self Portrait*, Max Beckmann, 1927

*Whaam*, Roy Lichtenstein, 1963

### **Change in the Works: New Ways of Seeing**

By 1700, 13 elements had been discovered or isolated in a pure form. Copper (Cu), gold (Au), silver (Ag), mercury (Hg), and lead (Pb) were among these elements. In 1896, 26 elements were known, including sulfur (S), oxygen (O), and aluminum (Al). By 1908, 81 elements were known, and by 1993, 109 elements had been isolated or synthesized. The late nineteenth century was a time of great discovery and enlightenment in chemistry.

**Essential Question: How did the identification of 81 elements, completed in the early twentieth century, help to enhance relief sculpture creations?**

In art, the twentieth century was a time of many changes. Many artists turned from realistic interpretations of the world to more individual ways of seeing things. Artists began to alter their subject matter by distorting or changing what they viewed. Others drew upon their imagination and dreams to express themselves. Many of the examples in this and previous chapters show how varied and personal their works can be. Throughout all centuries, however, the tools of the artist (line, color, texture, shape, and value contrast) and the principles of good composition (strong center of interest or focal point, movement of the eye through the composition, balance of parts, interesting negative and positive space, and unity and harmony) have continued to shape the world of art.

### **Fauvism, Cubism, and Surrealism**

Some artists, such as Henri Matisse, chose to use bold colors not natural to the subject, distortion, simplification, and visual texture to describe their ideas. Because of the shocking effect of the works of Matisse and the works of other expressive artists of the early twentieth century, the artists were given the name *fauves*, meaning “wild beasts.” Others, such as Pablo Picasso, chose to break down their subjects into simple geometric forms, calling their form of abstraction *cubism*. Still others, such as Salvador Dali and Rene Magritte, chose to draw upon dreams and fantasy to express their views in a style called *surrealism*.

**ACTIVITY**

## 7.3

### ***A Discussion of Fauvism, Cubism, and Surrealism***

#### **Objectives**

1. Students will view reproductions of work by Matisse, Picasso, Dali, and Magritte.
2. Students will discuss how each artist expresses their ideas based on the definition of each style, the meaning of the title of the work, and how the title is seen in the picture.
3. Students will discuss how each artist uses the elements of art and the principles of good composition.
4. Students will compare and contrast the styles of these artists.

#### **Materials**

Slides (or photographs) of work by Matisse, Picasso, Dali, and Magritte; slide projector.

#### **Time**

50 minutes

#### **Procedure**

1. The teacher should list the elements of art and the principles of good composition in a prominent location.
2. Discuss the characteristics of fauvism, cubism, and surrealism (a discussion follows this activity).
3. The teacher should show reproductions of works by Matisse, Picasso, Dali, and Magritte (and other artists of the fauvist, cubist, and surrealist movements).
4. Compare and contrast the works of artists from the three movements, in terms of style and subject matter. Discuss how each artist expresses his ideas based on the definition of each style and how he uses the elements of art and the principles of good composition.

■ *Note:*

It may be helpful to research Matisse, Picasso, Dali, and Magritte (and other fauvist, cubist, and surrealist artists) and share with the class what you learn.

**Fauvism: 1900 to 1920.** Some of the artists involved in the fauvist movement were Henri Matisse, Andre Derain, and Raoul Dufy. They used bold colors that were not natural to the subject and made use of visual texture to enrich the painting surface. They painted simplified shapes without realistic shading, and their paintings had flat areas of color. These “wild beasts” broke the rules and shocked the art world.

**Cubism: 1900 to 1950.** Some of the artists involved in the cubist movement were Pablo Picasso, Georges Braque, and Juan Gris. They broke down form into geometric parts and were not interested in color. For them, form and shapes were more important. They used multiple views of the same object, painting objects as seen from many angles at the same time. Their art was a form of abstraction taken from reality but changed by the artist.

**Surrealism: 1920 to the Present.** Artists who have been involved in the surrealist movement include Salvador Dali, Joan Miró, Rene Magritte, and Max Ernst. Surrealism combines realism, the subconscious, and the dream world. Imaginative objects, the real and unreal, exist in the same picture. This movement was inspired by Sigmund Freud’s study of the subconscious. The surrealist artists are also excellent technicians. A surrealist painting usually suggests a specific mood (e.g., eerie, sad, playful, mysterious).

#### **What did Matisse say about fauvism?**

- Matisse and his friends were first called *fauves* when they exhibited together at the Paris Salon d’Automne of 1905.
- A fellow artist, Georges Duthuit, said, “Matisse tells me that he still has no idea what ‘fauvism’ means.”<sup>2</sup>

#### **What were the two most popular themes of the cubists?**

- Still life and cityscape were the two most popular themes of the cubists.
- Still life allowed the Cubists to test their revolutionary compositions against the reality of objects observed in everyday life.

#### **How did the surrealists’ paintings give an impression of heightened dream images?**

- Their landscape paintings had a glassy rigidity, diamond hardness, and cold, gemlike strangeness.
- The contours of their images stood out with crystal clarity.

These artists, intentionally or unintentionally, stepped into the world of atoms, molecules, and subatomic particles and incorporated theories concerning atomic and subatomic particles into their works of art. The simplified shapes of fauvism might resemble our concept of the arrangement of particles in a crystalline solid—a uniform display of the crystal particles. The geometric shapes in cubist paintings often resemble the geometric shapes of molecules. The dream-world shapes of the surrealists often resemble molecules or atoms floating, as in a gaseous phase, or intermingling to resemble the liquid or solid phases of matter. Shapes resembling electron-cloud probability areas are seen in works of Salvador Dali and Joan Miró. The imagination of fauvist, cubist, and surrealist artists has resulted in an unintentional interpretation of the structure of matter.

## **Examples of Fauvist, Cubist, and Surrealist Paintings**

### **Fauvist Paintings**

*Green Stripe (Madame Matisse)*, Henri Matisse, 1905

*Open Window, Collioure*, Henri Matisse, 1905

*Indian Model in the Studio at L'Impasse Guelma*, Raoul Dufy, 1928

*Oriental Rugs*, Henri Matisse, 1906

*Spanish Still Life*, Henri Matisse, 1906

### **Cubist Paintings**

*Girl with Mandolin*, Pablo Picasso, 1910

*Accordionist*, Pablo Picasso, 1911

*Card Player*, Pablo Picasso, 1913–1914

*Violin and Palette*, Georges Braque, 1909–1910

*Portrait of Picasso*, Juan Gris, 1912

### **Surrealist Paintings**

*The Persistence of Memory*, Salvador Dali, 1931

*The Harlequin's Carnival*, Joan Miro, 1924–1925

*Europe after the Rain*, Max Ernst, 1940–1942

*The Castle of the Pyrenees*, Rene Magritte, 1959

*Inventions of the Monsters*, Salvador Dali, 1937

## **ACTIVITY**

### **7.4**

## **Series of Four Drawings with Emphasis on Value Contrast: Fauvism, Cubism, and Surrealism**

### **Objectives**

1. Students will apply the principles and techniques of value contrast, fauvism, cubism, and surrealism in creating drawings of molecular models.
2. Students will apply the principles of good composition to their drawings.

### **Materials**

6-x-16-in. white drawing paper; ruler; pencil; eraser; selection of molecular models; posterboard or other heavy mounting surface large enough to hold a set of four drawings; rubber cement; colored pencils; scratch paper; magazines; scissors.

### **Time**

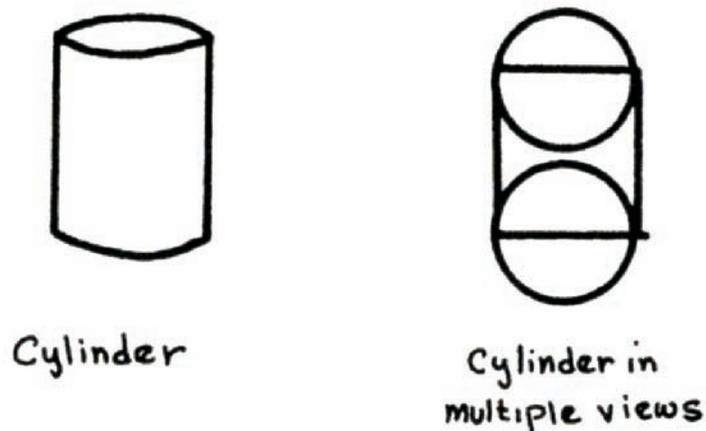
300 minutes

**Procedure**

1. Choose one or more molecular models to use as the subject for a series of four drawings. Arrange the models into a composition in preparation for a drawing.
2. Divide the white drawing paper into four 4-x-6-in. rectangles.
3. A black pencil should be used for the first drawing (leftmost rectangle), which will be realistic, emphasizing value contrast:
  - a. Lightly sketch an outline of the molecular-model composition, drawing it as it actually appears.
  - b. Using the edge of the pencil point, add shading values (light-dark contrast). Try to define the edges of the shapes using only shading, and try to achieve a realistic, three-dimensional effect. When complete, the drawing should have no outlining, and the subject should appear against a lighter- or darker-colored background.
4. A colored pencil should be used for the second drawing, which will be fauvist: Using the principles of fauvism, interpret the molecular-model composition in the second rectangle. Use the principles of good composition and the following techniques:
  - a. Distort or alter the size and shape of parts.
  - b. Add visual texture to some parts.
  - c. Simplify the shapes.
  - d. Incorporate “flat” areas of color and avoid three-dimensional (realistic) shading.
5. A black lead pencil should be used for the third drawing, which will be cubist:
  - a. Using the same molecular models, create a composition that rests on a table. Using a magazine as a source for interesting ideas, add at least two more objects to the composition (e.g., molecular models with a toy and a book; molecular models with a microscope and a textbook).
  - b. On scratch paper, make a quick sketch of a cubist interpretation of the composition. Show all of the table or only part of it.
  - c. In the third rectangle, interpret the items in the sketch by breaking down the shapes of the objects into their closest geometric shape or shapes (see Figure 7.7). Interpreting the basic forms is important, not the color. If desired, use multiple views of the objects (see Figure 7.8).
  - d. Shade the shapes with values of gray for contrast. Try to avoid using outline alone to separate shapes from one another.



**Figure 7.7. A Face Drawn in Cubist Style.**



**Figure 7.8.**

6. A colored pencil or black pencil should be used for the fourth drawing, which will be surrealistic:
  - a. Using the molecular models as the center of interest, create a surrealistic or fantasy composition in the fourth rectangle.
  - b. Create an unusual setting or location for the molecular models, such as underwater or on top of a mountain, or combine the molecular models with something else, such as the hood ornament of a car or the head of an animal. All objects and settings depicted (including the models) should be drawn in a realistic manner.
  - c. Add other realistically depicted objects to the composition, as desired.
7. Cut out all four pictures and use rubber cement to mount them on posterboard or some other heavy mounting surface. Label the first drawing Realistic. Label each subsequent drawing with the name of the movement represented.

## THE PUZZLE IS COMPLETED

We have studied color, line, shape, texture, and value contrast as the elements that, together, make a complete work of art. These are the puzzle pieces that fit together to make the entire picture. There are many ways to use these pieces to compose a work of art. In the next chapter we use new techniques to organize the five elements into a pleasing work of art. The same puzzle pieces will be placed together in new ways, with interesting results.

## NOTES

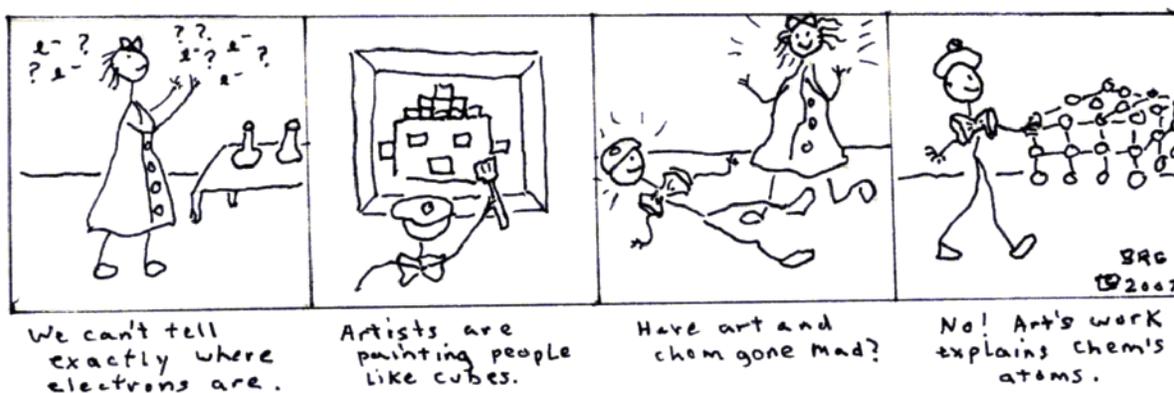
1. [www.armeniapedia.org](http://www.armeniapedia.org)
2. John Elderfield, *The "Wild Beasts:" Fauvism and Its Affinities* (Oxford University Press, 1976), 13.

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## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 7.1 Making Molecular Models

#### Level One

1. H<sub>2</sub>S (hydrogen sulfide) is bent, CaCl<sub>2</sub> (calcium chloride) is linear, CH<sub>4</sub> (methane) is a tetrahedral, BF<sub>3</sub> (boron trifluoride) is a trigonal pyramid, and KBr (potassium bromide) is linear.
2. CO<sub>2</sub> (carbon dioxide) has double bonds. N<sub>2</sub> (nitrogen) and C<sub>2</sub>H<sub>2</sub> (acetylene) have triple bonds.
3. In NH<sub>3</sub> molecules, the nitrogen atom is bonded to the hydrogen atoms in *p* orbitals with 109.5 degree angles between each bonding site pair. The bonding between aluminum and chloride atoms in AlCl<sub>3</sub> is in *sp*<sup>2</sup> orbitals, where 120 degrees separates each bonding site pair.

#### Level Two

1. H<sub>2</sub>S bonds in *p* orbitals, CaCl<sub>2</sub> bonds in *sp* orbitals, CH<sub>4</sub> bonds in *sp*<sup>3</sup> orbitals, BF<sub>3</sub> bonds in *sp*<sup>2</sup> orbitals, and KBr bonds in *s* orbitals.
2. For H<sub>2</sub>S the electronegativity value for hydrogen is 2.1, and for sulfur it is 2.5. The difference between these values is 0.4, which indicates covalent bonds. The molecule itself is polar since electron density accumulates on the oxygen atom side of the molecule. For CaCl<sub>2</sub> the electronegativity value for calcium is 1.0, and for chlorine it is 3.0. which indicates ionic bonds. Even though the bonds are polar, the molecule is nonpolar. The molecule is linear, with chlorine atoms equal distance from the central calcium atom, so the electron density is balanced, leaving no net charge. For CH<sub>4</sub>, the electronegativity value for carbon is 2.5, and for hydrogen it is 2.1, leaving a difference of 0.4. This indicates covalent bonds are within the molecule. CH<sub>4</sub> is nonpolar. There is equal electron density throughout the molecule. For BF<sub>3</sub>, boron has an electronegativity value of 2.0, and fluorine has a value of 4.0. The electronegativity difference is 2.0. This indicates ionic bonds within the molecule. However, the molecule is nonpolar. The three terminal fluorine atoms have the same negative charge, are the same distance from the boron atom, and are arranged symmetrically around the central boron atom, making the molecule electrically neutral. For KBr, the electronegativity value for potassium is 0.8, and for bromine it is 2.8, leaving a difference of 2.0. This indicates an ionic bond within the molecule. The molecule is polar since the electron density is concentrated around the bromine atom.
3. The polar covalent bonds result in a concentration of electrons around the oxygen atom. Water is a bent molecule. In general, bent molecules are polar, since a lone pair of electrons exist where there is no bond.



# Photography

## *A Picture Is Worth a Thousand Words*



Answers to questions and conclusions are found at the end of the chapter.

**Essential Question: Will digital photography ever totally replace film photography? Explain your answer.**

## INTRODUCTION

### Picture This

Picture this: a world without photography. Magazines, books, and newspapers are filled with photographs of current events. Advertisers bombard us with photographs of famous people and new products. In advertising, it is well known that a picture is worth a thousand words. What would a wedding or a graduation be without someone taking pictures to capture a memory of the event? However, life without photography was the case before the 1830s, when L. J. M. Daguerre, a French painter and stage designer, created a process named after him—the *daguerreotype*. In this process, a reverse image, reversed by the lens of a camera, was projected onto a specially treated plate (see p. 308), which was then developed, and the image was fixed (made permanent), producing the final picture. The disadvantage of this first daguerrotype was the length of time the plate had to be exposed to produce the image. Samuel F. B. Morse, better known for the invention of the telegraph, was instrumental in improving the daguerreotype. He was able to decrease the exposure time, creating a more user-friendly procedure. By 1840 the daguerreotype was widely accepted and in use in America. However, the final image was not in color; artists were employed to color the images by hand to achieve a realistic effect.

■ *Note:*

A suggested example of a daguerreotype is *Girl with a Portrait of Washington*, Southworth and Hawes, mid-nineteenth century. Also, any examples of daguerreotype from books listed in the “References” section at the end of this chapter may be used.

**How was a daguerreotype photo made?**

- The “film” was a sheet of silver plated copper.
- The plate was sensitized with iodine vapor.
- Next the plate was placed in the camera.
- A subject was exposed for three to fifteen minutes.
- The plate was developed with mercury vapor. Later the sensitivity of the developing process was increased by using chlorine or bromine fumes.

**A Record of Going West and Wars**

At the same time that the daguerreotype was in use, William Henry Fox Talbot, an English chemist, was developing a process using glass negatives and paper prints. This process, although slow to overtake the popular daguerrotype, was being used extensively by 1860 to record many historical events, such as the Civil War and the move westward by the pioneers. Photography was not only used to record people and important events but also provided a means of more accurately recording events previously unobserved, such as the motion, in separate steps, of a running horse or a human jumping. It gave artists a new tool for recording what they saw. However, photography as an art form in its own right was not realized until much later.

**Cameras for the Average Person**

In 1888 the camera moved into the hands of the average person when George Eastman developed the Kodak™, a small camera for making quick, simple exposures, or “snapshots.” The Kodak was made to be used with a roll of film.<sup>1</sup> Heavy, awkward photographic plates for recording images were no longer needed, so the camera was no longer a tool only for professionals.

Later developments expanded the possibilities provided by the camera. In 1924, for example, the Leica camera introduced 35mm photography. It was small, unobtrusive, and quick, making it easier to take pictures that were difficult to take with the traditional camera.

Today digital cameras are available and easily used by average people of all ages. Digital camera technology evolved from recorded television images. In 1951 the first videotape recorder captured live images from television cameras by converting the information into electrical digital impulses and saving this information on magnetic tapes. During the 1960s NASA converted from analog to digital signals within its space probes. These space probes sent digital images of the moon back to earth. In 1991 Kodak released the first professional digital camera system. The first digital cameras for the average person were available in 1994. Today digital cameras are the camera of choice for people of all ages.

In a digital camera, light from an object strikes a digital sensor in place of a sheet of film. The digital sensor is a computer chip with tiny sensor points called *pixels*, short for picture elements. These sensor points are arrayed in rows and columns. A six megapixel camera has 3,008 megapixels arranged in rows and 2,000 megapixels arranged in

columns. Light from an object passes through colored filters and excites the sensor points, producing an analog signal, which is converted into a digital signal representing an image of an object. This image is transferred to a memory card ready to be observed, redone, or printed.

The basic elements necessary to take a photo are the same for all cameras: a dark container, a controllable opening to admit light, and a means for recording the light admitted. A simple camera that is easy for you to construct and that includes these elements is a pinhole camera.

**ACTIVITY****8.1*****Making a Pinhole Camera*****Objectives**

1. Students will construct a pinhole camera.
2. Students will understand how a film camera works.
3. Students will use light as a paint brush.
4. Students will create photos of molecular models and/or crystalline structures that express the principles of good composition.

**Materials**

A two pound coffee can; a no. 10 sewing needle; dull black paint; an awl or ice pick; opaque black paper; clear tape; 4 inch x 5 inch photopaper (Kodabromide Paper F-glossy); aluminum foil; a safelight; molecular models from Activity 7.1 plus a model of the oxygen ( $O_2$ ) molecule.

**Time**

60 minutes

**Procedure**

1. Paint the inside of your coffee can with dull black paint or line it with black paper.
2. Paint the coffee can plastic lid on both sides with dull black paint.
3. Push a no. 10 needle through the center of a  $2\frac{1}{4}$ -x- $3\frac{1}{4}$ -in. piece of aluminum foil to a point halfway up the needle shank.
4. Use an awl or ice pick to make a hole  $\frac{1}{4}$  in. in diameter in the center of the metal end of your coffee can.
5. Tape your aluminum foil piece over the metal end of your coffee can so that the small pinhole is placed over the larger hole.

6. Make the camera shutter by taping a flap of black paper over the pinhole. You can use a small piece of tape to close the shutter while it's not in use.
7. Load the photographic paper into the camera. **YOU MUST DO THIS IN A DARKROOM UNDER A SAFELIGHT.** You can make a safelight by placing several layers of red cellophane paper over a flashlight and keeping the flashlight six to eight feet away from the film. The photographic paper should be taped firmly on the inside of the painted plastic lid. Place the plastic lid back on the coffee can camera with the film emulsion (glossy) side facing the pinhole. Be sure the black paper flap is securely covering the pinhole. Now your camera is assembled.
8. Arrange your molecular models to illustrate a chemical equation while placing the models in a composition that illustrates the principles of good composition. (See Chapter 1.) A possible equation is
$$2\text{H}_2 + \text{O}_2 \longrightarrow 2\text{H}_2\text{O}$$
(You can work in groups so enough molecular models are available.)
9. Aim your camera about three feet from your composition. Anchor the camera to a table or surface with tape or clay. With your composition in bright sun, expose (open your black flap) for one to three seconds. In cloudy bright light, open your shutter for four to eight seconds. If possible, take three different exposures of the same composition, but for different lengths of time.
10. Have the film printed.
11. Evaluate your photo, considering the principles of good composition and the accuracy of your equation.

## Questions and Conclusions

### Level One

1. Why do you paint the inside of the coffee can and the plastic cover black?
2. What is the function of the hole in the end cover of your coffee can camera?
3. Why is the hole covered with a black flap?
4. What are the principles of good composition that you should consider in evaluating your photo?
5. Identify your equation within your composition. Write it as a word equation.

### Level Two

1. Compare your coffee can camera to a digital camera. For each camera identify the lens, film, and shutter.

2. Compare and contrast the features of a coffee can pinhole camera with the features of a digital camera. Some areas of comparison include resolution, depth of field, use in varied lighting conditions, richness of colors and tone, and convenience.
3. What kinds of equations make the best compositions? Explain your answer.

### **Challenge Activity**

Find a room that has windows but can be thoroughly darkened. This room can be in your school or at home. This room will be your camera! Choose a bright, sunny day. Darken the room but leave a small hole at the window so light can enter. Look at the wall opposite the hole. You should see an upside down image of objects outside the window. Using a digital camera, take a picture of the image. Explain why the image is upside down.

## **THE CHEMISTRY BEHIND THE ART OF FILM PHOTOGRAPHY**

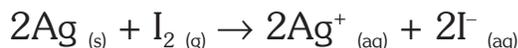
Historically, the development of photography as an art parallels the advancement of our knowledge concerning light-sensitive chemicals and our ability to control these chemicals. Photography is the art of painting with light. To make a photo from film, light from an image must strike a chemical substance. The chemical darkens in degrees proportional to the quantity of light that the chemical is exposed to. Even before the 1830s, scientists were experimenting with chemicals that changed in appearance upon exposure to light.

### **Silver Provides the Answer**

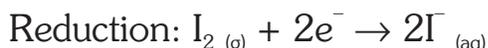
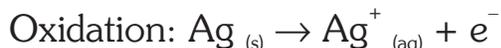
In 1727 a German physicist, Heinrich Schulze (1684–1744), discovered that silver nitrate ( $\text{AgNO}_3$ ) and other silver salts darkened upon exposure to light. Thomas Wedgwood (1771–1805), son of the English potter Josiah Wedgwood, was the first to make practical use of the phenomenon. In 1802 he published a paper that described a paper soaked in silver nitrate that was used to make photograms, pictures made without a camera (see Activity 8.3). Objects were placed on the paper, and light, striking the area surrounding the objects, reduced the silver ions ( $\text{Ag}^+$ ) to silver metal ( $\text{Ag}$ ), darkening the area exposed to light. The areas beneath the objects were not exposed to light and remained unchanged. Unfortunately, one major problem remained: The photograms produced were not permanent. Any exposure of the entire photogram to ordinary light turned the entire photogram black.

## Photo Permanency: How Is It Done?

In the 1830s L. J. M. Daguerre solved the problem of photo permanency. His specially treated plate was a sheet of copper (Cu) plated on one side with silver. The silver was oxidized with iodine (I) vapor to produce silver ions:



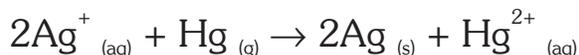
with half reactions:



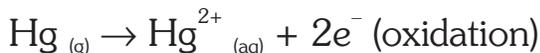
■ *Note:*

(s) indicates a solid, (g) gas, and (aq) aqueous.

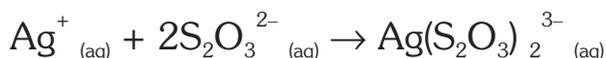
After exposure to reflected light, the plate was exposed to mercury (Hg) vapor, converting the silver ions to silver atoms and producing an image:



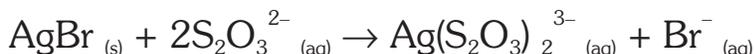
with half reactions:



Daguerre used sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) to make the photo permanent. Today we still use sodium thiosulfate for this purpose, but we call it *hypo*. The sodium thiosulfate removes unexposed silver bromide (AgBr) as follows:



or



Even though we still use light-sensitive silver salts in film to produce an image and sodium thiosulfate to preserve the image, we do not encourage iodine and mercury vapor use for film development. In hat making, mercury vapor was commonly used for felt enhancement. Constant inhalation of mercury vapor is not good for brain cells, as is evidenced in the Mad Hatter's story in *Alice in Wonderland*. Chapter 10 addresses the issue of chemical hazards in art.

## Changing Solubility Preserves the Image

If the solubility of silver bromide or any slightly soluble silver salt could not be increased, we would not be able to fix a photographic image. When sodium thiosulfate reacts with insoluble silver bromide, the silver complex produced,  $\text{Ag}(\text{S}_2\text{O}_3)_2^{3-}$ , is quite

soluble in water and can be washed away. Certain molecules or ions, called ligands, have an unbounded outermost electron pair that can be used to bond a metal ion, usually a transition-metal ion such as a silver ion, to form a complex ion that is often quite soluble in water. When children have excess lead ions ( $\text{Pb}^{2+}$ ) in their body tissues, a ligand that bonds lead ions is given to the child to remove the excess lead ions.

### What is a solution?

- A solution is a homogenous mixture.
- Simple solutions have two ingredients: a solute and a solvent.
- The solvent dissolves the solute.
- Usually a solution has more solvent than solute.

### General Rules of Solubility

The general rules of solubility help us to predict whether or not a substance is soluble in water. If 1 g of a substance can dissolve in water to make 100 g of solution, we say that the substance is *soluble*. If less than 1 g but more than 0.1 g can dissolve, the substance is *slightly soluble*. If a substance can only dissolve in water if less than 0.1 g is present, we say that the substance is *insoluble*. These criteria for solubility of substances are determined at 25°C. The following rules summarize the solubility of a large number of substances:

1. Most alkali metal and ammonium ( $\text{NH}_4^+$ ) compounds are soluble.
2. Most nitrate ( $\text{NO}_3^-$ ), acetate ( $\text{C}_2\text{H}_3\text{O}_2^-$ ), and chlorate ( $\text{ClO}_3^-$ ) compounds are soluble.
3. Most chloride compounds are soluble, except silver chloride ( $\text{AgCl}$ ), lead chloride ( $\text{PbCl}_2$ ), and mercury I chloride ( $\text{Hg}_2\text{Cl}_2$ ).
4. Most hydroxide compounds are insoluble, except alkali metal hydroxides and barium hydroxide [ $\text{Ba}(\text{OH})_2$ ], which are soluble, and calcium hydroxide [ $\text{Ca}(\text{OH})_2$ ] and strontium hydroxide [ $\text{Sr}(\text{OH})_2$ ], which are slightly soluble.
5. Most sulfate compounds are soluble, except lead sulfate ( $\text{PbSO}_4$ ) and barium sulfate ( $\text{BaSO}_4$ ), which are insoluble, and silver sulfate ( $\text{Ag}_2\text{SO}_4$ ) and calcium sulfate ( $\text{CaSO}_4$ ), which are slightly soluble.
6. Most carbonate ( $\text{CO}_3^{2-}$ ), phosphate ( $\text{PO}_4^{3-}$ ), and sulfide ( $\text{S}^{2-}$ ) compounds are insoluble.

**Essential Question: What would happen to living things if most sodium compounds and nitrate compounds were not soluble in water? Explain specifically how these compounds are used in plants and animals.**

**Regarding the ratio of solute to solvent in a solution, what is the meaning of *unsaturated*, *saturated*, and *supersaturated*?**

- An unsaturated solution can dissolve more solute in the solvent at a particular temperature.
- A saturated solution has the maximum amount of solute able to dissolve in the solvent at a particular temperature.
- A supersaturated solution has more solute than the amount that normally dissolves in the solvent at a particular temperature.

### **Challenge Activity**

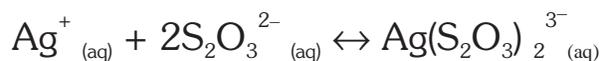
In your classroom, form human solutions that are unsaturated, saturated, and supersaturated. Eight students can be solvent (water) molecules. Eight students can be solute (glucose) molecules. Have signs or costumes to identify what you are. All of you should secretly decide what type of solution you are representing. Then you should group together to form the decided on solution. Remember that solutions are homogeneous throughout. The remaining students should identify the type of solution and explain their decision. All three types of solutions can be modeled. Since solubility of most solutes increases as temperature increases, a model can be revised to illustrate solubility at a higher temperature. Remaining students can try to explain what is happening as the model changes.

To understand why the addition of thiosulfate ions ( $S_2O_3^{2-}$ ) to silver ions ( $Ag^+$ ) is an extremely efficient way to remove unexposed silver ions on photographic film, it is necessary to investigate the concept of equilibrium.

### **Equilibrium: What Is Equal?**

When a substance is dissolved in water to form a saturated solution (see “Types of Solutions” in Chapter 2), some of the substance remains undissolved, so we know we have reached the saturation point. Present in the solution would be the dissolved ions and a small portion of the undissolved substance. When all these substances are present, we can say that we have reached *equilibrium*. To have equilibrium, the rate of the substance dissolving has to equal the rate of the dissolved ions reforming the original substance. To show that a system is at equilibrium, we use a double arrow in the equation. When sodium

thiosulfate reacts with silver ions to form a complex, and the reaction reaches equilibrium, the equation is written as follows:



### **Equilibrium Concentrations**

At equilibrium, depending on the temperature of the reaction, almost any concentration of the substances present can exist. If, at equilibrium in the reaction between sodium thiosulfate and silver ions, mostly silver ions and thiosulfate ions are present, we would not be successful in removing the silver ions to preserve a photo image. We need a system that shows us which substances are in excess at equilibrium, the reactants or products. It is possible to have equal concentrations of reactants and products at equilibrium, but this is usually not the case. At equilibrium, forward and reverse reaction rates are equal, not the amounts of reactants and products. At equilibrium, the rate of reactants making products equals the rate of products making reactants. This results in constant product and reactant concentrations.

### **Challenge Activity**

Using a digital camera, take photos of situations that illustrate the principles of equilibrium. Team sport events such as basketball, football, and baseball games work well. In your photos identify the “reactants” and “products.” Use your team photos to explain how the forward and reverse “reaction rates” are equal throughout the game. Identify the “concentrations” of the “reactants” and “products” at equilibrium.

### **What is the general formula for finding a constant at equilibrium, and what are some practical uses for the equilibrium constant?**

- We can use the general reversible reaction  $aA + bB \leftrightarrow cC + dD$  to illustrate the equilibrium constant.
- The equilibrium constant expression for this equation is:  $K_{\text{eq}} = \frac{[C]^c [D]^d}{[A]^a [B]^b}$ . (It is assumed that there are no solid or liquid reactants or products. Only aqueous solutions and gases change concentrations as they reach equilibrium and then maintain constant concentrations at equilibrium. Also, brackets represent moles/liter.)
- In general, when it is necessary to remove certain ions from a chemical system, the equilibrium constant can help to determine what substances should be used. In photography, in order to remove excess silver ions from developing film, we need a substance that will combine with the silver ions and at equilibrium produce a large amount of product, resulting in a very large equilibrium constant value. When a child has excessive amounts of lead ions in his or her system, these ions can be removed by administering a substance that combines with lead ions to form a complex substance where the equation for this reaction has a very large equilibrium constant value.

### **A System for Determining Equilibrium Concentrations**

When we consider a system at equilibrium, we find that if, at a specific temperature, we arrange the reactant and product concentrations expressed in moles per liter in a particular way, no matter what these concentrations are, a constant value results. This constant value is called the *equilibrium constant* and, for solubility, is given the symbol  $K_{sp}$ . The general formula to find the  $K_{sp}$  is the product (multiplication) of the concentrations of the products expressed in moles per liter over the product of the concentrations of the reactants expressed in moles per liter. Also, to find the constant, coefficients in the dissolving equation become exponents. Once we know the  $K_{sp}$  for the solubility of a substance, we can know precisely how soluble that substance is. When we are looking for a fixing agent for film development, we need a substance that will combine with silver ions and form a very insoluble product. The  $K_{sp}$  for a substance is determined from an equation as follows: For



the preliminary  $K_{sp}$  expression is

$$K_{sp} = \frac{[\text{Ag}^+][\text{Cl}^-]}{[\text{AgCl}]}$$

The brackets represent concentration in moles per liter. Because the constant, the  $K_{sp}$ , is dependent on concentration, we remove solids such as silver chloride ( $\text{AgCl}$ ) from the expression. The concentration of a solid is constant. The density of a solid is a way to express the solid's concentration. Therefore, the  $K_{sp}$  of a solid dissolving is simply the product of the concentration of the ions produced. For



the  $K_{sp}$  expression is:

$$K_{sp} = [\text{Ag}^+][\text{Cl}^-]$$

It can be seen that the higher the value for the  $K_{sp}$ , the greater the solubility of the substance.

### **Constants for Film Fixing Substances**

Using the same general formula that we used for  $K_{sp}$ , we can examine constants for the formation of complex ions and determine what would be the best substance to use as a film fixer; in other words, what substance can remove a large number of silver ions from the unexposed portion of the film. We use the symbol  $K_f$  for the formation constant of a complex ion. We know that thiosulfate ions are combined with silver ions to form the  $\text{Ag}(\text{S}_2\text{O}_3)_2^{3-}$  complex:

$$\text{For } \text{Ag}^+_{(aq)} + 2\text{S}_2\text{O}_3^{2-}_{(aq)} \leftrightarrow \text{Ag}(\text{S}_2\text{O}_3)_2^{3-}_{(aq)}, \text{ the } K_f \text{ expression is}$$

$$K_f = \frac{[\text{Ag}(\text{S}_2\text{O}_3)_2^{3-}]}{[\text{Ag}^+][\text{S}_2\text{O}_3^{2-}]^2}$$

The  $K_f$  value at 25°C for  $\text{Ag}(\text{S}_2\text{O}_3)_2^{3-}$  is  $2.9 \times 10^{13}$ . This extremely large value tells us that at equilibrium, there will be mostly  $\text{Ag}(\text{S}_2\text{O}_3)_2^{3-}$  ions present.

The  $K_f$  value for the  $\text{Ag}(\text{CN})_2^-$  complex ion is  $5.6 \times 10^{18}$ . Cyanide ions ( $\text{CN}^-$ ) would be better removers of silver ions than thiosulfate ions. However, most of us know that cyanide is a deadly poison if inhaled or ingested. In the play *Arsenic and Old Lace*, it was used very effectively to rid the cast of unwanted characters. Refining the process of film developing, which included not only the discovery of proper fixing solutions but also the development of film surfaces and developers that were reliable, helped to plunge us into the age of modern photography.

## MODERN PHOTOGRAPHY

### Photography Comes of Age: Art and Photography

Alfred Stieglitz (1864–1946) is widely considered to be the founder of modern photography. He took photography from being just a means of recording what we see and raised it to an art form. His photographs include not only artistic and personal images of what he saw, but also abstract images beyond realistic subject matter. These abstract images began in the 1920s with his cloud compositions.

Nature photography was raised to an art form by the most famous of the American nature photographers of the twentieth century, Ansel Adams (1902–1984). He is considered to be the master technician of black-and-white photography. His nature scenes are still some of the most beautiful pictures ever taken.

With the creation of many new magazines and newspapers during the early part of the twentieth century, photography grew into its own as a means of recording the visual images of the times, such as the Great Depression, the growth of industry, life in the city, and World War II. These events were recorded on film by photojournalists. As many new magazines and newspapers appeared, there came an increase in advertising and a need for the photographer to illustrate everything from baby booties to sleek new cars.

After World War II, photography as an art form took two directions. Some photographers turned from realism to abstraction and fantasy, as seen in the work of Minor White (1908–1976) and Bill Brandt (1904–1983). Others, such as Robert Frank (1924–), used realism and words to portray a personal view of American culture.

Great digital photographers are yet to be established. David Hiser, a famous *National Geographic* photographer, in recent years converted from film photography to digital photography, with amazing results. His beautiful digital photos, which exhibit total depth of field and clarity throughout the image, surpass his film photos. To achieve a photo with the best clarity, he can take numerous photos of an object and immediately select the right one. Digital cameras are the cameras of the future.

### Works by Significant Photographers

*Portrait (I) 1918 Georgia O'Keeffe*, Alfred Stieglitz, 1918 (or any cloud photograph by Alfred Stieglitz)

*Moonrise*, Ansel Adams, 1941 (or any nature photograph by Ansel Adams)

*Migrant Mother* (Depression era), Dorothea Lange, 1936

*Fort Peck Dam* (first cover of *Life* magazine), Margaret Bourke-White, 1936

*Ritual Branch* (abstraction), Minor White, 1958 (or any work by Minor White)

*London Child* (fantasy), Bill Brandt, 1955 (or any work by Bill Brandt)

*Santa Fe, New Mexico* (realism), Robert Frank, 1955–1956 (or any work by Robert Frank)

## Picture Perfect

Anyone can click the shutter of a camera, but will a good picture result? As in other forms of art, composition is an important element in photography. A photograph is judged by how well the picture is composed. Composition has already been discussed in relationship to other art forms (see Chapter 1), but a brief review of composition basics, focusing on their application to photography, follows:

1. **Strong center of interest or focal point:** This is what the photographer wants the viewer to look at first. The entire subject, however, need not be shown; close-ups of only a portion of the subject can sometimes be very effective. Also, the center of interest need not be at the center of the picture. Try moving it off-center, up or down, or to either side. The subject can be framed in a number of ways just by moving the camera.
2. **Movement of the eye through the picture:** The viewer's eye should move through the picture easily. Avoid having confusing lines in the background that move in too many directions. Simplicity is the key. Too much confusion in the background may overwhelm the focus of the picture.
3. **Balance of parts—symmetrical (equal) or asymmetrical (unequal):** If the subject is placed off-center in the picture, another visual element should be used to balance the subject. Sometimes visual balance can be achieved by framing. In a landscape, for instance, a tree branch can often be used to add interest in the foreground, to balance a subject, and to add depth to the picture.
4. **Interesting negative and positive space:** The subject is important, but so is the space around the subject. Do not let the negative space dominate the composition. If necessary, move in closer to the subject. The photographer has control over what appears in the picture and where it appears. Do not “cut off” feet or the tops of heads, and be aware of where objects are in relation to one another. If photographing a person, for example, avoid having the person stand in such a way that a tree behind the person appears to be growing from his or her head.
5. **Unity and harmony:** Everything in the composition should complement everything else. Move in closer to the subject, if necessary, and avoid any distracting elements. It is the photographer's responsibility to ensure a good composition. (Before taking a picture, many photographers use their hands to make a frame around the subject. This helps them ensure a better composition before they shoot the photo.)

**ACTIVITY****8.2*****Analysis of Photographs*****Objectives**

1. Students will identify the principles of good composition as observed in magazine or student-supplied photographs.
2. Students will discuss how the principles of good composition have been used effectively or ineffectively in the photographs.
3. Students will suggest ways to improve existing photos if they feel improvement is needed.

**Materials**

Digital cameras; computer image projector photographs (digital or film) or magazines containing photos.

**Time**

50 minutes

**Procedure**

If a digital camera and a computer image projector are available:

1. Take a photo of classmates or objects within your classroom.
2. Project the photo on a screen.
3. The class should critique the photo using the questions listed under 2. a, b, c, d, e, f, and g below.
4. Retake the photo, taking the class comments in consideration.
5. Project the new photo on the screen.
6. Decide if the elements of good composition are improved.

If a digital camera and computer image projector are not available:

1. Bring to class several photographs that you have taken or photographs taken by friends or family. If no photographs are available, look through magazines and find photographs you think are well composed and some you think are not well composed.
2. Either individually in writing, or in a class group discussion, answer the following questions for each photograph:
  - a. What is the center of interest in the picture?
  - b. Is the center of interest well identified or obvious? If not, how can it be improved?

- c. Does the photograph have any shortcomings as far as the composition is concerned? If so, what are they? How can they be corrected?
- d. How does the eye move through the composition? Should something be added or removed to improve the picture?
- e. Has framing been used? If so, is it effective?
- f. In what ways could the subject be framed in the photograph for an effective composition?
- g. If your photograph is being evaluated, explain how the photograph could be improved if it were retaken.

## THE PHOTOGRAM: PICTURE WITHOUT A CAMERA

Following World War II, a group of artists called the Dadaists, frustrated and disenchanted with the art establishment and society in general, reacted against tradition by moving art in a new direction, away from the accepted forms. One of the techniques that became popular with these artists was the photogram. Christian Schad, a member of the Dadaist group, began by creating images cut from paper, which he put together in groups and laid out on light-sensitive paper. He then exposed the paper to light for a specific period of time and developed his prints. Later, in 1921, the artist Man Ray used some of these same methods to create what he called Rayographs. Another artist of the period, Moholy-Nagy, who also experimented with these shadow pictures, called them photograms.

When making a photogram, the medium is light. Pictures can be created using any object, solid or transparent, that is exposed to light after being placed on light-sensitive paper. Objects can be exposed in one position, moved, and exposed again for a different amount of time for a repeat effect. Transparent and translucent objects can be used, as well as linear and solid objects, to achieve a variety of effects.

### ACTIVITY

## 8.3

### ***Photography: Printing Negatives and Making Photograms***

#### Objectives

1. Students will prepare a developing solution and use the solution to make photograms.
2. Students will explore a variety of techniques to achieve unique photogram compositions (using a variety of two- and three-dimensional objects, creating a feeling of depth through overlapping and multiple exposure of objects, etc.).

- Students will explain the use of some of the chemicals needed to make a print from a negative or to make a photogram.

### Materials

$\text{Na}_2\text{SO}_3$  (sodium sulfite); hydroquinone (paradihydroxybenzene);  $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$  (sodium carbonate); KBr (potassium bromide); concentrated  $\text{HC}_2\text{H}_3\text{O}_2$  (acetic acid); Kodak fixing solution; Elon; gram balance; 1 l volumetric flask distilled water; photographic printing paper; trays; scissors; tongs; solid or translucent two- and three-dimensional objects for making a photogram (e.g., laboratory equipment such as a beaker, funnel, glass tubing, and other objects such as wire mesh, lace, jewelry pieces, twigs, leaves, flowers); 60-watt light bulb; darkroom and safelight; automatic stirrer; 250 ml beaker; 50 ml graduated cylinder.

### Time

100 minutes

### Procedure

■ *Note:*

All discarded solutions should be placed in containers provided for hazardous waste collection.

■ *Note:*

Distilled water should be used for all chemical dilutions.

- Prepare a solution for developing paper:
  - In a 1 L volumetric flask, combine the following chemicals:
    - 3.0 g Elon
    - 45.0 g  $\text{Na}_2\text{SO}_3$
    - 12.0 g hydroquinone
    - 80.0 g  $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$
    - 2.0 g KBr
  - Add distilled water to make 1 L of developing solution. Agitate until dissolved, using an automatic stirrer.
- Prepare a stop-bath solution:
  - In a 250 ml beaker, combine 15.5 ml of concentrated  $\text{HC}_2\text{H}_3\text{O}_2$  with 40.0 ml distilled water to make a 28% solution of acetic acid.

■ **Warning!**

**Concentrated acetic acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , is damaging to the skin. Always add concentrated acid to water.**

- In a 1 L volumetric flask, combine 48 ml 28%  $\text{HC}_2\text{H}_3\text{O}_2$  solution and enough distilled water to make 1 L of solution.

## C. Make prints:

1. In a darkroom under a safelight, open a package of printing paper and cut a test strip about 1 in. wide.
2. Cover the strip to block all light. Turn on a light bulb (a 60-watt bulb works well) and gradually remove the cover from the strip, exposing portions of the strip for gradually longer periods of time. Keep track of the time for each exposure (exposures might be made in five-second increments, for example, but some experimentation is necessary).
3. Dilute the prepared developing solution 1 to 1 using distilled water.
4. Place the test strip in the diluted developing solution in the developing tray. Developing time will vary from 45 to 60 seconds.
5. Observe the test strip to determine the proper amount of time for light exposure to make a clear, detailed print.
6. With the safelight still on, remove another piece of printing paper.
7. Place objects on the paper, composing them to make an attractive picture. (Use the principles of good composition. Try to achieve movement of the eye through the composition, interesting positive and negative space, and a strong center of interest.) Experiment with a variety of objects and arrangements, using a variety of sizes, shapes, and textures. Objects might be overlapped to create a feeling of depth. The objects do not need to lie flat on the surface of the paper. Negatives may also be used. If only negatives are used, the result will be a proof sheet, which is used to examine negative-size prints of the photos (a discussion follows this activity). In your composition, try to establish a chemistry theme. Possible themes are solubility, equilibrium, and chemical changes.
8. Expose the prepared photogram to light for the appropriate amount of time to make a clear, detailed print. Multiple exposures might be made as new objects are added or removed. The light source might be flashed on and off at different angles. Positive shapes will appear light in the photogram, and negative shapes will appear dark. Prepare two copies of the photogram (one copy will be used in Activity 8.4).
9. Place the exposed photogram in diluted developing solution in a developing tray. Tongs should be used for handling the printing paper. Agitate the paper until a clear print appears, then remove the paper.
10. Wash the paper in a tray containing stop-bath solution for 30 seconds.
11. Next, wash the paper in a tray containing Kodak fixing solution for 5–10 minutes.
12. Wash the paper in running tap water for 30 minutes.
13. Finally, air dry the photogram.
14. All of the solutions can be reused several times and then disposed of according to acceptable waste disposal procedures.

## Questions and Conclusions

### Level One

1. Examine the finished photogram and evaluate it for the following:
  - a. fog
  - b. clarity
  - c. contrast
  - d. density
  - e. spotting
2. Considering the procedure for making a photogram, discuss how problems concerning photogram quality, such as fogging, spotting, and unintentional blurry images, can be prevented.
3. Explain how making a photogram differs from making a photograph.

### Level Two

1. Suggest various materials and describe new techniques that might be used to make photograms. If possible, make a photogram using some of these materials and techniques. New techniques might include light exposure using a flashlight or projecting the light from a variety of angles.
  2. If a proof sheet is prepared, critique the photos appearing on the proof sheet, in terms of light-dark contrast.
  3. Using oxidation and reduction reactions and your knowledge of acids and bases, describe the chemical changes needed to prepare a photogram.
  4. Research the use of  $\text{KBr}$  and  $\text{Na}_2\text{SO}_3$  in the developing solution and the use of  $\text{HC}_2\text{H}_3\text{O}_2$  in the stop bath.
- 

## Proof Sheets: A Way to Examine Prints

Film negatives can be printed with the aid of an enlarger or by direct contact printing. The enlarger is a projector with a lens. Light from the projector is sent through a negative, then through a lens, and then onto photographic paper, on which the negative image is focused and enlarged. After the paper is exposed, it is printed.

In contact printing, the enlarger is eliminated. The negatives are placed on print paper and exposed to light for a predetermined time. This is how photograms were made in Activity 8.3. The printed contact sheet can be examined with a magnifying glass to determine the best photos, which can be printed again with the aid of an enlarger. This system allows the photographer to make several exposures of the same picture and then decide which photos are worth enlarging.

## Pen-and-Ink Drawings

In Activity 8.4, a photogram will be used as a model for a pen-and-ink drawing. The pen-and-ink technique is a linear drawing technique. To create the effect of shading, a series of lines placed close together create the effect of darkness, a technique called *hatching*. Using crisscrossing lines is a second technique for shading with pen-and-ink drawings, called *cross-hatching*. A third shading technique is *stippling*, also referred to as *dot density*. The closer together the dots, the darker the area appears. (See Figure 8.1.)

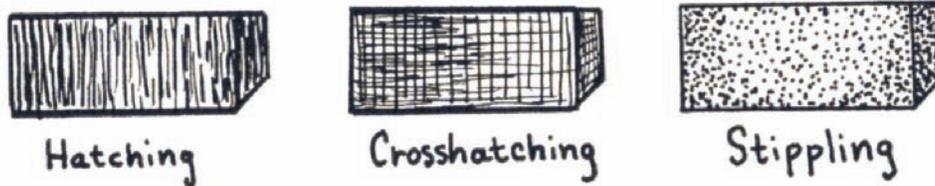


Figure 8.1.

### Well-Known Artists Famous for Pen-and-Ink Drawings

Leonardo da Vinci (1452–1519)  
Rembrandt van Rijn (1606–1669)  
Vincent van Gogh (1853–1890)  
Pablo Picasso (1881–1973)

Albrecht Dürer (1471–1528)  
Hans Holbein (1497–1543)  
Aubrey Beardsley (1872–1898)

## ACTIVITY

### 8.4

## ***Photogram and Pen-and-Ink Drawings: Same Subject, Different Media***

### Objectives

1. Students will apply the principles of good composition to pen-and-ink drawings based on their photograms.
2. Students will explore various pen-and-ink techniques in creating an inverse image of a photogram.
3. Students will properly use and care for pen-and-ink materials.

### Materials

Photograms made in Activity 8.3; typing paper (for preliminary drawing); bristol board, index paper, or any hard-surfaced white paper (for final drawing); pencil; nib straight pen and pen holder; technical pen (Rapidograph™); appropriate ink (India ink for straight pen and special Rapidograph ink for Rapidograph pen); commercial pen cleaner (for cleaning India ink); scissors. (See figure 8.2.)

### Time

150 minutes

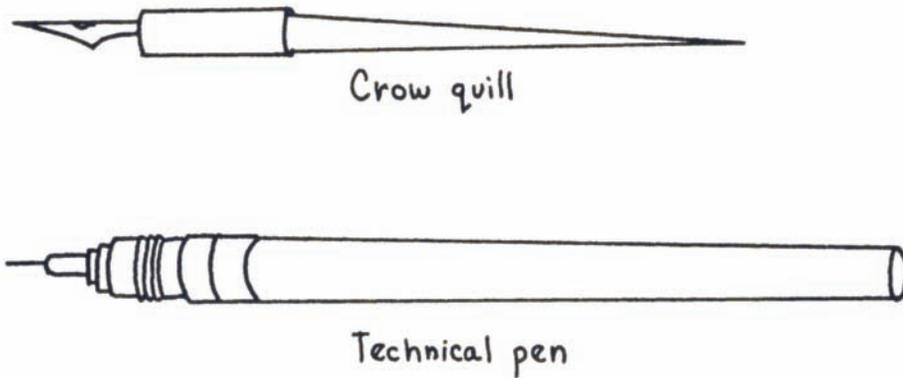


Figure 8.2.

### Procedure

1. Use typing paper and India ink (with a straight pen) or special ink (with a Rapidograph technical pen) to experiment with the three shading techniques—hatching, cross-hatching, and stippling. Choose a simple shape (circle or square) and draw it three times on the typing paper. Shade the shapes using the techniques, one for each shape.
2. Cut the paper that will be used for final drawing to the same size as the photogram. Use a pencil to draw a composition similar to or the same as the one in the photogram. Draw lightly and observe the principles of good composition.
3. Use a straight pen or Rapidograph to shade the shapes in the composition, using one or all of the pen-and-ink techniques practiced. Do not use an outline in ink to separate one shape from another. The shading should define the shapes.

■ *Note:*

The pen-and-ink drawing should be an inverse image of the photogram. The objects will be in black ink and the background will remain white. If using a straight pen, it is important to clean it after each use in a solution of pen cleaner and water. If using the Rapidograph pen, be sure to replace the cap after each use to prevent the ink from drying.

**Essential Question: Will computer programs such as Photoshop™ eliminate the use of chemical toners for photo enhancement? Explain your answer.**

## Adding Color to a Black-and-White Photograph

Before color film was available, it was popular to tone black-and-white photographs to make the black, white, and gray areas sepia, tan, blue, or green. Toning is still practiced today to provide a new richness to a photograph. It can make black areas appear richer and more dramatic or duller, without affecting white areas.

In the toning process, a bleaching or oxidizing by potassium ferricyanide [ $K_3Fe(CN)_6$ ] of metallic silver atoms (Ag) on exposed portions of a photograph produces silver ions ( $Ag^+$ ), which are combined with sulfide ions ( $S^{2-}$ ) to form very insoluble silver sulfide ( $Ag_2S$ ). Silver sulfide has a  $K_{sp}$  of  $6 \times 10^{-50}$ . The silver sulfide provides brown or sepia tones to the photograph by replacing the metallic silver that produced the black and gray tones.

## A PICTURE IS WORTH TEN THOUSAND WORDS

With modern technology, we can take photographs using a digital camera and input the resulting data into computers, cropping and adjusting our photographs as we proceed. We might then use our computer printer to print the desired photographs. No film is needed. No chemicals are needed. No darkroom is needed. Wait a minute! How much computer memory is required for a single picture, perhaps a scenic view in Yellowstone Park? One photograph can require more computer memory than 10,000 words. However, with the development of new, increased-memory computer chips, digital photography may be the way of the future. Still, no matter how the photograph is made, it will be worth at least a thousand words.

## NOTES

1. Milton W. Brown et al., *American Art* (New York: Harry N. Abrams, 1988), 335.
2. Norman S. Weinberger, *The Art of the Photogram: Photography Without a Camera* (New York: Caplinger, 1981), 17.

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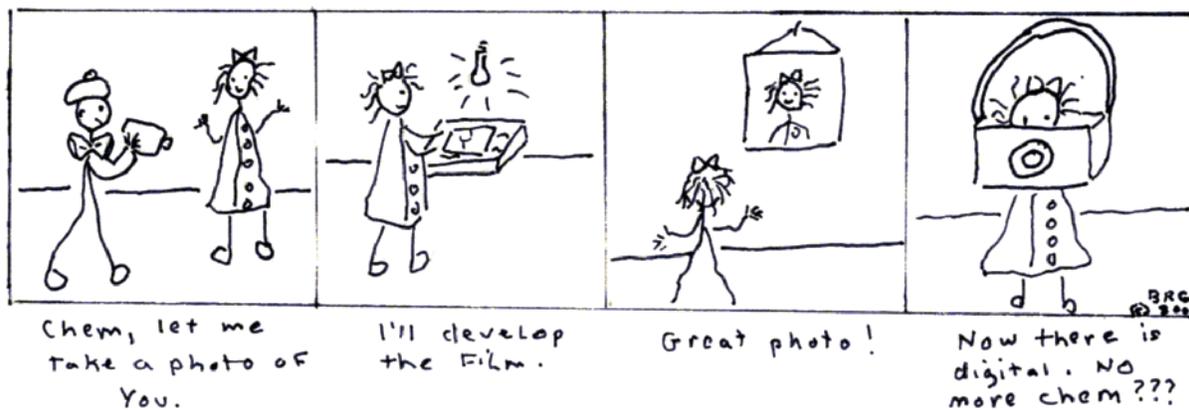
## FILMS

*Alfred Stieglitz: Eloquent Eye*. 88 min. crystalproductions.com, 2001. DVD.

*Ansel Adams*. 100 min. crystalproductions.com, 2002. Videocassette.

*Drawing: Learning Professional Techniques*. crystalproductions.com

*The World of Chemistry. Molecules in Action 14*. 30 min. University of Maryland and the Educational Film Center, 1990. DVD.



## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 8.1 Making a Pinhole Camera

#### Level One

1. The inside of the coffee can and lid are painted black so no extra light enters the camera. The only light that should enter the camera is light reflected from the scene that is being photographed. Extra light will expose the film and the intended image will not be achieved.
2. The hole acts as a lens. A smooth, round hole allows light from an object to project directly on the film.
3. The black flap keeps light from entering the camera. Once the flap is lifted, light reflected from an object enters the camera and strikes the film. After optimal light has entered the camera, the flap is lowered to close the hole and block out excess light.
4. The center of interest, the movement of one's eye through the composition, the balance of the parts, positive and negative space, and unity and harmony.

#### Level Two

1. The lens in the pinhole camera is the hole. In a digital camera, a series of lens elements focus light entering the camera. The film in the pinhole camera is paper coated with a light sensitive emulsion. In a digital camera, the film is an electronic sensor. In the pinhole camera, the black flap is the shutter. In a digital camera, a mechanical device opens and closes a lens opening. (This is comparable to the iris of the eye.)
2. Resolution: The resolution obtained in a digital image depends on the number of pixels in the sensor; the more pixels, the better the resolution. The resolution in a pinhole camera depends on the type of film used. Depth of field: In a pinhole camera, depth of field is 100%. In a digital camera, a combination of the lens opening size and shutter speed determines the depth of field. Lighting conditions: A digital camera can be used in any type of lighting conditions. Light input to a pinhole camera is controlled by exposure time. In very low light, it may not be possible to take a picture. Richness of color and tone: For a digital camera, the richness of color and tone depends on the printer. For a pinhole camera, the richness of color and tone depends on the film used. Convenience: A digital camera can be used in any kind of light. Photos can be viewed immediately, deleted, and retaken. Prints can easily be adjusted on a computer and then printed for immediate access. A pinhole camera is cumbersome, fragile, and easily shaken. However, it is cheap and simple to use.

## Activity 8.3 Photography: Printing Negatives and Making Photograms

### Level One

2. Fogging occurs when all of the unexposed silver bromide is not removed by the hypo, sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ). Spotting can occur when the photogram is not covered evenly with developing solution or when the developing solution is not properly mixed to form a true solution. Blurry images result when the film or the objects on the film or both are inadvertently moved during the exposure time.
3. In a photogram, there is no camera with a lens that controls the amount and direction of light used to record an image. Objects on film paper are recorded directly with light from all directions. In a photograph, the first image recorded is a negative, a reverse image of the objects. From the negative, a final photo is produced.

### Level Two

3. When the film paper is exposed to light, silver ions are reduced to silver atoms. Next excess silver ions are removed by combining them with thiosulfate ions to form a silver thiosulfate complex ion. This happens when the exposed film paper is placed in a hypo solution. To completely stop the developing process, the film paper is next placed in a fixer such as acetic acid to neutralize the basic hypo solution.
4.  $\text{KBr}$  and  $\text{Na}_2\text{SO}_3$  remove excess  $\text{S}_2\text{O}_3^{2-}$  ions.  $\text{HC}_2\text{H}_3\text{O}_2$  neutralizes the basic developing (hypo) solution.



# The Art of Forgery

## Art Conservation and Restoration



Answers to activity questions and conclusions are at the end of this chapter.

**Essential Question: If we could walk into Rembrandt's studio today, would we see him creating an entire painting? How do we know that a painting claimed to be a Rembrandt is a Rembrandt?**

### INTRODUCTION: IS IT OR ISN'T IT?

We have all seen paintings in museums that have been signed by artists such as Rembrandt or Picasso, and we assume that these works are the original and “real” thing made by the artist whose signature appears on the painting. As with Coca Cola™, we must question whether or not we are looking at the real thing. Even museums can be fooled by highly skilled forgers. Since ancient times, works of art have been forged to deceive the public, collectors, and sometimes even the experts.

What do we mean by the word *forgery*? Technically speaking, a forgery is a copy of a work of art done in the exact manner of the original style of the artist with the intent of passing the work off as an original. The intent is to deceive. A forgery differs from a legitimate copy in that a copy is not meant to be presented as the original. Many artists, as part of their learning process, will copy the works of the masters to develop skill and learn from great works of art. Often young artists will be allowed to make a copy from a museum original, on location, setting up their easels in the museum gallery in front of the original. Throughout history, artists have copied famous works of art often for persons who would have liked to own the original but could not afford it or, for other reasons, could not obtain it for themselves. The next best thing, then, would be a well-executed copy. In a copy of this nature, the medium, size, and appearance are as close to the original as possible. Copies are not meant to defraud but are made merely as a facsimile of the original, and they do not claim to be the original.

Legitimate copies are, in a sense, reproductions of the original. The term *reproduction* also refers to a mechanically made version of an original. Usually a copy is made so that the work can be illustrated in a book or magazine or sold in volume to those who want a relatively inexpensive example of the work for themselves. Often the size of the reproduction is reduced to accommodate the page size of a book, a postcard, or a print. Ceramic and sculpture are also made as reproductions in various sizes and materials different from the originals.

## **FAKES OR FORGERIES THROUGHOUT THE AGES**

Forgery of works of art has existed throughout the history of the world. However, by the nineteenth century forgery was big business. Some European art dealers actually established factories and employed artists to paint forgeries, which they sold to unscrupulous dealers, who in turn sold them to American collectors for high prices as originals done by well-known artists.<sup>1</sup> Forgery, by this time, was regarded as a crime.

### **What two ways can an art forger deceive the public?**

- The art forger can actually create the fraudulent artwork.
- The art forger can discover a forgery and sell it as an original.

Related to this topic, many paintings done by followers or students of famous artists, in “the style of the master” and unsigned, were frequently assumed to be painted by the artists themselves. They were not meant to be forgeries, but they were sometimes mistaken for the work of the artist. Many of these works were later correctly identified as done by others, “in the style of.” In recent years, it has been discovered that many paintings originally attributed to Rembrandt van Rijn were not painted by Rembrandt. It is often difficult to pinpoint the artist’s work. Many times, especially during the sixteenth and seventeenth centuries, well-known artists would frequently paint only significant parts of a work, then assign students in their workshops to paint the portions of lesser importance.

### ***Trompe l’Oeil*: Fool the Eye but Not a Forgery**

Forgery is meant to fool viewers into thinking that they are looking at the real painting or sculpture produced by a famous artist. *Trompe l’oeil* (tromp-loy) is a French term referring to a type of art meant to fool the eye into believing it is seeing not a work of art but reality. The work, frequently a painting, is done in such a way that it appears as if the viewer could actually reach out and touch the objects depicted. *Trompe l’oeil* works have existed since the time of the Romans: The walls of their villas were painted realistically with scenes that appeared to extend beyond the wall into a garden or courtyard. Throughout the ages, even to the present day, the idea of fooling the eye has appeared in paintings and sculptures. During the seventeenth and eighteenth centuries, ceilings in churches and mansions of Europe were often painted with clouds and angels so real that the ceiling *became* the sky.

Today, with computer-controlled lights and sounds, a ceiling painted with clouds can not only mimic the appearance of a sky but also exhibit meteorological events, such as storms with lightning and thunder. Such a modern *trompe l’oeil* ceiling exists in Las Vegas at the Caesar’s Palace ancient-Rome theme complex in the shopping mall.

### **Examples of Trompe l'Oeil Works**

Any fresco wall-painting from a Roman villa

Any work by American artist William Michael Harnett, nineteenth century

*Still Life with Bird*, Francis van Myerop, 1670

*Flower Piece with Curtain*, Adrian van der Spelt, 1658

*St. Ignatius Carried into Paradise* (ceiling painting), Andrea del Pozzo, 1685

### **Real or Fake? Solving the Mystery: Investigation Pays Off**

How do we determine if a work of art is what it claims to be? The methods of investigation range from the opinion of the experienced eye of the expert to state-of-the-art scientific tests. Before 1930 scientific investigation was unknown. The art experts relied on their knowledge of art, and maybe a magnifying glass, to find the fakes. Today experts use their personal knowledge along with X-ray, ultraviolet, and infrared electromagnetic radiation; spectroscopy; radioactive dating; and the microscope, among other tools, to detect forgeries.

#### **Challenge Activity**

The Vermeer painting, *Young Woman Seated at the Virginals*, was regarded as a forgery from 1947 until March 2004, when it was declared a genuine Vermeer painting. Research the scientific methods used to make this determination. This should include the instrument analysis of the painting and the pigment analysis. Write a report explaining how scientists could decide that this was a real Vermeer.

### **WAYS TO DETECT ART FORGERIES**

A forgery presents many clues. Is the surface consistent with the age of the paint? Are the brush strokes typical of those used by the artist? Are the colors, the shading, and the style of the figures consistent with those the artist typically used? Are the paper (or canvas) and supports consistent with the age of the work?

A chemical analysis of the materials used in a work can be done. In an oil painting, for example, a sample of the pigment can provide the expert with much information. Is the paint consistent with the apparent age of the painting? Many pigments, such as burnt sienna and raw umber, have been used since ancient times, but others, such as alizarin crimson, the cadmiums, and cerulean blue, were developed in the nineteenth century. Hansa yellow and phthalocyanine blue were not developed until the 1930s. If cerulean blue appears in a painting allegedly produced in the sixteenth century, something is afoot. At best, a recent touchup of an old master has occurred; at worst, the painting is a forgery.

Digital authentication is a new method recently used to detect art forgeries. A high resolution digital scan is made of an artwork under scrutiny. Then a statistical model of an artist is built up from scans of the artist's authentic works. A comparison is made between

authentic work scans and a scan of the work under scrutiny. The true artist's contribution can be identified. Digital authentication was used to identify five known forged paintings out of a group of thirteen that had all originally been attributed to Pieter Brueghel the Elder. Considering Pietro Perugino's painting, *Virgin and Child with Saints*, art historians suspected that Perugino had painted only a portion of the work. Digital authentication methods verified that at least four different artists had worked on the painting.

Qualitative chemistry is an area of chemistry concerned with identifying substances. In Activity 9.1 you will perform a qualitative analysis to detect the presence of certain ions that, in turn, may reveal an art forgery. The ions could come from paints that were not available at the time of the artwork. In this qualitative analysis, metal ions (cations) and nonmetal ions (anions) are reacted with solvents and with each other. Then the cations and anions present are identified by the products produced. In addition, flame tests and pH determinations are used to identify ions. Qualitative analysis is an engaging opportunity for you to develop experience with chemical change and review solubility principles. Nowadays, however, most of the time a chemist analyzes a substance to detect ion content using quantitative analytical computerized instruments.

**ACTIVITY****9.1*****Qualitative Chemistry and the Detection of Art Forgeries*****Objectives**

1. Students will detect the presence of anions and cations in solutions of unknown compositions.
2. Students will write a balanced chemical equation for each reaction in which a precipitate is formed.
3. Students will explain how qualitative ion analysis can be used to detect art forgeries.

**Materials**

General Rules of Solubility as listed in Chapter 8; 0.1 M solutions of the following compounds (these are the unknown solutions):  $\text{Ag}(\text{NO}_3)$  (silver nitrate),  $\text{Ca}(\text{NO}_3)_2$  (calcium nitrate),  $\text{Cu}(\text{NO}_3)_2$  (copper nitrate),  $\text{NaOH}$  (sodium hydroxide),  $\text{KCl}$  (potassium chloride),  $\text{Na}_2\text{SO}_4$  (sodium sulfate),  $\text{NaI}$  (sodium iodide), and  $\text{Na}_3\text{PO}_4$  (sodium phosphate); eight small test tubes; eight small disposable pipets; pH paper; one flame test wire in a cork; glass plates; a Bunsen burner; and 3M  $\text{HCl}$  (hydrochloric acid).

**Time**

55 minutes

## Procedure

1. Using the following procedure, you will use precipitation, flame tests, and pH levels to analyze eight unknown solutions to detect the presence of cations or anions in the solutions. Each solution will contain a cation or an anion to be detected. Solutions 1, 2, and 3 contain cations, and solutions 4, 5, 6, 7, and 8 contain anions to be detected. The possible cations are  $\text{Ag}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Cu}^{2+}$ . The possible anions are  $\text{OH}^-$ ,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{I}^-$ , and  $\text{PO}_4^{3-}$ . (Each unknown should be one of the solutions listed under materials above.)
2. Using clean pipettes, place about 3 ml samples of each unknown in small, numbered test tubes.
3. Detection of cations and anions by precipitation:
  - a. Prepare a data table by listing unknown numbers 4–8 vertically and the unknown numbers 1–3 horizontally so that a fill-in chart results.
  - b. Place a glass plate on a dark surface. Combine drops of unknown solutions according to the scheme on your data table. Use one to two drops of the first solution and slowly add one to two drops of the second solution. On your data table, record the color and appearance (grainy, smooth, etc.) of any precipitates that form.
  - c. The following information will help you identify your precipitates: (The formation of a precipitate indicates the presence of the precipitate ions in the solutions combined.)

Precipitate	Color	Precipitate	Color
$\text{Ca}(\text{OH})_2$	white	$\text{CuI}$	brown
$\text{CaSO}_4$	white	$\text{Ag}_2\text{O}$	brown
$\text{Ca}_3(\text{PO}_4)_2$	white	$\text{AgCl}$	white
$\text{Cu}_3(\text{PO}_4)_2 \cdot 3\text{H}_2\text{O}$	bluish-white	$\text{Ag}_3\text{PO}_4$	yellow
$\text{Cu}(\text{OH})_2$	blue	$\text{AgI}$	yellow

- d. A discussion about writing ionic equations to show precipitate formation follows this activity.
4. Detection of cations through flame tests:
  - a. Obtain a clean flame test wire.
  - b. Clean the wire by dipping it into 3M HCl solution.
  - c. Heat your wire in a Bunsen burner flame until no color is visible.
  - d. Test each solution by placing a drop of solution on the wire and heating it in the hottest part of the flame, above the inner cone.
  - e. Record the color produced by the solution in the flame.

f. The following table gives flame test colors of various cations:

Name	Formula	Flame Test Color
Copper(II) ion	$\text{Cu}^{2+}$	Deep blue or green
Calcium(II) ion	$\text{Ca}^{2+}$	Red orange
Silver ion	$\text{Ag}^+$	Colorless
Potassium ion	$\text{K}^+$	Fleeting weak violet

5. Detection of anions using pH paper:
  - a. Obtain a few strips of pH paper.
  - b. Tear each strip in half.
  - c. Place a drop of each solution on a piece of pH paper.
  - d. Record the approximate pH of each solution.
  - e. A pH above 7 indicates a basic solution. A pH below 7 indicates an acid.
  - f. Hydroxide ions ( $\text{OH}^-$ ) and phosphate ions ( $\text{PO}_4^{3-}$ ) form basic solutions.
6. Identify the cations in solutions 1, 2, and 3 and the anions in solutions 4, 5, 6, 7, and 8.

Test tube number	1	2	3	4	5	6	7	8
Cation	_____	_____	_____					
Anion				_____	_____	_____	_____	_____

### Questions and Conclusions

■ *Note:*

A detailed discussion of qualitative analysis follows this activity.

#### Level One

1. In number 6 of the procedure above, you identified the unknown ions in the eight test tubes. Give your reasons for choosing each ion as an unknown ion.
2. Write balanced net ionic equations for the reactions in step 3b of the procedure in which a precipitate forms.
3. Research the chemical composition of pigments used in Johannes Vermeer's paintings. (This information can be found at <http://vermeerspalette.20m.com/index.html.htm>.) Pick one pigment and make a paint using Vermeer's formula. Sample the paint on a ground and compare the color to Vermeer's color in one of his paintings. How did Vermeer achieve his bright, vibrant colors?

**Level Two**

In our activity, each unknown solution contained only one detectable ion. If a chip of paint is analyzed, it can contain more than one ion. Following this activity is a discussion about performing a qualitative analysis when two or more ions are present in a solution. Read the discussion and answer the following questions:

1. List lead chloride ( $\text{PbCl}_2$ ), silver chloride ( $\text{AgCl}$ ), and mercury I chloride ( $\text{Hg}_2\text{Cl}_2$ ) in order of decreasing solubility in water.
2. Imagine that a mixture of zinc, silver, and copper ions ( $\text{Zn}^{2+}$ ,  $\text{Ag}^+$ ,  $\text{Cu}^{2+}$ ) is thought to be present in a chip of paint taken from a work of art. Write a procedure for using a qualitative analysis scheme to detect these ions in the paint chip. Use reference books to find a substance that will form a precipitate with silver and not with copper and zinc. Next, a substance is needed to form a complex ion with copper, leaving the zinc in solution.
3. Describe several ways that a work of art can be analyzed to determine whether it is a forgery or real.

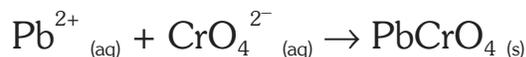
When a precipitate was formed in Activity 9.1, the reaction that occurred was a double displacement reaction. Each reactant contained two ions. When two reactants combined, a precipitate formed if two of the ions present were more stable and if they bonded to form a low solubility solid. An ionic equation for such a reaction is:  $\text{Ag}^+_{(\text{aq})} + \text{NO}_3^-_{(\text{aq})} + \text{K}^+_{(\text{aq})} + \text{Cl}^-_{(\text{aq})} \rightarrow \text{K}^+_{(\text{aq})} + \text{NO}_3^-_{(\text{aq})} + \text{AgCl}_{(\text{s})}$ . The net ionic equation is:  $\text{Ag}^+_{(\text{aq})} + \text{Cl}^-_{(\text{aq})} \rightarrow \text{AgCl}_{(\text{s})}$ . Potassium and chloride ions are called spectator ions. They only watch the reaction.

In certain qualitative analysis schemes, silver, mercury, and lead ions ( $\text{Ag}^+$ ,  $\text{Hg}_2^{2+}$ ,  $\text{Pb}^{2+}$ ) are known as group I ions. Other ions fall into other qualitative analysis groups, depending on the solubility of the ions. Tin, cadmium, and mercury II ions ( $\text{Sn}^{2+}$ ,  $\text{Cd}^{2+}$ ,  $\text{Hg}^{2+}$ ) are in group II. To detect their presence, these ions are precipitated as metal sulfides in an acidic solution. In analysis of a painting to detect a forgery, the presence of tin ions can indicate that cerulean blue pigment was used in the painting; the presence of cadmium ions indicates cadmium red is present; and the presence of mercury II ion can indicate that cadmium vermilion red pigment was used in the painting. Because these pigments have been available only since the nineteenth century, their presence in a pre-nineteenth-century painting would indicate a forgery.

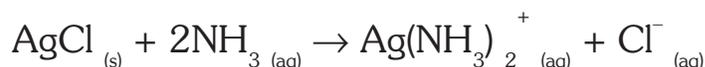
The group I ions are predicted to precipitate as insoluble chlorides, as indicated in the following equations:



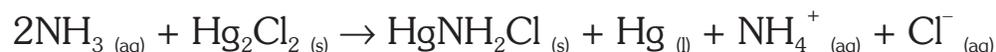
The lead chloride ( $\text{PbCl}_2$ ) precipitate is soluble in hot water, so when the three solids are placed in a hot water bath, the mercury I chloride ( $\text{Hg}_2\text{Cl}_2$ ) and the silver chloride ( $\text{AgCl}$ ) residues remain, and the lead chloride dissolves in hot water. To test for the presence of lead ion in the filtrate, chromate ion,  $\text{CrO}_4^{2-}$ , from  $\text{K}_2\text{CrO}_4$ , can be added to the filtrate:



The appearance of a yellow precipitate, lead chromate ( $\text{PbCrO}_4$ ), indicates the presence of lead ions. To separate silver ions and mercury I ions, ammonium hydroxide ( $\text{NH}_4\text{OH}$ ), which converts to  $\text{NH}_3$ , is added to the precipitates:



The silver chloride ( $\text{AgCl}$ ) is dissolved as the stable silver-ammonia-complex ion [ $\text{Ag}(\text{NH}_3)_2^+$ ] is formed. Meanwhile, the mercury II chloride ( $\text{HgCl}_2$ ) is undergoing oxidation and reduction at the same time! Mercury metal ( $\text{Hg}$ ) and mercury II amidochloride ( $\text{HgNH}_2\text{Cl}$ ) are formed and appear, respectively, black and gray in color:



The mercury substances are filtered, and silver ions ( $\text{Ag}^+$ ) are detected in the filtrate by adding hydrochloric acid ( $\text{HCl}$ ), which releases the silver ions from the silver-ammonia-complex ion [ $\text{Ag}(\text{NH}_3)_2^+$ ], allowing the silver ions to combine with chloride ions ( $\text{Cl}^-$ ) to form silver chloride precipitate ( $\text{AgCl}$ ):



Either through instrumental analysis or qualitative analysis, the forensic chemist can reveal the presence of ions in a paint chip from an artwork and use the ion information to detect an art forgery.

**Essential Question: Picasso once said he “would sign a good forgery.” What is an authentic work of art?**

### THREE IMPORTANT ART MOVEMENTS

The works of Claude Monet, Vincent van Gogh, and Jackson Pollock represent, respectively, impressionism, post-impressionism, and abstract expressionism. Even though it would be difficult to forge paintings by these well-known artists, forgeries still appear.

#### Impressionism

During the latter part of the nineteenth century, a group of French artists began to approach painting in a new and revolutionary way. They painted their canvases using short strokes of different colors. They believed that color should be mixed by the artist “in the eye of the viewer” and not on the canvas. This would capture the true color and light of

nature in a new and vivid way. In the greens of grass, for example, many colors, including blues and yellows, combine in the eye of the viewer to give the impression of green on the canvas. This new technique was not readily accepted by the critics or the public of the time, who were accustomed to a more realistic approach to painting—clearer, sharpened edges and carefully blended colors. One critic, Louis Leroy, commented that this way of painting only gave the impression of form and subject. The word *impressionism* became popular as a name for this style.

### **Examples of French Impressionism**

Any oil painting by Claude Monet (1840–1926), Auguste Renoir (1841–1919), and Edgar Degas (1834–1917)

Any later oil painting (after 1870) by Edouard Manet (1832–1883)

### **Impressionism Videocassettes**

*Impressionists: Rebels in Art*. 18 min. Washington, DC: Elaine Joselovitz Museum One, 1987.

*Monet: Legacy of Light Portrait of an Artist Series*. 28 min. Boston: Museum of Fine Arts, 1989.

## **Post-Impressionism**

A group of artists in the late nineteenth and early twentieth centuries took from the impressionists the use of short strokes and the brighter colors. To this they added their own ingredient—a strong personal quality that resulted in an emotion-filled interpretation of the subject matter. One such post-impressionist was Vincent van Gogh. His work was filled not only with emotion but also with texture and intense color.

### **Examples of Work by Vincent van Gogh (1853–1890)**

*The Starry Night* (oil), 1889

*The Night Cafe* (oil), 1888

Any Vincent van Gogh self-portrait

## **Abstract Expressionism**

During the 1940s and 1950s a group of artists created a style of modern art painting that was spontaneous and filled with action. Jackson Pollock was one of these artists interested in the act and movement of painting. He applied his paint to large canvases with a sweeping motion of his arm and hand. The subject matter for him was nonobjective (see Chapter 3). The results were paintings made of lines of interwoven color, moving in all directions across the canvas.

### **Examples of Work by Jackson Pollock (1912–1956)**

*Lavender Mist* (oil, enamel, and aluminum paint), 1950

*Ocean Greyness* (oil), 1953

*Night Ceremony* (oil), 1944

■ *Note:*

Use a magnifying glass to examine copies of works by van Gogh, Monet, and Pollock, closely observing the brush strokes of each painter.

### Challenge Activity

In preparation for Activity 9.2, make an 8-x-10-in. painting in the style of Vincent Van Gogh, Claude Monet, or Jackson Pollock. Your teacher may assign one of the artists to you. Your painting should have an original theme. Use the colors, brush strokes, line, and technique of that artist to create your painting. Acrylic, oil, watercolors, or poster paints can be used. When you're finished, post your painting on a wall. Classmates should guess what artist you are imitating and explain the reason for their guesses.

In Activity 9.2 you will prepare a “forged” painting and a “real” painting. You will study the styles and composition used by van Gogh, Monet, and Pollock and then analyze the prepared paintings to determine which one is a “forgery” and which one is “real.” If it is not practical for you to prepare the paintings, they can be obtained from:

Kemtec Educational Services  
4780 Interstate Drive  
Cincinnati, OH 54246

## ACTIVITY

### 9.2

## ***Using Three Methods to Detect Art Forgeries***

### Objectives

1. Students will compare and contrast the painting styles of Vincent van Gogh, Claude Monet, and Jackson Pollock, then prepare a “forged” painting and a “real” painting in each style.
2. Students will distinguish between an “art forgery” and the “real” painting and discuss methods of detecting art forgeries.
3. Students will detect an “art forgery” through chemical, ultraviolet, and paint-chip analyses.
4. Students will understand the chemical composition of “old” and “new” paint pigments.

**Materials**

Acrylic paints; drawing pencil; 2-x-3-in. pieces of foam board;  $\text{Pb}(\text{NO}_3)_2$  (crystalline lead nitrate); tweezers; razor blades or an X-ACTO knife; fluorescent paints; 0.1 M  $\text{K}_2\text{CrO}_4$  (potassium chromate) solution; small test tube; paintbrush for acrylic paints; a source of ultraviolet light (e.g., plant grow-light); book containing reproductions of works by van Gogh, Monet, and Pollock; Table 9.1 (page 338).

**Time**

150 minutes

**Procedure****■ Note:**

This activity can be done in groups, dividing the tasks among the group members.

1. Find reproductions of paintings by van Gogh, Monet, and Pollock and select one painting that will be copied as an “art forgery” and as a “real” painting.
2. List the differences and similarities among the composition and styles used by the three artists.
3. Prepare an “art forgery”:
  - a. On a 2-x-3-in. piece of foam board, make a pencil sketch of the selected painting.
  - b. Using acrylic paint, paint the sketched picture in a technique opposite from the artist’s technique. If it was known that the artist used mixed paints, the paints should be layered. If the artist used layered paints, the paints should be mixed. The paint should be applied in a variety of thicknesses.
  - c. When the acrylic paint is dry, apply small dots or lines of fluorescent paint to the surface of the acrylic paint, using the same color as the color of the acrylic paint.
  - d. Let the painting dry.
4. Prepare a “real” painting:
  - a. Make another pencil sketch of the same painting on a piece of 2-x-3-in. foam board. This sketch should be identical to the previous sketch.
  - b. Using acrylic paint, paint the sketched picture in the artist’s style. However, the paint in four or five areas of the painting should be thickened to make small nodules. Proceed with the next step as soon as the nodules have been painted.
  - c. Using tweezers, embed a small crystal of  $\text{Pb}(\text{NO}_3)_2$  in each paint nodule, covering the crystals with the acrylic paint.

d. Let the painting dry.

■ *Note:*

The teacher should match the paintings into sets of two paintings, one “art forgery” and one “real” painting. For the detection of the art forgery, each student or each group should use one matched pair. The students should not know which painting is the “forgery” and which painting is “real.”

5. Detection of an “art forgery”:
- Using Ultraviolet Light to Detect Art Forgeries.** Examine the paintings and make note of any differences or similarities between the paintings. Place each picture under an ultraviolet light and make note of any differences in the appearance. If ultraviolet light is not available, the paintings can be taken into a totally darkened room and observed. Record the identity of the painting that shows evidence of the presence of fluorescent paint.
  - Using Chemical Means to Detect Art Forgeries.** Remove a pea-sized chip of paint from a raised nodule of each painting (leave one nodule for the next detection method). In a test tube, drop one chip from one painting into 5 ml 0.1 M  $K_2CrO_4$ . Then drop the chip from the other painting into another test tube containing 5 ml 0.1 M  $K_2CrO_4$ . Shake the test tube vigorously several times and look for the appearance of a yellow precipitate. Record the identity of the painting whose paint produces a yellow precipitate.
  - Using Paint-Chip Analysis to Detect Art Forgeries.** Remove a paint chip from a raised nodule of each painting. Using a razor blade or an X-ACTO knife, make very thin slices through each chip. From the slices, try to determine whether the artist used mixed paints or layered paints. Record the painting style for each painting.
6. Use Table 9.1 and the results from the analyses to determine which painting is “real” and which painting is a “forgery.”

**Table 9.1**  
**Characteristics of a “Forgery” and a “Real” Painting**

	<b>Fluorescent Light</b>	<b>Precipitate</b>	<b>Chip Analysis</b>
<b>Real Painting</b>	No fluorescent paint	Yellow precipitate	Either layer or mix
<b>Forgery</b>	Fluorescent paint present	No precipitate	Either layer or mix

## Questions and Conclusions

### Level One

1. Which paints would be luminescent, old or new? How does luminescence explain whether or not a painting is real or a forgery?
2. If lead is present in a paint, is it likely that the paint is a new paint or an old paint? How does the presence of lead in paint explain whether or not a painting is real or a forgery?
3. In order to detect an art forgery, why is detection of paint layering or mixing not conclusive evidence?
4. Write a balanced net ionic equation for the production of the yellow precipitate when potassium chromate is added to the paint chip and yellow lead chromate precipitate is formed.
5. Define *art forgery*.
6. In the chemical analysis, we assumed that paints containing lead ions would not be present in a modern painting. However, in some paints today, we may still find chrome yellow pigment containing lead chromate and molybdate orange pigment containing lead chromate, lead molybdate, and lead sulfate. Lead-based paints were commonly used by artists as late as the mid-twentieth century. Write chemical formulas for each of these lead compounds used in paint pigments. Which formula represents the yellow precipitate produced in this activity?

### Level Two

1. List several reasons why it would be difficult to make a forgery of a painting by Vincent van Gogh, Claude Monet, or Jackson Pollock.
2. In addition to chemical analysis, ultraviolet, and paint-chip analyses, what other methods can be used to detect an art forgery?
3. Claude Monet, Vincent van Gogh, and Jackson Pollock represent, respectively, the movements of impressionism, post-impressionism, and modern art. Discuss the major characteristics of the artwork from each of these periods. Find reproductions of other works of art created by the impressionists, post-impressionists, and modern artists. Explain the principles of composition as expressed by each artist, using the works of art as examples.

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In Activity 9.2 it is assumed that lead ions are not found in modern paint pigments, but this is not entirely the case. Even though lead-based paints are prohibited from use in house painting, lead compounds still appear in some art paints. Some red, yellow, and white pigments contain lead compounds. Hazards in art are discussed in Chapter 10.

### Challenge Activity

In 1983 the sculpture *Getty Kouros* was offered to the J. Paul Getty museum in Malibu, California. To this day, the sculpture's authenticity remains uncertain. Research the methods that have been used to establish the authenticity of the statue. Suggest other methods of analysis that might be used to find out if the Kouros is a 530 B.C. sculpture or a modern forgery.

## METHODS USED TO DETECT ART FORGERIES

### Fluorescence

By shining violet or ultraviolet light on a painting, the presence of fluorescent paints can be detected. These paints will glow after being exposed to violet or ultraviolet light. The molecules in the fluorescent paints absorb radiation and emit characteristic energy waves that identify these molecules. Fluorescent paints are products of modern technology and would not appear in old paintings. The presence of fluorescent paints usually indicates an art forgery.

### Spectroscopy

Spectroscopy is another method used to detect art forgeries. In spectroscopy, electromagnetic radiation is applied to the substance or substances under consideration. The resulting spectra are recorded to identify the chemical composition of the substance or substances. When a spectrophotometer is used, the radiation, usually visible and invisible ultraviolet waves, can be applied to a solution in a tube, and the absorption of radiation is noted. For this type of analysis, a spectrophotometer must be available.

### X-Rays

The use of X-rays in detecting art forgeries deserves mention. X-rays have shorter wavelengths than ultraviolet waves. These short-wavelength, high-energy waves can penetrate the canvas of a painting and reveal a painting underneath. In addition, the artist's brush strokes can be examined and compared to those in other works by the same artist.

### Neutron Activation Analysis

Neutron activation is a method to detect as little as  $10^{-12}$  g of particular elements without destroying any of the artwork being investigated. This method of element detection is extremely valuable when an art forgery is suspected. Several paintings by the same artist can be analyzed for similarities in the paint composition. A different set of paint substances for one painting would place that painting under suspicion as being an art forgery.

In neutron activation analysis, the sample is bombarded with a beam of neutrons, some of which are absorbed into sample nuclei. These sample nuclei are now radioactive. They emit electromagnetic radiation, gamma rays. Each isotope is represented by a specific energy and frequency of gamma ray, which identifies the isotope and, thus, the element. In this method of detecting art forgeries, the sample is not changed and its composition can be accurately assessed.

## Radioactive Dating

To understand how radioactive substances can be used to determine the age of an object, it is necessary to understand radioactivity, the spontaneous or forced breakdown or rearrangement of the atomic nucleus with a release of radiation. We have discussed chemical changes in atoms in which outer electrons are shared, partially shared, or transferred, but the atomic nucleus remains intact. Here we are considering nuclear changes and the products produced, including radiation. We need a system of symbols to represent these nuclear changes.

### Nuclear Symbols

In Chapter 1 we learned about neutrons, uncharged particles, and protons, positively charged particles. These are the particles that will change in number when there is a nuclear change. The mass of an atom is largely determined by the protons and neutrons in the nucleus. (A neutron is slightly heavier than a proton, but an electron's mass is negligible at one two-thousandth the mass of a proton or neutron.) The relative masses of neutrons, protons, and electrons are 1, 1, and 0, respectively. The mass number of an atom is the total number of protons and neutrons in that atom. We can symbolize the mass of a nucleus by writing the name of the element and the mass number after the name, connected by a hyphen (e.g., iodine-131, strontium-90, uranium-235). In a nuclear equation, the symbol for the element is used, with the mass number written as a superscript before the symbol and the number of protons written as a subscript, also before the symbol (e.g.,  $^{131}_{53}\text{I}$ ,  $^{90}_{38}\text{Sr}$ ,  $^{235}_{92}\text{U}$ ).

### How many protons, neutrons, and electrons are represented in the following element symbols?

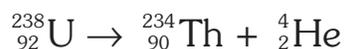
- $^{185}_{79}\text{Au}$ : 106 neutrons, 79 protons and 79 electrons.  $^{226}_{88}\text{Ra}$ : 138 neutrons, 88 protons and 88 electrons.
- $^{127}_{53}\text{Xe}$ : 77 neutrons, 54 protons and 54 electrons.  $^{27}_{13}\text{Al}^{3+}$ : 14 neutrons, 13 protons and 10 electrons.
- $^{127}_{53}\text{I}^-$ : 74 neutrons, 53 protons and 54 electrons.  $^{56}_{26}\text{Fe}^{2+}$ : 30 neutrons, 26 protons and 24 electrons.

### **Nuclear Equations**

In a nuclear equation, mass numbers and number of protons add up to the same total on either side of the equation. Also, in addition to atomic nuclei particles (protons and neutrons), called *nucleons*, other particles are emitted or absorbed in the nuclear change. Some of these particles include the following:

Beta Particle ${}_{-1}^0e$	Neutron ${}_{0}^1n$
Positron ${}_{+1}^0e$	Alpha Particle ${}_{2}^4He$
Proton ${}_{1}^1H$	Deuteron ${}_{1}^2H$

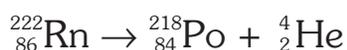
For example, in the spontaneous decay of uranium-238, thorium-234 is formed, and an alpha particle is emitted:



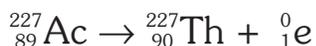
It can be seen that the mass numbers on either side of the equation add up to the same number, 238, and that 92 protons are accounted for in the equation's product and reactant sides. This is a balanced nuclear equation. Actually, some mass is converted into energy, but the amount of mass is very small. From Albert Einstein's equation,  $E = mc^2$ , very little mass,  $m$ , is needed to produce a tremendous amount of energy,  $E$ , because  $c$  is the speed of light,  $3 \times 10^8$  m/sec. This energy was evidenced when an atomic bomb was exploded over Hiroshima, Japan, during World War II. The fuel for that bomb was uranium-235.

### **Balancing Nuclear Equations**

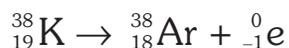
There are many ways that nuclear changes occur. Emission of alpha particles is one result of nuclear decay:



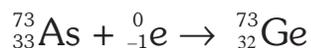
Emission of beta particles can also result from a nuclear change:



In addition, positrons can be emitted in a nuclear change:

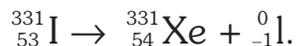


Also, electrons can be captured:



It can be seen that students can easily balance and complete nuclear equations if they are familiar with the symbols for nuclear particles and know the method of nuclear decay, such as alpha particle emission or electron capture.

How would you write balanced nuclear equations for the alpha particle decay of radium-226 and the beta particle decay of iodine-131?



## **Isotopes**

Isotopes are atoms of the same element that have different masses because of different numbers of neutrons. Uranium-238 atoms have 146 neutrons in their nuclei; uranium-235 atoms have 143 neutrons in their nuclei. Some isotopes are very stable; others decay spontaneously in a short period of time.

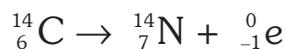
**Essential Question: Why do some isotopes decay spontaneously while others are very stable?**

## **Half-Life**

Isotopes that decay spontaneously have different rates of decay. Some radioactive isotopes decay in fractions of a second; others will not decay for thousands of years. Under normal conditions external factors, such as pressure and temperature, have no effect on the rate of decay. When we consider how long it takes for spontaneous decay of atomic nuclei, we measure this time in *half-life*, which is the time it takes for half a sample of radioactive nuclei to decay into other substances. The rate of decay, grams of radioactive nuclei remaining after a period of time, depends on the original number of radioactive nuclei present in the sample. For example, for iodine-131, the half-life is 8.07 days. If we have 1.0 gram of iodine-131 today, we will have 0.5 gram after 8.07 days, 0.25 gram after 16.14 days, and 0.125 gram after 24.21 days. The half-life of an isotope can be as short as 0.000164 second, the half-life of polonium-214, or as long as  $4.47 \times 10^9$  years, the half-life of uranium-238.<sup>2</sup>

## **Half Life and Radioactive Dating**

The age of an art object can provide a valuable clue to whether it is real or a forgery. Because the half-life for a specific isotope is constant, half-life can be used to find the age of an object. The isotope put to use for radioactive dating is carbon-14. The half-life of carbon-14 is 5,730 years. The amount of carbon-14 in our atmosphere remains fairly constant. When an object such as a plant is alive, it absorbs  $\text{CO}_2$ . The carbon atoms in the  $\text{CO}_2$  are made of a specific ratio of carbon-14 atoms to carbon-12 atoms. The carbon-14 atoms decay by emission of beta particles:



After the living tree is harvested to provide wood for a painting surface, or perhaps for a painting support or frame,  $\text{CO}_2$  uptake ceases and the ratio of  ${}_{6}^{14}\text{C}$  to  ${}_{6}^{12}\text{C}$  begins to decrease. A piece of wood from an art object can be analyzed for carbon-14 content. If it is

found that the ratio of carbon-14 to carbon-12 is one half that found presently in living trees, it can be assumed that the age of the object is approximately 5,730 years, the amount of time for half a sample of carbon-14 to decay.

The art of forgery is alive and well today. At a recent auction of art objects in New York City, it was determined that most of the objects were forgeries. Modern scientific methods, such as those outlined in this chapter, are available for the detection of an art forgery. It takes an alert collector of art objects to suspect an art forgery. Once there is a suspicion, the scientist can go to work to establish the truth of the matter.

### **Challenge Activity**

Use human atoms to illustrate half-life. Each student is one atom of a sample of an element that has a half-life of four days. Show how the number of atoms (students) decreases over a 20-day period. As each half-life passes, students who are no longer part of the sample will go to another location. Record the number of atoms (students) left as each half-life passes. See how many students are left after 20 days have passed. Make a graph of your illustration showing number of students (atoms) versus time in days. Compare your graph to graphs that show the decay of a radioactive element.

## **CONSERVATION AND RESTORATION**

### **Lasting Treasures**

Great works of art, whether they are paintings, drawings, sculptures, or other forms of the visual arts, are all susceptible to the effects of aging, temperature and humidity changes, and exposure to light. In some cases, natural disasters such as fire or flood can damage works of art. In the early 1990s, a fire raged through a wing of Windsor Castle in England, damaging many valuable works of art.

### **Conservation**

Conservation involves cleaning the work, analyzing the work for any damage, restoring the damaged areas, and preserving the original as much as possible. Many of the techniques used in investigating an art forgery are used in the conservation of artwork. The same scientific methods are used to analyze damage as are used to detect forgeries.

### **Restoration or Preservation?**

Whether the work is restored or merely preserved depends on several factors: What is the extent of the damage? Is the work very valuable? Can the restoration be done without destroying the integrity of the work? In the case of oil paintings, age cracks may appear, or

the canvas may become torn or begin to sag and pull away from the support. Bits of paint may flake off, and varnish may darken with age, hiding the true colors of the work.

## Organic Molecules Do the Job

In Chapter 5 we studied organic compounds, those compounds containing carbon atoms that are found in many living things. Some carbon compounds are useful cleaning compounds; they can be used to effectively clean and restore works of art. Alcohols, such as ethyl, isopropyl, and benzyl alcohols, are used to remove unwanted paint and varnish, lacquer, or shellac. Aliphatic hydrocarbons (e.g., n-hexane) are paint and lacquer thinners and degreasers. Aromatic hydrocarbons such as xylene, toluene, and benzene remove paint and varnish and act as ink and plastic solvents. Chlorinated hydrocarbons, such as carbon tetrachloride, are plastic and wax solvents. The trick to using these restorative chemicals is to remove unwanted substances but leave intact the artist's original materials. The hazards of using these materials are discussed in Chapter 10.

### What are the chemical formulas for xylene, toluene, and benzene?

- $C_6H_4(CH_3)_2$  (xylene);  $C_6H_5CH_3$  (toluene);  $C_6H_6$  (benzene).
- Benzene is a hexagon shaped compound and is symbolized by drawing a hexagon with a circle inside the hexagon.
- Carbon atoms are at each point of the hexagon.
- The bonds between the carbon atoms are neither single nor double bonds but a hybrid of both, making all the bonds equal in length and the molecule flat or planar.
- Toluene and xylene have benzene ring structures with one and two methyl branches, respectively.

## A Job for a Professional

If restoration or preservation is required, a professional is consulted to slow the deterioration, thus giving the work an extended life. With some works of art, this is difficult. Many modern works are made of materials that are difficult to preserve and restore, such as newspaper, poor-quality paint, and experimental materials that may be glued to the surface or mixed with the paint. Many pictures are painted on a poorly prepared surface using very heavy applications of paint; in time, the paint will begin to fall off the canvas or other working surface. It is the task of the restorer to do whatever is possible to preserve as much of the work as possible.

## A Stitch in Time

For the consumer, proper care and maintenance can prevent many of the causes of damage. Proper storage and methods of hanging are important. Watercolor paintings and other works on paper, for instance, should be matted and framed behind glass to protect them. Acid-free mat board should be used. Special glass that filters out harmful light rays that may fade the work is also recommended. Many articles and books about the care and maintenance of art of all types are available (see "References" in this chapter).

## THE MARRIAGE OF ART AND CHEMISTRY

Art forgeries are detected by chemical means. Art restoration and conservation is accomplished through applying the principles of solution chemistry. We have a true and faithful marriage of art and chemistry when we restore or conserve artwork and when we discover art forgeries. In these endeavors, art and chemistry will never be divorced.

### NOTES

1. Ann Waldron, *True or False? Amazing Art Forgeries* (New York: Hastings House, 1983), 12.
2. Donald A. McQuarrie and Peter A. Rock, *General Chemistry* (New York: W. H. Freeman, 1984), 951.

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- Zundall, Steven S., et al. *World of Chemistry*. Evanston, IL: McDougal Littell, a Houghton Mifflin Co., 2002. (Chapter 19.)

**FILMS**

*Abstract Expressionism*. 20 min. crystalproductions.com, 1990. Videocassette

*Artists of the 20th Century: Jackson Pollock*. 50 min. crystalproductions.com, 2004.  
DVD

*The World of Chemistry. Signals from Within 10*. 30 min. University of Maryland and  
the Educational Film Center, 1990. DVD



## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 9.1: Qualitative Chemistry and the Detection of Art Forgeries

#### Level One

- $$\begin{aligned} & \text{Ca}^{2+}_{(aq)} + 2\text{OH}^{-}_{(aq)} \rightarrow \text{Ca}(\text{OH})_{2(s)}; \text{Ca}^{2+}_{(aq)} + \text{SO}_4^{2-}_{(aq)} \rightarrow \text{CaSO}_{4(s)}; 3\text{Ca}^{2+}_{(aq)} + \\ & 2\text{PO}_4^{3-}_{(aq)} \rightarrow \text{Ca}_3(\text{PO}_4)_{2(s)}; \text{Cu}^{2+}_{(aq)} + 2\text{OH}^{-}_{(aq)} \rightarrow \text{Cu}(\text{OH})_{2(s)}; 3\text{Cu}^{2+}_{(aq)} + 2\text{PO}_4^{3-}_{(aq)} \\ & \rightarrow \text{Cu}_3(\text{PO}_4)_2(s); \text{Cu}^{+}_{(aq)} + \text{I}^{-}_{(aq)} \rightarrow \text{CuI}_{(s)}; 2\text{Ag}^{+}_{(aq)} + 2\text{OH}^{-}_{(aq)} \rightarrow \text{Ag}_2\text{O}_{(s)} + \text{H}_2\text{O}_{(l)}; \\ & \text{Ag}^{+}_{(aq)} + \text{Cl}^{-}_{(aq)} \rightarrow \text{AgCl}_{(s)}; 3\text{Ag}^{+}_{(aq)} + \text{PO}_4^{3-}_{(aq)} \rightarrow \text{Ag}_3\text{PO}_{4(s)}; \text{Ag}^{+}_{(aq)} + \text{I}^{-}_{(aq)} \rightarrow \text{AgI}_{(s)}. \end{aligned}$$
- Vermeer mixed powdered lapis lazuli with a drying oil and then white pigment to achieve a brilliant blue. He also used glazing to achieve amazing colors. He extracted red madder from the root of the madder plant and glazed it over blue pigment to get deep purple. He also glazed it over vermilion to get a cherry red color.

#### Level Two

- Lead chloride ( $\text{PbCl}_2$ ) is the most soluble, next is silver chloride ( $\text{AgCl}$ ), and the least soluble is mercury I chloride ( $\text{Hg}_2\text{Cl}_2$ ). Solubility of slightly soluble substances can be determined from  $K_{sp}$  values.
- 6 M HCl is added to the paint chip to extract the silver ions ( $\text{Ag}^+$ ) by forming a white silver chloride ( $\text{AgCl}$ ) precipitate. Then hydrogen sulfide ( $\text{H}_2\text{S}_{(aq)}$ ) in 3 M acid solution is added to the chip to extract a black  $\text{CuS}$  precipitate, removing the  $\text{Cu}^{2+}$  ions. The remaining zinc ions ( $\text{Zn}^{2+}$ ) are precipitated by adding hydrogen sulfide ( $\text{H}_2\text{S}_{(aq)}$ ) in 6 M  $\text{NH}_3_{(aq)}$  to form a white  $\text{ZnS}$  precipitate.
- Sometimes a thorough examination of the artwork can determine authenticity. Forgers may use colors not available during the artist's life. Brushwork, themes, and techniques can be assessed. Unusual materials make a work suspect. Also, the usual methods can be applied to detect a forgery: fluorescence, spectroscopy, X-rays, neutron activation analysis, radioactive dating and, more recently, digital analysis.

### Activity 9.2 Using Three Methods to Detect Art Forgeries

#### Level One

- Newer paints are more likely to be luminescent than older paints. If paints used are luminescent, then the painting may be a forgery.
- Older paints, especially yellow and white paints, usually contained lead ions. Newer paints less frequently contain lead ions. If much lead is detected in paint chips removed from a painting, then it can be speculated that the painting is old and an original work of art.

3. An artist may layer paint in one area of an artwork but not in another area. Monet used paint layering as a way of diffusing light and mixing colors. However, an entire painting would not be layered. Van Gogh mixed paints but might have small areas where paints were layered.
4.  $\text{Pb}^{2+}_{(\text{aq})} + \text{CrO}_4^{2-}_{(\text{aq})} \rightarrow \text{PbCrO}_{4(\text{s})}$
5. Art forgery refers to creating or obtaining works of art and falsely attributing these works to artists who did not create the works. Usually these artists are famous artists. The intent of the forger is to deceive and become rich.
6.  $\text{PbCrO}_4$ ,  $\text{PbMoO}_4$ ,  $\text{PbSO}_4$ . The yellow precipitate is  $\text{PbCrO}_4$ .

### **Level Two**

1. These artists and their works are so well known that the appearance of a new work would, by itself, create suspicion. It would be extremely difficult to drip paint in the same manner that Jackson Pollock did. Van Gogh used broad strokes and thick paint in a unique way. Monet painted watercolors in which nothing is as it appears. The essence of the works of Pollock, Van Gogh, and Monet can only be captured by the original artists.
2. Discussed in this chapter are the following methods: Spectroscopy, X-ray detection, neutron activation, radioactive dating, and digital authentication. In addition, dendrochronology is used to date a wooden object by counting the number of tree rings present in the object. Also, thermoluminescence is used to date pottery. When an old piece of pottery is heated, it will produce more light than a newer piece. Stable isotope analysis can be used to determine where marble used in a sculpture was quarried. Sometimes the *crackelure*, the paint cracking signature of a painting, is analyzed to detect a forgery.
3. The artworks of Claude Monet reflect the impressionist's focus on light and its effect on color. His objects are independent of form. He gives an impression of a scene. Nothing is painted exactly as it appears. He uses short brush strokes and layers his paints to let light define the hue.

Vincent Van Gogh, a post-impressionist, created paintings with heavily pigmented surfaces. He used broad stroked lines, selected intense colors, and used swirling shapes to make his paintings alive and dramatic, appearing to be in motion. Another post-impressionist, Paul Cezanne, represented objects in motion by selecting the most obvious viewpoint of his objects and then changing the eye levels, splitting the object planes and combining all of this in one painting.

Jackson Pollock, a modern artist identified as an abstract expressionist, dripped paint on surfaces and created nonrepresentative images. He wanted to express his emotional and spiritual state of being. This could be achieved through nonrepresentational art, where the value of doing the work was primary.



# Chemical Hazards in Art

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Answers to questions and conclusions are found at the end of the chapter.

**Essential Question: How can artists use chemistry to understand and prevent illnesses acquired from continuous use of their materials?**

## INTRODUCTION

Artists often insist that they must feel and breathe their materials to create art. There can be no interference between the artist and the art materials. However, the artist sickened by toxic material will not be able to create anything.

As early as 1713, Bernardino Ramazzini, the father of occupational medicine, observed that artisans who worked with paints, stone, and metal had physical problems and short life expectancies. In modern times, it is suspected that van Gogh's craziness and Goya's illness may have been the result of lead poisoning. It is known that van Gogh used leaded yellow paint for his numerous sunflower paintings and was careless with his paints, leaving them open to dry and scatter into his environment. He could easily have ingested lead paint chips.

## Challenge Activity

Identify van Gogh's paintings that show wild, improbable brush strokes. (An example is *Starry Night*.) Compare these paintings to earlier paintings that have more controlled appearances. In both types of paintings, compare van Gogh's use of color and size and shape of brush strokes. Consider realism versus fantasy. Would van Gogh have been a genius if he had not suffered from mental illness? Explain.

There are two reasons why artists are particularly vulnerable to diseases caused by exposure to toxic materials. First of all, artists, by the nature of their work, may have daily, long-term contact with materials that are highly toxic. Second, art materials are used as aerosols, powders, dusts, and in solution, from which maximum physical absorption and adsorption are possible. An artist can inhale aerosols. Powders and dusts are also inhaled and, in addition, can be absorbed through the skin. Solutions and many solvents evaporate into the air for the artist to inhale over long periods of time. This chemical assault, day after day, causes a variety of illnesses. In the following section on artists' illnesses, all the chemicals cited are used by artists as they draw and paint, sculpt, work with metals, or develop and print photos—in general, as they engage in any art-associated activity.

**When artists work with their materials, what are some risk factors associated with this work?**

- Amount of exposure to a certain material.
- Frequency of exposure.
- Conditions surrounding the exposure: ventilation, housekeeping, etc.
- Toxicity of the material.
- Total body burden: total exposure from all sources.

## **ARTISTS' ILLNESSES**

### **Skin Illnesses**

Toxic solvents, such as methyl alcohol, benzene, and chlorinated hydrocarbons, can penetrate the skin through cuts and abrasions. On contact, these solvents cause chronic dermatitis and allergic skin reactions in susceptible individuals.

### **Eye Illnesses**

Materials such as methyl alcohol, acids, ammonia, irritating gases, mercury compounds, and photography developers can cause eye irritation if splashed into the eye. With prolonged contact, eye inflammation and even cataracts can result.

### **Respiratory Illnesses**

Gases such as sulfur dioxide, nitrogen dioxide, hydrogen chloride vapor, and ozone can cause lung damage from minimal exposure. When glazed pottery is fired in a kiln, toxic emissions containing carbon monoxide, formaldehyde, sulfur dioxide and trioxide, chlorine, fluorine, and metal particles can be released and inhaled. Chronic and acute respiratory diseases result. Also, inhaling these substances can increase susceptibility to respiratory infection and even pneumonia and lung cancer.

## **Circulatory System Illnesses**

Constriction of blood vessels, arrhythmia, and even aplastic anemia, caused by ethyl alcohol, methylene chloride, and benzene, respectively, are circulatory system diseases that result from misuse of these chemical substances. Methylene chloride, a paint solvent, reacts in the body to produce carbon monoxide, which replaces oxygen in the hemoglobin molecule. This can cause carbon monoxide poisoning, which can be fatal.

## **Nervous System Illnesses**

Solvents, such as chlorinated hydrocarbons, toluene, benzene, and xylene, can cause a feeling of euphoria, but they can be deadly toxins. Small, daily doses may cause dizziness, mental confusion, and fatigue; high doses will cause permanent damage to the central nervous system. Lead, mercury, and manganese ion poisoning will alter and destroy central and peripheral nerve function and cause personality changes.

## **A KNOWLEDGE OF CHEMISTRY WILL PREVAIL**

Even though it appears that artists are doomed by their materials, a knowledge of chemistry and some simple precautions can minimize art material dangers. In *Art in Chemistry; Chemistry in Art*, students learn about the physical and chemical properties of the chemicals in art materials and thus should know how these chemicals can be manipulated or changed to provide a safer environment for producing a work of art. The prognosis for the physical well-being of artists is not as dire as it would appear.

## **CHEMICAL HAZARDS ASSOCIATED WITH SPECIFIC ART TECHNIQUES**

### **Painting and Drawing**

#### **Pigments and Dyes**

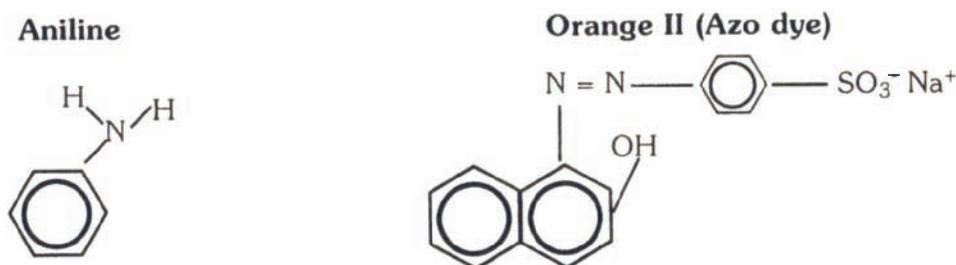
Pigments and dyes provide paint and ink colors. Many highly toxic pigments, such as copper acetate (blue-green), arsenic trisulfide (yellow), and mercury II iodide (red), are no longer used. However, other hazardous pigment compounds, such as lead carbonate, mercury II sulfide, and cadmium sulfide, are still used today. These compounds present a danger to those artists who use their mouths to make a brush more pointed.

#### **Organic and Inorganic Pigments**

Inorganic pigments are found in the earth. Iron and lead oxides provide earth colors. Copper calcium silicate and cobalt stannate provide blues. The colors burnt sienna and burnt umber come from iron oxides. Green pigments come from chromic oxide, calcinated cobalt, and zinc and aluminum oxides. Red pigments come from cadmium sulfide, cadmium selenide, and barium sulfate. All these chemical compounds come from the earth.

Cave dwellers, Native Americans, and the Ndebele people of southern Africa all have something in common. They all have used inorganic pigments from the earth to make a variety of paints. With these paints, they have painted walls to tell stories, to establish community status, and to embrace the beauty of the environment.

Organic pigments are found in living or once-living objects or can be laboratory-synthesized compounds. Charcoal from organic materials provides black pigment for paints. Complex organic molecules can be synthesized as red, blue, green, and yellow pigments. In the past, dyes were often made from aniline, derived from coal tar. Because these dyes were toxic, azo compounds replaced aniline compounds. (See Figure 10.1) Azo dye compounds almost always have an  $-\text{SO}_3^- \text{Na}^+$  group and  $-\text{N}=\text{N}-$  bonding that brings together two aromatic rings.



**Figure 10.1. Aniline Orange II (Azo Dye).**

In Chapter 2 we prepared inorganic and organic pigments for paints. An inorganic pigment was prepared by grinding cinnabar or azurite. Lead chromate, a yellow pigment, was prepared by precipitation, and organic pigment, carbon, was deposited on an evaporating dish during the incomplete combustion of a hydrocarbon.

### **Hazards and Help—Painting**

Some paint pigments are toxic; others are not. We do not know the long-term hazards of using many synthetic pigments. Some are thought to cause cancer and birth defects. Others might cause lung disease.

Paints become hazardous when they are ingested or inhaled, or when they come in direct contact with the skin, especially skin sores or cuts. Precautions should be taken regularly when paints are used. It is not wise to lick a paintbrush to make a pointed end. Powdered pigments used to make paints and paint droplets, possible from air brushes, should not be inhaled. A face mask protects against inhaling paints. There should be no eating or drinking during painting. Using gloves when handling powdered pigments and mixing paints is advisable.

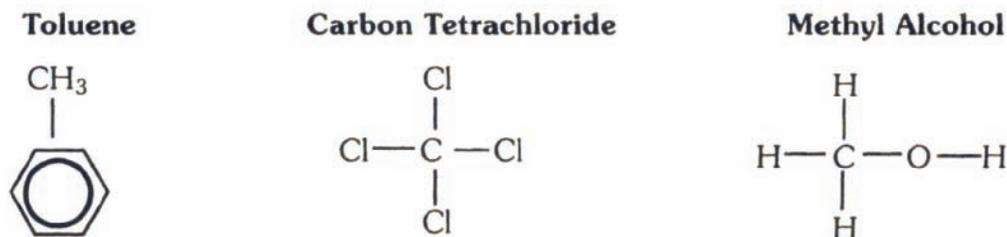
### **What are some natural pigments that present minimal harm to an artist?**

- Saffron: yellow. Charcoal: black or gray. Carrot: orange.
- Blackberries: purple. Thyme: green. Paprika: reddish brown.

Care should be taken to avoid inhaling powder when grinding minerals or when using dried lead chromate (see Activity 2.3). Hands should be thoroughly washed after any

pigment contact. A one-time direct contact with prepared pigments should not be hazardous to the user's health.

When a painting is finished, the artist often applies varnish or lacquer to the painting surface. Varnishes, and often paints, are thinned with turpentine. Turpentine can be used to remove surface varnish. Turpentine is moderately toxic if inhaled or ingested. Carbon tetrachloride, toluene, and methyl alcohol are also used to remove varnish (see Figure 10.2). Carbon tetrachloride and toluene are highly toxic if routinely inhaled.



**Figure 10.2.**

A complete list of paint and ink pigments, their chemical compositions, and their hazardous effects, is found in *Artists Beware* and *The Artist's Complete Health and Safety Guide* (see "References" at the end of this chapter).

## Ceramics

Artists often have to touch and feel their materials to create their artwork. Potters become intimate with their materials. They must manipulate and handle their clay to produce desired results. Direct contact with these materials for extended periods of time can be dangerous to the potter's health.

In Chapter 4 we learned that clay is made of minerals, including potassium, aluminum, and silicon oxides. Barium and other metal oxides, vermiculite, and mold controllers are often added to clay to enhance clay properties. If dry clay is mixed with water, large amounts of silica can be released into the air.

### **Hazards and Help**

Many years of inhaling clay dust can be hazardous to the potter's health. If the clay dust contains silica, silicosis and a variety of lung-related illnesses can result. Clay dust can also contain harmful bacteria and molds.

In addition, clay wedging, throwing, and building can cause hand and wrist injuries, including median nerve damage resulting in carpal tunnel syndrome (identified by numbness in the thumb and first three fingers).

To minimize clay dust inhalation, it is best to buy premixed clay. Potters should change clothes before leaving their work area. Fresh clay should be used to minimize bacteria and mold growth. To avoid median nerve damage and resulting carpal tunnel syndrome, the potter's wrist should be unflexed frequently. A face mask can be worn when clay dust is present.

## Glazes

In Activity 4.3 we prepared and applied glazes to clay slabs. The glazes were composed mostly of silicon dioxide, along with aluminum and potassium oxides (to reduce the melting point) and compounds such as copper oxide and iron oxide (colorants).

### **Hazards and Help**

Metal oxides such as copper oxide and iron oxide have replaced lead compounds in glazes. Lead compounds should not be used in glaze compositions because lead inhalation or ingestion can cause nervous system and brain damage, organ damage, and anemia.

Glazes should be prepared where adequate ventilation is available. If glazes are routinely prepared from powders, a face mask should be used. Another option, if available, is to use a plain-opening exhaust hood or wear a toxic-dust respirator approved by the National Institute for Occupational Safety and Health. Also, gloves should be worn during the preparation and application because glaze substances can be irritating to the skin.

National Institute for Occupational Safety and Health (NIOSH)  
4676 Columbia Parkway  
Mail Stop C-13  
Cincinnati, OH 45226-1998  
1-800-35NIOSH  
Web site: [www.Cdc.gov/niosh/](http://www.Cdc.gov/niosh/)

## Firing

Because of obvious (and not-so-obvious) dangers involved, it is the teacher who does the firing in the activities in Chapter 4. In schools, electric kilns are usually chosen for firing because fuel-fired kilns require wood, natural gas, oil, coke, coal, or charcoal as fuel, as well as chimney ventilation systems. Electric kilns also require ventilation systems, such as negative pressure systems and a canopy hood, but the placement is more flexible than room placement for a fuel-fired kiln with a chimney ventilation system.

### **Hazards and Help**

Many by-products of bisque firing are highly toxic if inhaled, so all kilns must be vented. Carbon monoxide, sulfur dioxide and trioxide, chlorine, and fluorine are just some of the gases released in kiln firings. Metal ions such as cadmium, copper, chromium, and precious metal ions including silver and gold, appear in metal fumes at high temperatures and can be inhaled or deposited in the kiln, to be released during future firings.

Heat is also a hazard produced by kiln firing. Electric kilns should be off the floor, with adequate space surrounding the kiln to prevent heat buildup and fire. The heat produced can cause burns and eye damage, and can possibly accelerate cataract development.

Constant exposure to kiln firings may cause chronic lung problems, such as emphysema. Carbon monoxide poisoning can occur (symptoms are lethargy and a continuing headache). Proper ventilation can prevent most kiln-induced health problems.

## **Jewelry Making and Metalworking**

Metals can be shaped and designed into an immense variety of jewelry pieces. In Chapter 6 we sawed and soldered metal and cast molten metal to produce pieces of jewelry. Using electrolysis, we added metal coatings to the jewelry pieces. It is necessary to consider health precautions that should be taken regarding metalwork.

### **Soldering**

Joining silver pieces with silver solder requires temperatures of 316–760°C. At these temperatures, impurities in the silver solder, such as antimony and cadmium, are released. The flux may contain fluoride compounds, such as potassium fluoride and boron trifluoride, or other boron compounds.

### **Casting**

Metals, usually gold and silver, are often cast to make rings and other small jewelry pieces. In lost wax casting, a wax pattern for a jewelry piece is burned out of a mold. A large variety of waxes, such as beeswax, paraffin, and tallow, can be used. The waxes can release formaldehyde and acrolein.

Pouring liquid metal into the mold requires a steady hand and constant attention. When the mold containing liquid metal is placed in a centrifuge, hot metal can fly out of the centrifuge. This is why it is preferable to use the vacuum casting method, for which a centrifuge is not needed.

### **Metal Colorants**

Metal colorants such as copper sulfate, ferricyanide, and ferrocyanide compounds can be irritating or highly toxic. If a colorant reacts with the metal, irritating acid fumes can be released.

### **Hazards and Help**

In soldering, zinc chloride and other metal chloride fluxes are the safest, and fluoride fluxes, such as boron trifluoride, are the most hazardous. However, zinc chloride fumes can be irritating. Fluoride gases can cause lung damage and, with long-term exposure, bone and teeth damage. While soldering, a safe flux should be chosen and fluxes should not be mixed. Goggles and gloves should be worn. An exhaust system is needed to quickly remove toxic gases.

When an artist or metalworker is casting, burns are easily acquired. Asbestos gloves and goggles, of course, will minimize hand and eye burns. During centrifugal casting, a shield around the centrifuge protects against flying metal. The metalworker should be sure that the centrifuge is in balance before starting the centrifuge.

Applying colorants to metals should be done in a well-ventilated room. Copper sulfate can release irritating sulfur dioxide, and ferricyanide or ferrocyanide compounds with acid and/or heat will release hydrogen cyanide gas. Needless to say, these combinations should not be used to color metal.

Sterling silver, silver, and copper, or gold, can be used to cast a jewelry piece with a minimal amount of health hazard. Alloys with large amounts of cadmium, chromium, nickel, antimony, and arsenic should not be used.

## **Photography**

Many photographers use commercial processing and avoid contact with hazardous chemicals. However, when photographers do their own processing, they come into direct contact, often for long periods of time, with a large variety of chemicals. Keep in mind that digital photography requires no chemical contact. This makes digital photography a desirable alternative to film photography.

### **Hazards and Help—Developers**

Because developing solutions are placed in large trays with an immense surface area exposed to the user, there can be considerable eye, skin, and lung contact between the photographer and the solution. Developing solutions can cause skin rashes, irritate eyes, and enhance respiratory allergies.

Metol (monomethyl p aminophenol sulfate), used in most developing solutions, can cause severe skin irritation and allergies. Phenidone-based developers are less toxic to the skin than metol, amidol, or pyrogallol. When developing powders are mixed, inhalation is a concern.

There are many ways to protect the user from developer hazards. A face mask will protect against inhalation of developer powder, which can be quite toxic. Eating small amounts of developer powder can be fatal to adults. Therefore, it is prudent to not eat where photos are being processed. Using liquid developer should minimize inhalation dangers. When handling negatives or prints in solutions, tongs should be used. In the darkroom, an apron and goggles should be worn when developing solutions are handled. Any developing solution that splashes onto the skin or into an eye should be immediately washed with copious amounts of water and checked by school health personnel.

### **Hazards and Help—Stop Baths**

Standard stop bath is 28% acetic acid. A pH indicator is added, usually bromcresol purple, which is yellow below pH 5.2 and blue above pH 6.8. When the stop bath is blue, the hydrogen ion concentration is too low to be effective. Dilute acetic acid is an irritant to the skin and can cause allergic reactions and chronic bronchitis.

Adequate ventilation in the darkroom will eliminate acid fumes. The photographer should wear goggles, an apron, and plastic gloves, and should use tongs when handling negatives and prints in a stop bath.

### **Hazards and Help—Fixers**

Sodium thiosulfate, sodium hydrogen sulfite, and aluminum potassium sulfate are used to remove remaining light-sensitive silver bromide or silver chloride, maintain an acid pH, and harden the negative or print finish.

Sodium thiosulfate and aluminum potassium sulfate are not very toxic upon skin and eye contact, and sodium thiosulfate is moderately toxic if inhaled, as is sodium hydrogen sulfite. However, sodium hydrogen sulfite is toxic if ingested.

As with developers and the stop bath, having adequate ventilation; wearing goggles, aprons, and gloves; and avoiding inhalation or ingestion of fixer solutions will minimize health risks.

### **Hazards and Help—Toners**

Because gold and silver salt toners are very expensive, selenium toners in diluted, commercially prepared form are presently used. If the toner is heated, poisonous hydrogen sulfide gas can be released.

Because selenium powder and sodium selenite are extremely toxic, they can only be used under a fume hood with local exhaust ventilation. In addition, goggles, rubber gloves, an apron, and a dust mask should be worn. If the toner is heated, local exhaust ventilation should be provided.

### **Challenge Activity**

Debate the safety advantages and disadvantages of digital photography as compared to film photography. Consider not only safety issues but also photo quality. When considering safety, discuss darkroom best practices procedures and when considering quality, discuss photo size.

**In summary, what can artists and chemists do to protect themselves and other from harm?**

- Choose the safest material.
- Read labels.
- Set up studios or laboratories carefully.
- Have adequate ventilation.
- Protect against fire.
- Wear safe aprons and goggles.
- Clean up.
- Avoid physical and electrical hazards.
- Seek medical advice.

### **THE POISON IS IN THE DOSE, BUT ALL IS NOT LOST**

In general, the longer the exposure to a toxic substance, the greater the risk of health problems. Also, the concentration of a substance determines its degree of toxicity.

Artists and chemists should not despair. They can continue to create and investigate without fear of failing health or instant injury to their well-being. With a knowledge of the

chemicals and chemistry involved in their materials, artists can select proper alternatives to harmful materials. In fact, an artist might invent a new, better process or material for accomplishing a result by informed experimentation with different chemical combinations. *Art in Chemistry; Chemistry in Art* should help the artist to be more creative than ever before!

### **PRECAUTIONS TO TAKE TO PREVENT HEALTH PROBLEMS**

Table 10.1 should be used to determine what precautions can be taken in particular *Art in Chemistry; Chemistry in Art* activities. However, even if a substance is not listed, attention should still be paid to the proper use of that substance.

The information in Table 10.1 reflects currently available information concerning chemicals used in both art and chemistry. It should be understood that the authors and publisher can take no responsibility for the use or misuse of any information provided herein. Readers should use common sense and seek advice from the medical profession, regulatory agencies, and associated professionals about specific hazards and problems.

### **CHEMICAL HAZARDS FOR THE CHEMIST**

Chemists are subject to the same hazards as artists from long-term, direct contact with toxic chemicals. In addition, some highly toxic chemicals can be deadly on single contact. Chemical warfare makes use of this knowledge. Fortunately, most chemists and artists will never come in contact with such chemicals.

The artist and the chemist should take the same precautions when chemical substances are present. As can be seen in Table 10.1, it is prudent to wear goggles and a fireproof apron when working with any chemicals. Because many chemicals are skin irritants, the use of gloves is wise. If powders or gases are present, a face mask protects lung and nasal tissue.

**Table 10.1**  
**Materials Used in Art in Chemistry; Chemistry in Art Activities and Demonstrations**

Chemical or Art Material	Activities and Demonstrations	Hazards	Precautions
Acids: Sulfuric (H <sub>2</sub> SO <sub>4</sub> ), Hydrochloric (HCl), Nitric (HNO <sub>3</sub> )	6.1, 6.4, 9.1	Highly irritating to eyes, skin, respiratory system. Can release toxic gases when reacted with metals	Wear face mask, goggles. Use under hood with exhaust.
Acrylic paints	2.2, 9.2	Drying acrylic paints release ammonia (NH <sub>3</sub> ) and formaldehyde, which irritate nose and eyes.	Use with good ventilation.
Ammonium carbonate [(NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub> ]	2.4	Can release ammonia (NH <sub>3</sub> )	Use with good ventilation.
Ammonium dichromate [(NH <sub>4</sub> ) <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> ]	Demo 1.2	Moderately toxic. Releases ammonia (NH <sub>3</sub> ). Potent animal carcinogen.	Use under hood with local ventilation. Wear goggles.
Lead nitrate [Pb(NO <sub>3</sub> ) <sub>2</sub> ]	9.2	Moderately toxic. Causes reduced mental acuity (neurotoxin).	Avoid contact for long periods of time. Wear face mask when in contact with powder.
Markers	1.6, 1.7, 1.8, 1.11, 1.12, 1.14, 4.4, 4.9, 5.9	Toxic solvents. Water-based are safest.	Use with good ventilation.
Matches	1.5, 2.1, 2.3, 6.1, Demos. 1.2, 1.5, 4.1	Can cause burns. Inhaling sulfur fumes can cause throat and lung irritation.	Blow out quickly. Use with good ventilation.
Methyl alcohol (CH <sub>3</sub> OH)	Demos 1.2, 10.1	Toxic in high doses or chronic exposure.	Avoid skin and eye contact. Never ingest.
Silicon dioxide (SiO <sub>2</sub> )	4.3	Can cause silicosis and lung diseases.	Wear plastic gloves, face mask. Do not inhale.
Silver nitrate (AgNO <sub>3</sub> )	Demo 4.1	Stains and burns skin. Irritates mucous membranes. Can cause blindness if splashed in eyes.	Wear plastic gloves, goggles.
Sodium carbonate (Na <sub>2</sub> CO <sub>3</sub> )	3.1, 6.7	Moderately toxic. May cause skin and eye irritation.	Use with local exhaust ventilation. Wear dust mask, goggles, apron, gloves.
Sodium hypochlorite (NaHClO) (bleach)	3.4	Can cause severe eye, skin, and mucous membrane damage. Can release chlorine gas (Cl <sub>2</sub> ).	Wear gloves, goggles. Use with local exhaust ventilation.
Sulfur (S)	1.17	Toxic if inhaled or burned. Can produce sulfur dioxide (SO <sub>2</sub> ) and sulfur trioxide (SO <sub>3</sub> ), which are skin and eye irritants.	Do not inhale. Wear face mask. Do not burn.
Turpentine	2.4	Can cause dermatitis, asthma, kidney and bladder damage.	Use under hood with exhaust system.
Wax	2.4, 6.4, 10.1	Hot wax can release formaldehyde and acrolein, which irritate skin and eyes.	Use with good ventilation.

**ACTIVITY****10.1*****How to Properly Use Chemical Materials*****Objectives**

1. Students will observe and evaluate the proper and improper ways to handle chemical materials used in art projects.
2. Students will describe the molecular or ionic makeup of hazardous materials used in art projects.
3. Students will suggest substitute materials for hazardous art materials.
4. Students will experiment with methods of restoring a work of art.

**Materials**

Photography developing trays; old negatives; tongs; cube of wax; crucible; oil paints; varnish; methyl alcohol; surface for oil painting; paintbrushes for oil painting; soft white cloth; goggles; fireproof aprons; gloves; Table 10.1.

**Time**

100 minutes (two class periods, about one week apart)

**Procedure**

- A. The teacher should demonstrate the proper and improper use of chemicals in photo development:
  1. Put on an apron, goggles, and gloves.
  2. Fill two developing trays with water. The water represents developing solution.
  3. Place a negative in the water.
  4. Using tongs, remove the negative and transfer it to the next tray without dropping “chemicals” onto the surface of the table.
  5. Using tongs, transfer the negative to a sink and run water on the negative.
  6. Repeat the process, without wearing an apron, goggles, or gloves; using the tongs improperly; and dropping “chemicals” onto the surface of the table.
  7. Record five correct procedures and five incorrect procedures that students observed.

- B. The teacher should demonstrate the proper and improper use of metalworking materials:
1. Put on an apron, goggles, and gloves.
  2. Add water to a crucible. The water represents molten metal.
  3. Make a tunnel in a wax cube.
  4. Using tongs to handle the crucible, pour the “molten metal” into the tunnel in the wax cube.
  5. Repeat the above process, without wearing gloves, an apron, or goggles, using the tongs improperly to pour the “molten metal” around the wax cube.
  6. Have students record five correct and five incorrect procedures that they observed.
- C. Have students prepare an oil painting, apply a varnish finish, and remove the “dirty” varnish with methyl alcohol:
1. Wear aprons and goggles.
  2. Prepare an oil painting, using the principles of good composition. The oil paint should be applied thinly.
  3. When the paint is dry, apply a thin coat of varnish to the oil paint. This should be done under a hood with a running exhaust fan. Wear gloves, aprons, and goggles.
  4. Add a small amount of dirt or dust to a small area of the wet varnish.
  5. When the varnish is dry, have students remove the “dirty” varnish methyl alcohol. The methyl alcohol should be absorbed by a soft cloth and gently rubbed onto the varnish to be removed. Care should be taken not to remove paint. This should be done under a hood with a running exhaust fan. Wear gloves, aprons, and goggles.

## Questions and Conclusions

### Level One

1. What health hazards exist for the art restorer?
2. Discuss reasons for wearing aprons, goggles, and gloves when working in the darkroom and when pouring liquid metals into molds.
3. Consider techniques involving clay, such as glazing and firing, and describe how the materials involved should be handled for safety.
4. Explain how health hazards from paints can be avoided.

### Level Two

1. Make a list of several chemical formulas for substances used in painting, photography, clay sculpting, metalworking, and art restoration.

2. Make a list of alternate, less-toxic chemicals that could be used in each of these art disciplines. Explain your choices.
3. Where there is no alternate chemical choice, describe precautions that the artist can take when working with relatively toxic materials.

■ *Note:*

The Art and Creative Materials Institute, Inc. (ACMI) is an association of art material manufacturers. Its goal is to require toxicity labeling on all art products. An art material approved by ACMI and so labeled will be certified “nontoxic.”

## A REMARRIAGE OF ART AND CHEMISTRY

As with art conservation and restoration, when chemical hazards in art are considered, art and chemistry have again reached a state of matrimonial bliss. The artist needs the chemist and the chemist needs the artist. The artist, with the help of a sound knowledge of chemistry, can substitute less-toxic materials for highly toxic substances. For example, methyl alcohol, toluene, or methylene chloride can be substituted for benzene, which is used as a paint and varnish remover, and boric acid can be substituted for phenol, which is used as a preservative. The chemist needs the artist to shed new light and for a new point of view so that the chemist can develop appropriate and better art materials.



## REFERENCES

- McCann, Michael. *Artist Beware*. Guilford, CT: Lyons Press, 2005.
- Rempel, Siegfried. *Health Hazards for Photographers*. New York: Lyons and Buford, 1993.
- Rossol, Monona. *The Artist's Complete Health and Safety Guide*. 3rd ed. New York: Allworth Press, 2001.



## ANSWERS TO ACTIVITY QUESTIONS AND CONCLUSIONS

### Activity 10.1 How to Properly Use Chemical Materials

#### Level One

1. The art restorer can work on restoring an art object for several months. This means daily contact with the restoring materials. The restorer's room needs excellent ventilation. The restorer should wear gloves to prevent skin contact with restoring materials. Eyes should be protected with goggles. Mainly, the restorer should read the labels on the restoration chemicals and adhere to toxicity advice.
2. Photography darkroom chemicals can irritate skin and eyes. It is obvious that liquid metals are hot and can, on contact, cause first-, second-, or even third-degree skin burns and severe eye damage. In third-degree skin burns, all layers of the skin are damaged.
3. Glazes should be prepared in a well-ventilated room. The preparer should wear gloves. A kiln used for firing pottery should be ventilated so no fumes can return to the artist's studio. Ideally, firing should be done outside.
4. Avoid paint contact with your hands and mouth. Do not put paintbrushes into your mouth to shape them. Do not smoke while painting. Read paint labels to see if the paint is labeled nontoxic.

#### Level Two

1. Painting:  $\text{PbO}$ ; photography:  $\text{HC}_2\text{H}_3\text{O}_2$ ; clay sculpting:  $\text{SiO}_2$ ; metal working:  $\text{Cu}_2\text{S}$ ; art restoration:  $\text{C}_6\text{H}_6$ .
2. Painting:  $\text{PbO}$  (lead II oxide);  $\text{ZnO}$  (zinc oxide) can be substituted to provide a white pigment. Photography:  $\text{HC}_2\text{H}_3\text{O}_2$  (acetic acid); water ( $\text{H}_2\text{O}$ ) in large quantities can act as a stop bath. However, acetic acid stop bath will provide a more permanent result. Clay sculpting:  $\text{SiO}_2$  (silicon dioxide); silicon dioxide is the major constituent of natural clays. It might be possible to use plastic clay for small objects. Glazes should not be applied to plastic clays. Metal working:  $\text{Cu}_2\text{S}$  (copper I sulfide); carbon itself can produce a black finish to a pottery piece. Art restoration:  $\text{C}_6\text{H}_6$  (benzene); ethyl alcohol,  $\text{C}_2\text{H}_5\text{OH}$ , can be substituted for benzene.
3. Three main rules are:
  - a. Store chemicals in a separate room with good ventilation.
  - b. Order minimum amounts of relatively toxic materials.
  - c. Get technical information and a safety release to use the materials.



# A

## Periodic Table

																		Noble Gases 8A	
																		Halogens 7A	
																		6A	
																		5A	
																		4A	
																		3A	
																		2B	
																		1B	
																		8B	
																		7B	
																		6B	
																		5B	
																		4B	
																		3B	
																		2A	
																		1A	
																		Alkali Metals	
																		Alkaline Earth Metals	
																		Transition Metals	
																		Inner-Transition Metals	
																		Lanthanides	
																		Actinides	



**B****Materials List**

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Art and chemistry materials can be obtained at:  
Kemtec Educational Services  
4780 Interstate Drive  
Cincinnati, OH 45246

**Chemistry Materials**

Numbers listed are activity and demonstration numbers.

50 ml. beaker: 4.1, 5.5  
100 ml. beakers: 2.3, 4.3  
150 ml. beakers: Demo 1.4  
250 ml. beakers: 2.3, 2.4, 3.1, 3.2, 3.4, 4.1, 5.5, 6.3, 6.4; Demos 1.3, 4.1  
1 liter beaker: 3.1  
10 ml. graduated cylinder: 2.1, 2.4; Demos 1.2, 1.3  
25 ml. graduated cylinder: 5.5  
50 ml. graduated cylinder: 6.1, 8.3  
100 ml. graduated cylinder: 2.3, 3.2, 4.1  
1 liter graduated cylinder: 3.1  
1 liter volumetric flask: 8.3  
1 liter Erlenmeyer flask: 4.1  
12 or 14 gauge wire: 5.6

Acetic acid: 8.3  
Aluminum foil: 5.4, 8.1  
Aluminum oxide: 4.3  
Ammeter: 6.4  
Ammonium carbonate: 2.4  
Atomic model kits: 5.2, 5.3, 7.1, 7.4  
Automatic stirrer: 8.3

Bunsen burner: 1.5, 2.1, 2.3, 2.4, 3.2, 6.1; Demos 1.2, 1.5, 4.1  
Bromine: 1.13

Calcite: 2.3  
Calcium carbonate: 4.3  
Calcium chloride: 3.1  
Calcium metal: 1.13, 6.1  
Calcium nitrate: 1.13, 9.1  
Calcium oxide: 3.1, 4.3

Calculator: 4.2  
Carbon powder: 1.13, 1.17  
Carbon tetrachloride: 5.5  
Centigram balance: 1.12, 1.13, 2.1, 2.3, 2.4, 3.2, 3.4, 6.1; Demos 1.2, 1.3, 1.4, 6.2  
Cinnabar or azurite: 2.3  
Cobalt: 1.13  
Cobalt nitrate: 1.13, 2.3  
Cobalt oxide: 4.3  
Conducting wires with clips: 6.3  
Copper carbonate: 4.3  
Copper foil: 6.1  
Copper metal: 6.1, 6.2, 6.3, 6.4; Demos 1.13, 6.1  
Copper nitrate: 1.13, 6.3  
Copper sulfate: 1.12, 1.13, 1.14, 1.17, 6.4  
Copper wire: 6.5; Demos 4.1, 6.1  
Crucible: 10.1

Developing tanks: 8.2  
Direct current source: 6.5 Demo 1.1

Emery cloth 6.1, 6.2, 6.4, 6.5, 6.6. Demo 1.2  
Evaporating dish: 1.17, 2.3  
Eye dropper: 2.5, 5.5, 6.1

Filter paper: 2.3, 3.1  
Fireproof aprons: All activities  
Flame test wire: 9.1  
Fireproof heat resistant gloves: When handling hot materials  
Flashlights: 1.8, 1.12  
Funnel: 2.3, 3.1, 8.2

Gas discharge tubes (hydrogen, argon, neon); Demo. 1.1  
Glass plates: 9.1  
Glass stirring rod: 2.1, 2.4, 2.5, 3.1, 3.2; Demo 1.4  
Goggles: All activities.  
Gypsum: 2.3

Hexamethylene diamine: 5.5  
Hot plate: 3.2, 3.4, 6.4

Hydrochloric acid: 6.1, 9.1  
Hydroquinone (paradihydroxybenzene): 8.3

Iron III nitrate: 1.13  
Iron III oxide: 4.3  
Iron metal 1.13  
Iron wire: 6.1

Kodak fixing solution: 8.3

Lead metal: 6.1  
Lead nitrate (crystalline): 9.2  
Litmus paper: 3.1, 3.4

Magnesium nitrate: 1.13  
Magnesium oxide: 4.3  
Magnesium strips: 1.2, 1.13, 6.1; Demo 1.5  
Matches: 1.5, 2.1, 2.3, 6.1; Demos 1.2, 1.5, 4.1  
Methyl alcohol: 10.1; Demo 1.2  
Mortar and pestle: 2.3

Nickel metal: 1.13  
Nickel nitrate: 1.13  
Nickel oxide: 4.3

Periodic table: 1.12, 1.13, 4.2, 4.4, 6.1  
Petri dishes: Demos 1.2, 4.1  
Phenolphthalein: 6.1  
Photography developing trays: 8.3  
pH paper: 9.1  
Pipettes (disposable): 9.1  
Potassium aluminum sulfate: 3.4, 4.1  
Potassium bromide: 8.3  
Potassium chloride: 1.1, 9.1  
Potassium chromate: 1.12, 1.13, 1.17, 9.2  
Potassium oxide: 4.3  
Potassium thiocyanate: 1.13  
Prism: 1.4

Sebacoyl chloride: 5.5  
Silicon dioxide: 4.3  
Silver foil and wire: 6.1  
Silver nitrate: 9.1; Demo 4.1  
Sodium acetate: 2.1  
Sodium carbonate: 2.3, 3.1, 6.7, 8.3  
Sodium chloride: 1.13, 4.1  
Sodium hydroxide: 5.5, 9.1  
Sodium hypochlorite: 3.4  
Sodium iodide: 9.1  
Sodium nitrate: 6.3  
Sodium phosphate: 9.1  
Sodium sulfate: 9.1  
Sodium sulfite: 8.3  
Spatula: 1.17, 2.3, 4.1

Spectral line charts (hydrogen, argon, and neon):  
Demo 1.1  
Stoppers: 2.5  
Styrofoam balls: 1.1, 4.1  
Sucrose: 4.1  
Sulfur powder: 1.13, 1.17  
Sulfuric acid: 6.4

Talc: 2.3  
Test tube holder: 2.1  
Test tube rack: 2.1  
Test tubes: 1.12, 1.13, 2.1, 2.3, 2.4, 2.5, 6.1,  
9.1, 9.2  
Thermometer: 2.1, 6.1  
Tin metal: 6.1  
Titanium dioxide: 3.2  
Tongs: 2.3, 6.1, 8.3, 10.1; Demos 1.2, 1.5, 6.2  
Tweezers: 5.5, 9.2; Demo 6.1

U-tube: 6.3  
Voltmeter: 6.3

Wash bottle: 2.3, 3.1; Demo 4.1  
Wire: 5.6

Zinc metal: 1.13, 6.3  
Zinc nitrate: 1.13, 6.3  
Zinc oxide: 3.2, 4.3

### **Art Materials**

Numbers listed are activity and demonstration numbers.

Acrylic paints: 1.1, 2.2, 9.2  
American flag picture: 1.18  
Awl or ice pick: 8.1

Balsa wood: 5.10  
Beads: 5.6, 6.5, 6.6  
Beeswax: 2.4  
Bowl: 7.2  
Box (small): 1.1, 6.6  
Brush: Demo 6.1

Cardboard: 5.5, 7.2; Demo 6.2  
Carving tools: 6.6  
Casting container of sand: 6.6  
C-clamp: 6.2, 6.6  
Charcoal block: Demo 6.1  
Cheese cloth: 3.2, 3.4  
Clay tools: 7.2  
Clay: 4.3, 4.5, 4.6, 4.7, 7.2  
Coffee can: 8.1  
Colored cards: 1.2

- Colored pencils: 1.3, 1.4, 1.6, 1.7, 1.9, 1.13, 5.2, 5.8, 7.4; Demos 1.1, 1.4
- Commercial pen cleaner: 8.4
- Compasses: 1.10
- Construction paper: 3.5, 8.1
- Copper tongs: Demo 6.1
- Cotton plugs: 6.3
- Digital camera: 8.2
- Drawing paper: 1.3, 1.6, 1.9, 5.1, 5.2
- Dry curd cottage cheese: 3.2
- Egg yolk: 2.4, 3.3
- Embroidery hoops: 3.4
- Erasers: 7.4
- Fettle knife or kitchen knife: 5.4
- Files: 6.6
- Fluorescent paints: 9.2
- Flux: Demo 6.1
- Foam board: 9.2
- Food color: 5.5
- Glass tubing: Demo 4.1
- Glue or rubber cement: 1.16, 3.4, 3.5, 5.6, 5.9, 5.10
- Hammer: 6.5
- Hand drill: 6.5
- Hand held hole punch: 5.10
- Heavy duty aluminum foil: 5.4
- Heavy paper: 1.10, 3.5
- Illustration board: 5.10
- Ink: 8.3
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# About the Authors

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**Barbara R. Greenberg** is an adjunct faculty member at National Louis University, Chicago, Illinois, in the College of Education. She is also an intellectual property attorney and retired chemistry teacher in Hinsdale, Illinois. She has taught at various schools in Illinois and New York and was chosen “Teacher of the Year” at Willowbrook High School in Villa Park, Illinois. Barbara developed integrated curriculum and taught chemistry at the Illinois Math and Science Academy, Aurora, Illinois. She received her bachelor of science (chemistry) from the University of Illinois-Champaign, her master of arts (guidance and counseling) from Northeastern Illinois University, and a doctorate in law from Loyola University of Chicago School of Law.

**Dianne Patterson** is a retired art teacher in Elmhurst, Illinois. She is past chairperson for the art department at Willowbrook High School in Illinois and is currently associated with the Elmhurst Art Museum as a docent and lecturer. Dianne is a former member of the Illinois Alliance for the Arts, Chicago Art Education, and the Illinois Art Education Association. She is currently pursuing watercolor painting, creation of wearable art, writing, and travel. Dianne received her bachelor of fine arts (art education) from the University of Illinois, and her master of arts from the University of Illinois. She has pursued postgraduate work in fine arts and art education at the University of Wisconsin, University of Colorado, and Northern Illinois University.

