



The Chemistry of Materials

Janice and her father walked into the cell phone store. It was time to buy new phones. As they headed for the long row of the latest models, she noticed a sign: “Go green! Turn in your old phone and get 15% off a new phone!”

“Wow!” She thought, “I have my old phone, so I can turn it in for recycling. That’s an easy 15% discount!”

They continued along the row of phones. The signs for one group displayed a logo with three green arrows in a triangle. It reminded Janice of the recycling symbol on the bottoms of plastic bottles. She noticed that the three phones with this symbol were cheaper than other phones with similar features. “I wonder why these are cheaper?” she asked. Just then the salesperson came by. Janice asked, “Excuse me, could you please tell me what this green symbol means?”

“If a phone carries a green label, it fits green criteria.” the salesperson said. “That means that its materials or the way it was manufactured are less harmful to the environment than a standard phone.”

“The green phones are so much cheaper than the others!” Janice said in amazement.

“Yes, isn’t it great? The government offers lower taxes to electronics companies that meet green standards. They can sell their products for less.”

“Yow,” thought Janice, “not only do I need to choose a phone, but I have to think about the environment too.”

• • •

The scenario you just read about does not exist—yet. When we buy a cell phone, there is no label that describes how much waste, some of it toxic, was created in manufacturing the phone. But should there be? When you buy a new product, do you think about what materials it is made of? How it was manufactured? What will happen to it when you no longer have a use for it? In this unit you will consider these questions as you investigate the chemistry of materials. With this information, you will be able to analyze the environmental impact of a product and decide which products to purchase.



12 Evaluating Materials



Consider the world around you. The book in your hands, the floor underneath your feet—each is made from a type of material. The word “material” can have several meanings. To a scientist, a **material** is a type of solid matter used to make things. For example, clothing, homes, and computers are all made from different materials. **Materials scientists** and **materials engineers** study materials and design new ones. When they design these materials, some of the things they think about are:

- How will they be used?
- What resources are needed to make them?
- What will happen to them when they are no longer useful?

For example, think about the materials that can be used to make containers for drinks. Until 1947, almost all drink containers in the United States were made of glass. Consumers could return glass milk and soft drink bottles and have their deposits paid back, and the drink bottling companies would clean and refill the bottles to sell again. Today, most drink containers are made mainly of aluminum, plastic, or glass. Each material has particular characteristics, or properties, that make it useful for holding drinks. Each material is made from specific resources and has a set of effects on the environment when it is discarded or recycled.

You are a materials scientist working for a bottling company. The president of the company has asked you which type of material to use to make containers for a new drink brand. You decide to look for a material that will both work well and have the fewest bad effects on the environment. Should it be aluminum, glass, or plastic? How will you decide? What evidence will you use?



Which is the best material for making a drink container?



MATERIALS



For each group of four students

- 1 set of 21 Material Data Cards
- 1 set of blank slips of paper for category titles



For each student

- 1 Science Skills Student Sheets 3a and 3b, “Bar Graphing Checklist”
graph paper


PROCEDURE

1. Prepare a data table for recording the advantages and disadvantages of each of the three materials—aluminum, glass, and plastic. Your table should fill an entire page in your science notebook. Give the table a title.
2. With your group:
 - a. List the properties of each of the three materials—aluminum, glass, and plastic.
 - b. Decide whether each property is an advantage or disadvantage if you are using the material to make a drink container.
 - c. Record in your data table your decision from Step 2b.
3. Spread the Material Data Cards out on a table and read the information on each card.
4. Sort the cards into categories for comparing the three materials.
 - Listen to and consider the explanations and ideas of other members of your group.
 - If you disagree with other members of your group, explain why you disagree.
5. Create a title that describes each category of sorted cards. Write the title of each category on a slip of paper and place it above that group of cards.
6. Compare your categories with those of another group in the class. Discuss any differences in the way they sorted their cards.
7. If necessary, adjust your categories and titles based on your conversation with the other group.

8. Decide if the information on each card is an advantage or a disadvantage of the material it describes. Record these advantages and disadvantages in your data table.
9. Your teacher will assign you one of the categories. Prepare a bar graph comparing the three materials in that assigned category. Be sure to label the axes and title your graph.

ANALYSIS



1. What two types of information do you think are the most important in deciding which material to use to make drink containers? Explain.
2. What additional information would you like to have about these materials? Explain.
3. Based on the information in your data table, which material is the best for making a drink container, from the viewpoint of each person listed below? Explain your answer for each of these people and support it with evidence from the activity.
 - a. a consumer concerned with cost and convenience
 - b. an environmentalist concerned with energy usage, litter, and problems with a bottle's impact on the environment
 - c. a recycling-center owner who must handle all of the containers turned in for recycling
4. Did the graphs of the data help you make a decision about the advantages and disadvantages of each material? Explain.
-  5. What do you think is the best material to use to make drink containers? Write a letter or prepare a presentation to the president of the drink company describing your recommendation. Support your answer with evidence and identify the trade-offs of your decision.

13 Product Life Cycle



When deciding what material will be used to make a drink container, it can be helpful to think about what is needed to make the container, how it will be made, and what will happen to it when it is no longer being used. All of these stages together are called the **life cycle** of a product. One way of illustrating each stage in the cycle is a **life-cycle diagram**. Materials engineers use life-cycle diagrams when making decisions about a product. These diagrams show how the inputs and outputs from one stage relate to the inputs and outputs of other stages. Life-cycle diagrams can be used to make decisions that reduce the harm that manufacturing and disposing of a product might cause to the environment.

In this activity, you will read about the life cycle of a drink container. Then your group will construct a life-cycle diagram for that type of container. You will then be able to use the life-cycle diagram to determine ways to reduce the harm the container might cause to the environment.



How can a life-cycle diagram be used to make a decision about a product?



Products like water bottles are a part of our everyday lives. It takes many steps to manufacture the material and produce the bottle.

MATERIALS



For each student

- 1 Student Sheet 13.1, “Stages in the Life Cycle of a Product”
- 1 Student Sheet 13.2, “Green Chemistry Guidelines”

PROCEDURE

1. The stages in the life cycle of a glass bottle are described below. With your partner, read the description of the stages.

The Life Cycle of a Glass Bottle

RAW MATERIALS: Raw materials come from the earth. They are substances that are used to manufacture a product. It takes energy of both humans and machinery to gather or mine raw materials for products. This may include cutting down trees to make paper or mining sand to make glass for a glass bottle.



Raw materials of glass: sand, soda ash (sodium carbonate), limestone (calcium carbonate), yellow barium carbonate and brown iron oxide. The last two ingredients are added for color.

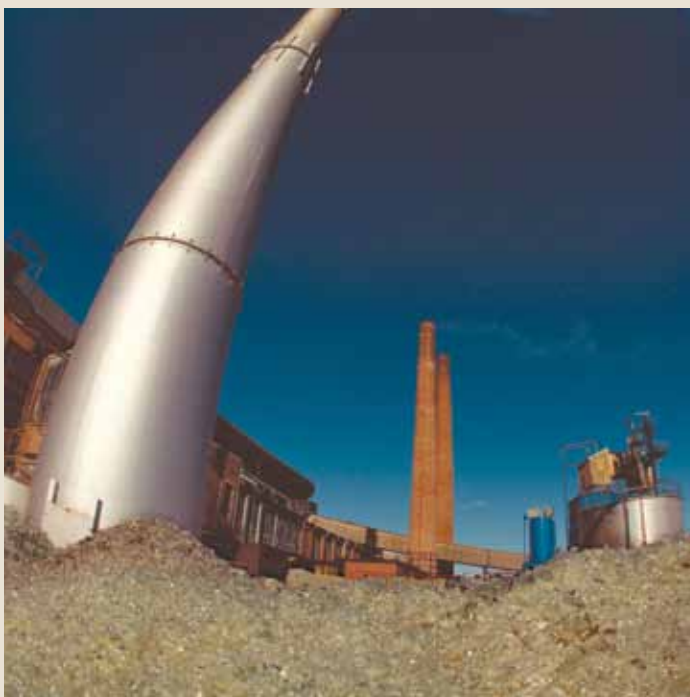
Glass is a mixture of three main raw materials: silica sand, soda ash, and limestone. Energy to mine, gather, or collect the raw materials are inputs of this stage. These materials are mined from earth’s surface. Recycling a product is one way to reduce the amount of new raw materials taken from the earth to produce new products.

MANUFACTURING: In the manufacturing stage a product or material is created. Raw materials and energy are inputs. To manufacture glass for a glass bottle the three main raw materials, silica sand, soda ash, and limestone, are heated to approximately 1500°C (2700°F) to make a liquid mixture. The molten mixture is then poured into a mold where it cools and becomes solid. Once cooled, the bottle is prepared for use. It is cleaned and, if necessary, a label is printed on it. Then it can be filled and used to hold a drink. The main product of this step is the glass bottle. Other products include the wastewater used to cool the glass, and other wastes that are a result of the manufacturing process.

2. Your teacher will show and explain a life-cycle diagram that summarizes the stages below.
3. Your teacher will assign you one of the remaining types of drink containers. With your partner, read about the life cycle for the type of container you are assigned. As you read, record information about the life cycle on Student Sheet 13.1, “Stages in the Life Cycle of a Product.”
4. Compare the information you have collected on your student sheet with that of the other pair in your group. If there are any differences in the information you have listed, consider adding new information to your sheet.

USEFUL LIFE: During its useful life, the product is used for its intended purpose, or, perhaps, an unintended purpose. Products that are designed from more durable materials will have a longer useful life, reducing the overall energy and resources needed to replace them.

END OF LIFE: When a product is no longer useful, it is in its end-of-life stage. This is when it is thrown away. There are several end-of-life options for glass bottles. One is to sort discarded glass by color and clean and crush each color of glass separately since each is made by adding slightly different material when the glass is made. The different pieces of glass can then be melted and reused to manufacture other glass products of the same color, such as brown jars or green bottles. An advantage of recycling glass is that manufactured glass melts at a lower temperature than the raw



A pile of broken glass sitting by the smoke-stack of a recycling plant.

materials. This can save energy in the next round of manufacturing.

Finding ways to reuse a product extends its life and can reduce the need to make more products.

5. With your group, create a diagram of the life cycle for the drink container you were assigned. The purpose of your diagram is to show the connection between the stages of the life cycle. Decide the best way to illustrate this, and then make the life-cycle diagram on a piece of chart paper. Be sure to include the information you collected on Student Sheet 13.1, "Stages in the Life Cycle of a Product," on your life-cycle diagram.

The Life Cycle of an Aluminum Can

RAW MATERIALS: Pure aluminum metal does not occur on the earth's surface. However, compounds that include aluminum are abundant. Aluminum-containing compounds are most easily mined from the earth's surface in a type of rock called bauxite.

Bauxite is ground up and mixed with a hot solution of sodium phosphate. This reaction changes the minerals chemically. Next they are exposed to an electrical current, which chemically changes the compounds into liquid aluminum metal. When the liquid is cooled it is molded into bars of solid aluminum. The process to this point is expensive and uses a large amount of energy. By the early 1900s, manufacturers realized that it is much cheaper to use recycled aluminum than to extract and process aluminum from bauxite.

MANUFACTURING: To produce aluminum cans, aluminum bars are transported to factories. There they are flattened and rolled into thin sheets. The sheets are pressed into cans.

USEFUL LIFE: The useful life of an aluminum can starts when it is labeled, filled and sealed, and shipped to a store.

END OF LIFE: Once it is empty, the can is no longer useful, and the end-of-life stage begins. It might be recycled or tossed into a trash can to end up in a landfill. If recycled, the metal is crushed and melted to produce sheets of aluminum that can be used for new cans.

(Right) Aluminum is isolated from bauxite, an ore shown in this photograph.

(Far right) An aluminum can factory where sheets of metal are cut and formed into cans.



The Life Cycle of a Plastic Bottle

RAW MATERIALS: Plastics are commonly made of hydrogen and carbon compounds called hydrocarbons. Petroleum and crude oil are the raw materials most frequently used to produce them. Oil or gas is pumped from the ground and transported to a processing factory.

Before oil can be used it is heated to temperatures greater than 980°C (1800°F). This heating causes large molecules in the oil to break apart chemically or “crack” into smaller molecules. Specific types of these smaller molecules are combined with other chemicals, including some for color. At this stage the plastic is a hot liquid. The liquid is cooled to form pellets of plastic, each smaller than a marble.

Materials engineers are inventing ways to make plastics out of non-petroleum-based materials such as plant-derived materials. Drink containers may someday be made out of plant-based plastics.

MANUFACTURING: Next, machinery physically changes the pellets as it melts them and shapes them into plastic rods. The rods are placed into a mold and formed into bottles.




Once the bottles are filled, labeled, and packaged, they are shipped to stores to enter the useful-life portion of the life cycle.

END OF LIFE: When a plastic bottle has reached the end-of-life stage, one of several things occurs. The plastic may be put into a landfill where it will last for hundreds of years. Or, the plastic bottles can be recycled. If they are to be recycled, the bottles will be sorted (the number in the recycling symbol on the bottom of a bottle indicates its type of plastic). The sorted bottles are cleaned and shredded. The shreds can be reused, but only to make other products. For example, the plastic from water bottles can be recycled to make polar fleece materials for vests and jackets. It cannot be melted at a temperature that will allow it to be formed into new bottles. Other recycled plastics can be used to make detergent bottles, storm drains, paintbrushes, and even carpet fibers. Another end-of-life option is to reuse containers to hold things such as coins, or cooking supplies like flour and sugar. Reusing containers reduces the need for new plastic materials.

(Right) Pellets can be made in any color. (Far right) The bottle on the right was molded from one of the rods shown in the pile.



ANALYSIS

1. For the drink container you were assigned:
 - a. What are its raw materials?
 - b. Does the product have more than one end-of-life option? Explain.
2.  Use your life-cycle diagram to explain what would happen to all of the other stages in the life cycle of the drink container if:
 - a. the demand for the drink container increases.
 - b. the raw materials used to make the product run out.
 - c. materials engineers design a way to manufacture the container with less waste produced.
3.  Explain why or why not a life-cycle diagram would be a useful tool for:
 - a. the director of a drink company who wants to choose a container for a new drink.
 - b. a materials scientist working to reduce the negative impact a drink container has on the environment.
 - c. a person buying a bottle of sports drink in a store.
4.  Look at the life cycle of a product shown on Student Sheet 13.1, “Stages in the Life Cycle of a Product.” Using the “Green Chemistry Guidelines” on Student Sheet 13.2, make a list of ways to reduce the negative environmental impact of this product.
5. **Reflection:** Based on what you’ve learned in this activity, do you think that the life cycle of a product should be included on the label? Explain.

Compacted bottles are ready for shredding, the next step in the plastic recycling process.





EXTENSION

Where do the raw materials come from to make products used in everyday life, such as CDs and plastic bags? What are the life cycles of these products? How many life-cycle stages does a cell phone have? Go to the *Issues and Physical Science* page of SEPUP website for links to the life cycles of different products. Use these and other Internet resources and books to find out about the life cycle of products. Then make a list of the ways to reduce the environmental harm that these products might cause.

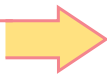
14 Physical and Chemical Properties of Materials



In the last activity, you compared glass, plastic, and aluminum—three materials that can be used to make drink containers. When designing a product, materials engineers consider the properties of materials to determine which is best to use. These properties can be grouped into two categories—physical and chemical. A **physical property** is one that you can identify without seeing if the material reacts with another substance. Examples of physical properties are color, hardness, and density. A **chemical property** describes how a material **reacts** with another substance, such as an acid or oxygen.

In this activity, you will test the physical and chemical properties of a variety of materials. You will then use this information to consider how those materials could best be used to make products.

CHALLENGE



How do the properties of materials determine their uses?

Steel can be formed into many shapes, and is very durable. This makes it ideal for external building supports and stainless steel medical equipment.



MATERIALS



For each group of four students

- 1 9-oz. plastic cup
- 1 stir stick
- 1 glass scratch plate
- 1 battery harness and light bulb
- 1 9-volt battery
- 1 dropper bottle of 1M hydrochloric acid
- 1 strip each of:
 - aluminum
 - copper
 - iron
 - formica plastic
 - polystyrene plastic
- 1 piece of ceramic tile
- 1 piece of wood
- 1 glass rod
- 1 piece of granite
- 1 piece of limestone
- 1 small carbon rod
- water
- paper towels



For each student

- 1 pair of safety goggles



SAFETY

Wear safety eyewear. If a material does not bend easily, do not use more force because you could break or tear it. Watch out for sharp edges.

PROCEDURE



1. Review how to test the properties of materials by examining the table, “Testing Physical and Chemical Properties,” on the next page.
2. You will test the properties of 11 materials. Make a data table in your science notebook to record your observations.
3. Put the materials you have tested into groups based on their properties. Each group must have one, two, or more properties in common. Record your groupings in your science notebook.

Activity 14 • Physical and Chemical Properties of Materials

PHYSICAL PROPERTIES		
Properties	Procedure	Interpreting Test Results
Color	<ol style="list-style-type: none"> 1. Observe the object material. 2. Record its color. 	Describe your observations in detail.
Light transmission	<ol style="list-style-type: none"> 1. Hold the material above some printed material, such as the facing page. 2. Observe and record whether you can: <ul style="list-style-type: none"> • see print clearly through the material. • see the print, but it is blurry. • not see the print. 	<p>It is TRANSPARENT if you can see through it clearly.</p> <p>It is TRANSLUCENT if the print is blurry.</p> <p>It is OPAQUE if you cannot see through it at all.</p>
Luster	<ol style="list-style-type: none"> 1. Hold the material near a good source of light. 2. Observe how well light reflects off your material. 3. Record whether it is very shiny, somewhat shiny, or not shiny. 	<p>It is BRILLIANT if it reflects a lot of light and is very shiny.</p> <p>It is GLASSY if it reflects some light and is somewhat shiny.</p> <p>It is DULL if it does not reflect any light and is not shiny.</p>
Texture	<ol style="list-style-type: none"> 1. Feel the material. 2. Record how it feels. 	Describe your observations in detail. Words like <i>smooth</i> , <i>rough</i> , <i>grainy</i> , and others can be used to describe the texture of a material.
Flexibility	<ol style="list-style-type: none"> 1. Try to bend the material gently. 2. Record how easily it bends. 	<p>If it does not bend, it is NOT FLEXIBLE.</p> <p>If it bends slightly, it is SOMEWHAT FLEXIBLE.</p> <p>If it bends easily, it is VERY FLEXIBLE.</p>
Hardness relative to glass	<ol style="list-style-type: none"> 1. Gently press the material across the surface of a glass scratch plate. 2. If a mark appears, see if you can rub it away. 3. Record your observations. 	<p>If a scratch appears that is not easily rubbed away, the material is HARDER THAN GLASS.</p> <p>If no scratch appears, or if the scratch is easily rubbed away, the material is SOFTER THAN GLASS.</p>

PHYSICAL PROPERTIES (continued)		
Properties	Procedure	Interpreting Test Results
Electrical conductivity	<ol style="list-style-type: none"> 1. Attach the bulb and battery assembly to opposite ends of the object. 2. Record whether the lightbulb lights. 3. Immediately disconnect the battery harness. 	<p>If the bulb does not light, the material does NOT CONDUCT electricity.</p> <p>If the bulb lights, the material CONDUCTS electricity.</p>
Density relative to water	<ol style="list-style-type: none"> 1. Fill the plastic cup half full of water, and place the material in the cup. 2. Check to see if the material sinks or floats. With your stir stick, push under-water any material that floats, and see if it returns to the surface. 3. As soon as you have recorded results, remove and dry the material. 	<p>If it floats, it is LESS DENSE than water.</p> <p>If it sinks, it is MORE DENSE than water.</p>
CHEMICAL PROPERTY		
Properties	Procedure	Interpreting Test Results
Reaction to hydrochloric acid	<ol style="list-style-type: none"> 1. Place 2–3 drops of 1 M hydrochloric acid (HCl) on each material. 2. Observe and record the results. 3. As soon as you have recorded results, rinse the material in water and dry it. 	<p>If the material does not bubble or change in any way, it DOES NOT REACT with hydrochloric acid.</p> <p>If the material bubbles or changes in any way, it REACTS with the hydrochloric acid.</p>

ANALYSIS

1. Were your groupings the same as those of the other students? If they were different, explain how.
2.  Should the shape of an object be considered a property of the material? Explain.
3.  In this activity, you recorded the color of each material. Think of and explain two cases in which color does not help identify a material.

Activity 14 • Physical and Chemical Properties of Materials

4. In your science notebook, make a copy of the table, “Selecting Materials for Products,” shown below. For each product listed in the first column, complete the table by listing one material you tested that would work well and one that would *not* work well. Explain your reasons for each choice in the appropriate column.

Selecting Materials for Products					
Use of Material	Materials that would work well	Reasons	Materials that would NOT work well	Reasons	
Electrical wire					
Garden statue					
Toy boat					
Tabletop					
Inexpensive container for an acid, such as vinegar					

15 Families of Elements



In the last activity, you grouped selected materials based on their properties. Some of those materials were elements, while others were made of combinations of elements. An **element** is a substance that cannot be broken down into simpler substances by heating it or causing it to react with other chemicals.

Did you know that there are only 90 naturally occurring elements in our world, and scientists have made about 25 more elements in laboratories? That may seem like a lot, but think of it this way: everything—yes, everything—around you is made from one or more of these elements. In this activity you will investigate 14 of the 90 naturally occurring elements and think of ways to group them based on their chemical and physical properties.



How can elements be grouped based on their physical and chemical properties?



Samples of elements. Clockwise from upper center, they are chlorine (Cl), sulfur (S), mercury (Hg), copper (Cu), and silicon (Si).

MATERIALS



For each group of four students




- 1 set of 14 Element Cards
- 4 half-sheets of paper of various colors

PROCEDURE

1. With your group, spread the Element Cards out on a table. Each card provides the following information about an element:
 - Element symbol
 - Element name
 - Whether the element is a metal or nonmetal
 - Whether the element is solid, liquid, or gas at room temperature
 - Color
 - Atomic mass: the mass of the smallest particle (an atom) of the element
 - Reactivity: how likely the element is to react chemically with other elements
 - Number of bonds to hydrogen: the number of hydrogen atoms that usually combine chemically with this element when they react
2. Examine the information on each card carefully, noting similarities and differences among the elements.
3. Working together, sort the elements into at least three groups. Each group should have at least two similar properties. Agree on a classification system. As you work remember to:
 - Listen to and consider the explanations and ideas of your group.
 - If you disagree with other members of your group, explain why you disagree.
4. In your science notebook, list the groups you made and the common features of each. Be sure to record all the elements in each group.
5. Present your classification system to the class. As you look at other students' systems, observe similarities and differences between theirs and yours. Discuss your observations with your group.
6. Your group will receive four Element Family Cards. Each card describes a group of elements called a **family**. Based on the information on the Family Cards, place each element under a card.

7. Arrange the elements in each family in order from lowest atomic mass at the top to highest atomic mass at the bottom. Place the column on a half-sheet of paper.
8. Line up the four columns of elements to form a table, so that the elements are in columns and rows. Use the atomic masses of the elements to decide on an order for the holders.
9. In your notebook, record your new classification system, complete with:
 - family names
 - similar properties within each family
 - elements in each family in order of increasing atomic mass

ANALYSIS

1. Which of the properties listed on the Element Cards are:
 - a. physical properties?
 - b. chemical properties?
-  2. How did your first classification system compare to the second classification with the Element Family Cards?
-  3. In what ways could grouping elements help scientists understand their properties?
4. Use the table of elements you constructed to find the family or families of elements that are:
 - a. not usually reactive.
 - b. highly reactive.
 - c. all metals.
 - d. all solids.
 - e. all gases.
-  5. The element strontium (Sr) is below calcium (Ca) in Column 2 on the periodic table. Design an Element Card that shows the properties you predict for strontium.



EXTENSION

Visit the *Issues and Physical Science* page of the SEPUP website for:

- links to different versions of the periodic table.
- the latest update on the number of elements.

16 Elements and the Periodic Table



Materials—both natural and human made—have unique properties. Some are made of one type of element, and some are made of combinations of elements. But what are elements made of, and how do they differ from each other?

Each element is made of tiny particles called **atoms**. A pure sample of an element contains many atoms of the same type. For example, the millions of iron atoms that make up a piece of iron metal are of the same type and have the characteristics of iron. Iron atoms, however, are very different from atoms of other elements, such as gold or oxygen. The properties of each element depend on its atoms.

Some elements are rarely found in a pure form. They tend to combine chemically, or **react**, with other elements. Scientists say that these elements are **reactive**. When elements react, they can form substances called **compounds**.



What are elements, and how do they relate to compounds?



Think of the world around you. Everything—from the air you breathe to the shoes you walk in—is made from elements or combinations of elements.

MATERIALS



For each student

- 1 Student Sheet 16.1, “Periodic Table of the Elements”

READING

Discovering Elements

When reading, answer the Stopping to Think questions in your mind. They can help you find out whether you understand the main ideas.



Laboratory investigations in the 1700s similar to those shown in this illustration led to discoveries about the properties of elements.

The idea that everything on the earth is made of a basic set of elements began with the ancient Greeks more than 2,000 years ago. Greek philosophers thought that fire, earth, air, and water combined to make everything in the world.

Starting in the 1600s, early chemists realized that fire, earth, air, and water were not the basic building blocks of matter. They looked instead for substances that they could not break down into simpler substances. These substances are known today as the elements.

Some of the earliest known elements were carbon, gold, silver, copper, sulfur, tin, lead, mercury, and iron—all of them elements that occur in nature. Until the 1700s, very few new elements were discovered. But in the mid 1700s through the 1800s, chemists learned how to create chemical reactions and physical ways to separate pure elements. With these new techniques, they found dozens more elements. By 1869, approximately 63 elements were known. These included hydrogen, nitrogen, oxygen, sodium, and aluminum.

STOPPING TO THINK 1

In what way were the ancient Greek philosophers right about elements?

In what way were the ancient Greek philosophers wrong?

Mendeleev and the Periodic Table of the Elements

In 1869 the Russian scientist Dmitri Mendeleev (men-deh-LAY-eff) developed the ideas that led to the modern periodic table. Other scientists had some similar ideas, but Mendeleev made the most progress and published the first version of a table of the 63 elements known at the time.

Mendeleev collected information on the properties of those 63 elements and grouped them in a way similar to what you did in Activity 15, “Families



THE PERIODICITY OF THE ELEMENTS

The Elements	Their Properties in the Free State			The Composition of the Hydrates and (approximate) Combinations	Specific and Atomic Weights	The Composition of the Oxides		The Properties of the Oxides		Special Periodic Tables
	ρ	α	β			H A	H A	ρ	α	
Hydrogen	0.0898	0	0	1	1	1	1	1	1	1
Lithium	0.534	0	0	7	7	7	7	7	7	7
Beryllium	1.848	0	0	9	9	9	9	9	9	9
Boron	2.47	0	0	10	10	10	10	10	10	10
Carbon	2.26	0	0	12	12	12	12	12	12	12
Nitrogen	1.2506	0	0	14	14	14	14	14	14	14
Oxygen	1.429	0	0	16	16	16	16	16	16	16
Fluorine	1.696	0	0	19	19	19	19	19	19	19
Sodium	0.971	0	0	23	23	23	23	23	23	23
Magnesium	1.738	0	0	24	24	24	24	24	24	24
Aluminum	2.70	0	0	27	27	27	27	27	27	27
Silicon	2.329	0	0	28	28	28	28	28	28	28
Phosphorus	1.82	0	0	31	31	31	31	31	31	31
Sulfur	2.071	0	0	32	32	32	32	32	32	32
Chlorine	1.56	0	0	35.5	35.5	35.5	35.5	35.5	35.5	35.5
Potassium	0.86	0	0	39	39	39	39	39	39	39
Calcium	1.55	0	0	40	40	40	40	40	40	40
Scandium	1.45	0	0	44	44	44	44	44	44	44
Titanium	4.54	0	0	48	48	48	48	48	48	48
Vanadium	6.0	0	0	51	51	51	51	51	51	51
Chromium	7.19	0	0	52	52	52	52	52	52	52
Manganese	7.47	0	0	55	55	55	55	55	55	55
Iron	7.874	0	0	56	56	56	56	56	56	56
Cobalt	8.9	0	0	59	59	59	59	59	59	59
Nickel	8.908	0	0	58.7	58.7	58.7	58.7	58.7	58.7	58.7
Copper	8.96	0	0	63.5	63.5	63.5	63.5	63.5	63.5	63.5
Zinc	7.14	0	0	65.4	65.4	65.4	65.4	65.4	65.4	65.4
Gallium	5.907	0	0	69.7	69.7	69.7	69.7	69.7	69.7	69.7
Arsenic	5.727	0	0	74.9	74.9	74.9	74.9	74.9	74.9	74.9
Selenium	4.81	0	0	78.96	78.96	78.96	78.96	78.96	78.96	78.96
Bromine	3.12	0	0	79.9	79.9	79.9	79.9	79.9	79.9	79.9
Iodine	4.93	0	0	126.9	126.9	126.9	126.9	126.9	126.9	126.9
Barium	3.5	0	0	137.3	137.3	137.3	137.3	137.3	137.3	137.3
Strontium	2.54	0	0	87.62	87.62	87.62	87.62	87.62	87.62	87.62
Yttrium	4.47	0	0	88.91	88.91	88.91	88.91	88.91	88.91	88.91
Zirconium	6.49	0	0	91.22	91.22	91.22	91.22	91.22	91.22	91.22
Niobium	8.57	0	0	92.91	92.91	92.91	92.91	92.91	92.91	92.91
Molybdenum	10.22	0	0	95.94	95.94	95.94	95.94	95.94	95.94	95.94
Ruthenium	12.41	0	0	101.07	101.07	101.07	101.07	101.07	101.07	101.07
Rhodium	12.41	0	0	102.91	102.91	102.91	102.91	102.91	102.91	102.91
Palladium	12.02	0	0	106.37	106.37	106.37	106.37	106.37	106.37	106.37
Silver	10.49	0	0	107.87	107.87	107.87	107.87	107.87	107.87	107.87
Cadmium	8.65	0	0	112.41	112.41	112.41	112.41	112.41	112.41	112.41
Indium	7.31	0	0	114.82	114.82	114.82	114.82	114.82	114.82	114.82
Tin	7.28	0	0	118.71	118.71	118.71	118.71	118.71	118.71	118.71
Antimony	6.69	0	0	121.75	121.75	121.75	121.75	121.75	121.75	121.75
Tellurium	5.24	0	0	127.6	127.6	127.6	127.6	127.6	127.6	127.6
Iodine	4.93	0	0	126.9	126.9	126.9	126.9	126.9	126.9	126.9
Cesium	1.93	0	0	132.91	132.91	132.91	132.91	132.91	132.91	132.91
Barium	3.5	0	0	137.3	137.3	137.3	137.3	137.3	137.3	137.3
Lanthanum	9.38	0	0	138.91	138.91	138.91	138.91	138.91	138.91	138.91
Cerium	9.84	0	0	140.12	140.12	140.12	140.12	140.12	140.12	140.12
Praseodymium	9.52	0	0	140.91	140.91	140.91	140.91	140.91	140.91	140.91
Thorium	11.7	0	0	232.04	232.04	232.04	232.04	232.04	232.04	232.04
Protactinium	15.37	0	0	231.04	231.04	231.04	231.04	231.04	231.04	231.04
Uranium	19.05	0	0	238.03	238.03	238.03	238.03	238.03	238.03	238.03

Photo (left) of Russian chemist Dmitri Ivanovich Mendeleev (1834–1907) and a table (right) he developed based on the properties of elements. This reference was translated into English in 1891.

of Elements.” He used data that many other scientists had collected about the properties of each of the elements. When he arranged the elements according to their atomic masses and their physical and chemical properties, he noticed that there was a repeating—or periodic—pattern. For example, as the atomic mass increased from lithium to fluorine, the elements in between changed from metals to nonmetals and from solids to gases. He saw a similar pattern repeated from sodium to chlorine and again from potassium to bromine. Mendeleev predicted that there were more elements that would fit into gaps in his chart, the first version of what came to be known as a periodic table. He even used the patterns in the table to predict the properties of new elements.

Other scientists used Mendeleev’s ideas and built on them to identify the elements he predicted. Later scientists found many more elements that follow the patterns he found. The modern version of the table is called the **Periodic Table of the Elements**. Based on new data about the elements, scientists around the world have agreed on some changes to the arrangement of the table.

STOPPING TO THINK 2

How did Mendeleev build on other scientists' work?

How did other scientists build on Mendeleev's work?

The Modern Periodic Table

Atomic number	6
	C
	carbon
Atomic mass	12.01

Today, there are more than 115 identified elements, and everything on earth is made of these elements. Look at the current periodic table shown below. Each element is represented by a symbol that includes either one uppercase letter, such as C for carbon, or an uppercase and a lowercase letter, such as Ca for calcium or Cu for copper. Each element shows an **atomic number** that corresponds to its order in the periodic table and an atomic mass, as shown in the example of the element carbon to the left.

Periodic Table of the Elements

SHADING KEY

A solid at room temperature

L liquid at room temperature

G gas at room temperature

1																	18
1 H hydrogen 1.008																	2 He helium 4.003
3 Li lithium 6.941	4 Be beryllium 9.012											5 B boron 10.81	6 C carbon 12.01	7 N nitrogen 14.01	8 O oxygen 16.00	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium 24.31											13 Al aluminum 26.98	14 Si silicon 28.09	15 P phosphorus 30.97	16 S sulfur 32.07	17 Cl chlorine 35.45	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.87	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.39	31 Ga gallium 69.72	32 Ge germanium 72.64	33 As arsenic 74.92	34 Se selenium 78.96	35 Br bromine 79.90	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.94	43 Tc technetium (98)	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs cesium 132.9	56 Ba barium 137.3	71 Lu lutetium 175.0	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium (209)	85 At astatine (210)	86 Rn radon (222)
87 Fr francium (223)	88 Ra radium (226)	103 Lr lawrencium (262)	104 Rf rutherfordium (267)	105 Db dubnium (268)	106 Sg seaborgium (271)	107 Bh bohrium (272)	108 Hs hassium (277)	109 Mt meitnerium (276)	110 Ds darmstadtium (281)	111 Rg roentgenium (280)	112 Cn copernicium (285)	113 Uut ununtrium (284)	114 Uuq ununquadium (289)	115 Uup ununpentium (288)	116 Uuh ununhexium (293)	117 Uus ununseptium ()	118 Uuo ununoctium (294)
Lanthanides		57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium (145)	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.0		
Actinides		89 Ac actinium (227)	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium (237)	94 Pu plutonium (244)	95 Am americium (243)	96 Cm curium (247)	97 Bk berkelium (247)	98 Cf californium (251)	99 Es einsteinium (252)	100 Fm fermium (257)	101 Md mendelevium (258)	102 No nobelium (259)		

From the periodic table you can find out a lot about an element. For example, if you look at the element cesium (atomic number 55) on the periodic table shown on the next page, you will see that it is in the alkali metal column. From this you can assume that cesium is a highly reactive, soft metal. On this periodic table, you can also tell if an element is a metal or nonmetal, because a dark “stepped line” divides the table into metals to the left of the stepped line and nonmetals to its right.

Most of the elements that border the stepped line between metals and nonmetals are called metalloids. Metalloids have chemical and physical properties intermediate between those of metals and nonmetals. Aluminum is not classified as a metalloid because it has metallic properties. Metalloids are often called semiconductors because they conduct electricity better than nonmetals but not as well as metals. Semiconductors, especially silicon, are essential components of electronic products.

STOPPING TO THINK 3

Use the Periodic Table of the Elements on the next page to decide whether each of the following is a metal or a nonmetal: lithium (Li), carbon (C), sulfur (S), calcium (Ca), titanium (Ti), and bromine (Br).

Most elements are solid at room temperature. The 11 elements that are gases tend to appear on the right and near the top of the periodic table. Their symbols are white. There are two elements that are liquid at room temperature—mercury and bromine. Their symbols are shaded in gray. You might also notice that one of the newer synthesized elements, 112, is a liquid. This is interesting to note because it falls below the element mercury (atomic number 80), which is a liquid at room temperature.

You can also predict the chemical reactivity of an element based on its position in the periodic table. The **reactivity** of an element describes how likely it is to **react**, or combine, with other elements. An element that is very likely to react with other elements is described as highly **reactive**. This means that they will react with many other substances. The least reactive elements are the noble gases to the right. The most reactive metals are in the two columns to the far left of the periodic table. The most reactive nonmetals are in the halogen family in column 17.

Periodic Table of the Elements

18

1

		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18																													
1	H hydrogen 1.008	2	He helium 4.003	3	Li lithium 6.941	4	Be beryllium 9.012	5	B boron 10.81	6	C carbon 12.01	7	N nitrogen 14.01	8	O oxygen 16.00	9	F fluorine 19.00	10	Ne neon 20.18	11	Na sodium 22.99	12	Mg magnesium 24.31	13	Al aluminum 26.98	14	Si silicon 28.09	15	P phosphorus 30.97	16	S sulfur 32.07	17	Cl chlorine 35.45	18	Ar argon 39.95																												
19	K potassium 39.10	20	Ca calcium 40.08	21	Sc scandium 44.96	22	Ti titanium 47.87	23	V vanadium 50.94	24	Cr chromium 52.00	25	Mn manganese 54.94	26	Fe iron 55.85	27	Co cobalt 58.93	28	Ni nickel 58.69	29	Cu copper 63.55	30	Zn zinc 65.39	31	Ga gallium 69.72	32	Ge germanium 72.64	33	As arsenic 74.92	34	Se selenium 78.96	35	Br bromine 79.90	36	Kr krypton 83.80																												
37	Rb rubidium 85.47	38	Sr strontium 87.62	39	Y yttrium 88.91	40	Zr zirconium 91.22	41	Nb niobium 92.91	42	Mo molybdenum 95.94	43	Tc technetium (98)	44	Ru ruthenium 101.1	45	Rh rhodium 102.9	46	Pd palladium 106.4	47	Ag silver 107.9	48	Cd cadmium 112.4	49	In indium 114.8	50	Sn tin 118.7	51	Sb antimony 121.8	52	Te tellurium 127.6	53	I iodine 126.9	54	Xe xenon 131.3																												
55	Cs cesium 132.9	56	Ba barium 137.3	57	Lu lutetium 175.0	58	Ce cerium 140.1	59	Pr praseodymium 140.9	60	Nd neodymium 144.2	61	Pm promethium (145)	62	Sm samarium 150.4	63	Eu europium 152.0	64	Gd gadolinium 157.3	65	Tb terbium 158.9	66	Dy dysprosium 162.5	67	Ho holmium 164.9	68	Er erbium 167.3	69	Tm thulium 168.9	70	Yb ytterbium 173.0	71	La lanthanum 138.9	72	Ce cerium 140.1	73	Ta tantalum 180.9	74	W tungsten 183.8	75	Re rhenium 186.2	76	Os osmium 190.2	77	Ir iridium 192.2	78	Pt platinum 195.1	79	Au gold 197.0	80	Hg mercury 200.6	81	Tl thallium 204.4	82	Pb lead 207.2	83	Bi bismuth 209.0	84	Po polonium (209)	85	At astatine (210)	86	Rn radon (222)
87	Fr francium (223)	88	Ra radium (226)	89	Th thorium 232.0	90	Pa protactinium 231.0	91	U uranium 238.0	92	Np neptunium (237)	93	Pu plutonium (244)	94	Am americium (243)	95	Cm curium (247)	96	Bk berkelium (247)	97	Cf californium (251)	98	Es einsteinium (252)	99	Fm fermium (257)	100	Md mendelevium (258)	101	No nobelium (259)	102	Lr lawrencium (262)	103	Lr lawrencium (262)	104	Rf rutherfordium (267)	105	Db dubnium (268)	106	Sg seaborgium (271)	107	Bh bohrium (272)	108	Hs hassium (277)	109	Mt meitnerium (276)	110	Ds darmstadtium (281)	111	Rg roentgenium (280)	112	Cn copernicium (285)	113	Uut ununtrium (284)	114	Uuq ununquadium (289)	115	Uup ununpentium (288)	116	Uuh ununhexium (293)	117	Uus ununseptium ()	118	Uuo ununoctium (294)

COLOR KEY

Yellow	Non-metals	Light Green	Rare earth metals
Blue	Alkali metals	Purple	Other metals
Red	Alkaline earth metals	Orange	Halogens
Teal	Transition metals	Light Yellow	Noble gases

57	La lanthanum 138.9	58	Ce cerium 140.1	59	Pr praseodymium 140.9	60	Nd neodymium 144.2	61	Pm promethium (145)	62	Sm samarium 150.4	63	Eu europium 152.0	64	Gd gadolinium 157.3	65	Tb terbium 158.9	66	Dy dysprosium 162.5	67	Ho holmium 164.9	68	Er erbium 167.3	69	Tm thulium 168.9	70	Yb ytterbium 173.0
89	Ac actinium (227)	90	Th thorium 232.0	91	Pa protactinium 231.0	92	U uranium 238.0	93	Np neptunium (237)	94	Pu plutonium (244)	95	Am americium (243)	96	Cm curium (247)	97	Bk berkelium (247)	98	Cf californium (251)	99	Es einsteinium (252)	100	Fm fermium (257)	101	Md mendelevium (258)	102	No nobelium (259)

SHADING KEY

- A** solid at room temperature
- A** liquid at room temperature
- A** gas at room temperature

Lanthanides

Actinides

STOPPING TO THINK 4

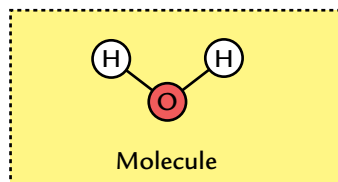
Find magnesium on the periodic table.

- What is magnesium's chemical symbol?
- What family does magnesium belong to?
- Is magnesium a solid, a liquid, or a gas?

Based on its family, would you expect magnesium to be very reactive, somewhat reactive, or not reactive at all?

Forming Compounds

Elements contain only one kind of atom. Other substances contain two or more types of atoms held together by chemical bonds. Bonds form when the atoms of one element are attracted to the atoms of one or more other elements. Substances with two or more types of atoms held together by bonds are called compounds. For example, the compound water forms when the elements hydrogen and oxygen react together. Sugars are chemical combinations of the elements carbon, hydrogen, and oxygen. Groups of differing atoms that are held together by chemical attraction are called **molecules**. The diagram below shows a water molecule, made of two hydrogen atoms and one oxygen atom.



Water molecule

There are more than 115 elements, and these elements can combine to form millions of compounds. To get an idea of how many, just look at a dictionary of the English language and think about how many words are formed from just 26 letters!

Compounds have different properties than the elements that form them. For example, the compound we call water is a liquid formed from two gases—hydrogen and oxygen. Table sugar is an edible white solid formed from a black solid (carbon) and the gases hydrogen and oxygen.

STOPPING TO THINK 5

What are two ways that compounds are different from the elements that form them?



Commonly referred to as salt, this naturally-occurring compound is sodium chloride, NaCl .

Chemical Names and Formulas

Scientists have created a system for naming compounds. These names often identify the elements that make up the compound. For example, the full chemical name for table salt is “sodium chloride.” This name tells you table salt contains sodium and chlorine. This is information about the compound that you would not have if you called it “table salt.” Notice that the ending of “chlorine” is changed to “-ide” in the name of the compound. A **chemical formula** is

a shorthand way to identify the kind and number of atoms that make up a compound. For example, the symbol for sodium is **Na**, and the symbol for chlorine is **Cl**. So you can write the formula for the compound sodium chloride like this: **NaCl**. This tells you that there is one chlorine atom for every sodium atom in sodium chloride.

Not all chemical formulas are as simple as **NaCl**. For instance, water is made up of the elements hydrogen (H) and oxygen (O), and its chemical formula is **H₂O**. (You say this “H-two-O.”) That is because each water molecule is made up of two hydrogen atoms bonded to one oxygen atom. The number “2” below and to the right of the “H” shows that there are two hydrogen atoms in a water molecule. When there is no number written below and to the right of the element symbol, then there is only one of that type of atom.

STOPPING TO THINK 6

The chemical formula for baking soda is **NaHCO₃**. What elements are in baking soda? How many of each kind of atom is represented by the formula for baking soda?

Ocean water is a mixture of compounds, including water (H_2O), salt (NaCl), and others.



Classifying Matter: Elements, Compounds, and Mixtures

Everything around you is an element, a compound, or a mixture of both. The oxygen in the air you breathe and the copper in pennies are examples of elements. The water you drink and the salt and sugars in the foods you eat are examples of compounds. So are the proteins, fats, and carbohydrates that make up the cells in your body. Everything that is not a pure element or compound is a mixture of elements, compounds, or both. Even air is a mixture of several elements and compounds, including the elements nitrogen and oxygen and the compounds carbon dioxide and water.

ANALYSIS



1. Make a copy of the table below in your science notebook. Use the Periodic Table of Elements to find out which atoms make up a molecule for each of the substances listed. The first row has been completed for you.

Chemical Formulas of Common Substances		
Substance	Chemical Formula	Atoms that make up the molecule
Water	H_2O	2 hydrogen atoms, 1 oxygen atom
Hydrogen peroxide	H_2O_2	
Carbon dioxide	CO_2	
Sucrose (table sugar)	$C_{12}H_{22}O_{11}$	
Alanine (an amino acid)	$C_3H_7O_2N$	
Oleic acid (a fat)	$C_{12}H_{24}O_2$	

2. Sodium is a metallic solid, and chlorine is a poisonous yellow-green gas. Sodium and chlorine react to form sodium chloride, which is common table salt.
 - a. Is table salt an element or a compound? Explain.
 - b. Describe the physical properties of table salt.
 - c. How do the properties of table salt compare with those of sodium and chlorine?
3. Is seawater an element, compound, or mixture? Explain your answer.
4. Explain the relationship between an atom and a molecule.



EXTENSION

Visit the *Issues and Physical Science* page of the SEPUP website for links to learn more about Dmitri Mendeleev's work and the work of other chemists.

17 Modeling Molecules



Most substances on earth are not pure elements made up of a single type of atom. “Energy connections” called **chemical bonds** can hold atoms together to form molecules. Molecules are composed of two or more atoms held together with chemical bonds. Atoms can combine with atoms of the same element, with atoms of another element, or even with atoms of several elements through chemical bonds. When the atoms of more than one element bond in specific, regular proportions they form a substance called a compound. Water, for example, is a compound because its molecules are made from atoms of hydrogen and oxygen in exact proportions. These proportions (2:1) are shown in its chemical formula, H_2O .

Compounds can be found everywhere. Many everyday materials—from wood to gasoline to aspirin—are made of compounds. In this activity, you will build molecules of several compounds.

CHALLENGE



How do atoms combine to form molecules?



The Atomium, a building modeled after the crystal structure of metal, was built in Brussels, Belgium for the 1958 World's Fair.

MATERIALS



For each pair of students

- 1 molecular model set containing:
- 32 white “atoms”
- 18 black “atoms”
- 14 red “atoms”
- 4 blue “atoms”
- 54 white “bonds”







For each student

- 1 Student Sheet 16.1, “Periodic Table of the Elements”

PROCEDURE

Part A: Making Simple Molecules

COLOR	ELEMENT	SYMBOL
	hydrogen	H
	carbon	C
	oxygen	O
	nitrogen	N

1. Build a model of a molecule of water with two hydrogen (white) atoms and one oxygen (red) atom. Use the white bonds (tubes) to make the connections that represent chemical bonds.
2. Follow your teacher’s directions to draw a diagram of this molecule in your science notebook.
3. What do you think is the name and chemical formula of this molecule? Record these on your diagram.
4. Pull the model apart.
5. Every time you make a molecule, all of the bonding sites (the “sticks” on the atom models) must be connected to the sites on another atom.
 - a. Using this rule, make two models: a molecule of hydrogen and carbon and a molecule of hydrogen and nitrogen.
 - b. Draw each molecule that you construct.
 - c. Record next to each drawing the chemical formula for the molecule.
6. Follow your teacher’s demonstration to construct a molecule using two oxygen atoms. Remember, all the bonding sites must be connected.
7. Construct two molecules: one using 2 hydrogen atoms and one using 2 nitrogen atoms.
8. Draw a diagram of each of the molecules you made for Steps 6 and 7.
9. Next to each diagram record the chemical formula for the molecule.
10. Take apart all of the models, and return all of the pieces to the set.

Part B : Making More Complex Molecules

11. Construct and draw at least four more molecules according to the following two rules:
 - Each molecule must contain between two and five atoms.
 - All the bonding sites (the protruding “sticks”) of an atom must be connected to those of another atom.
 After drawing each molecule, pull it apart before constructing the next.
12. Construct and draw two more molecules following only one rule:
 - All the bonding sites must be connected to those of another atom.
13. Take all the molecules apart, and return all the pieces to the set.
14. Compare your drawings with those of the other pair in your group.
15. Construct and draw a model of a molecule with the formula CO_2 .

ANALYSIS



1. How many different elements were you working with?
2. What was the role of the “sticks” on each atom model?
3. Was it possible for an atom to make more than one bond? Explain and give an example.
4. How many bonds could each of the following make with hydrogen?
Copy the table below into your science notebook. Use the atomic numbers to help you find the elements on the periodic table.

Bonds with Hydrogen			
Element	Atomic Number	Number of Bonds with Hydrogen	
Si	14		
Se	34		
I	53		
As	33		

5. If you had two oxygen atoms and one hydrogen atom, could you form a molecule? Explain.
6. Make a drawing to show the difference between an atom and a molecule.
7. Which model provides more information—a chemical formula or a sketch of the molecule?

18 Properties of Plastic



In Activity 12, “Evaluating Materials,” and Activity 13, “Product Life Cycle,” you compared plastic and glass bottles and aluminum cans to evaluate which was the best material for drinks. However, within these categories, there are more choices. For example, not all plastics are the same. Even plastics that look alike can have different properties and they can be used for different purposes.

You may have noticed that two plastic cubes can be the same size, shape, and color, but one is heavier. This could be because they are made of two types of plastic with different chemical and physical properties. Knowing the properties of plastics is helpful when deciding which plastic to use to manufacture a product.

CHALLENGE



How do the physical and chemical properties of plastics affect their uses?



Plastic is one of the most diverse synthetic materials in existence.

MATERIALS



For each group of four students

- 1 strip and 1 square of:
 - blue polypropylene (PP)
 - green polyvinyl chloride (PVC)
 - red high-density polyethylene (HDPE)
 - yellow polystyrene (PS)
- 1 vial of alcohol
- 1 vial of water
- 1 vial of alcohol-water mixture
- 1 vial of saltwater
- 1 paper clip
- 1 pair of plastic forceps



For each student

- 1 pair of safety goggles



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Investigating Plastics

1. Examine the four different types of plastic strips and squares. They have been coded by color so you can tell them apart. Your group will work together to determine the properties of each type of plastic.
2. Read the procedure for each test shown in the table, “Testing Properties of Plastics,” on the next page.
3. In your notebook, construct a data table “Properties of Plastics” to record the results of the tests. Be sure to add a column for the heat and acetone tests your teacher will conduct.
4. With your group, determine the properties of each of the four types of plastics using the tests in the table.

Testing Properties of Plastics	
Property	Test
Flexibility	<ol style="list-style-type: none"> 1. Gently bend the plastic strip back and forth. 2. Observe its flexibility (ability to bend). 3. Record your observations. <p>Hint: You may want to rank the relative flexibility of each plastic on a scale of 1–4, with 1 representing the least flexible.</p>
Crease color	<ol style="list-style-type: none"> 1. Gently bend the strip of plastic in half. 2. Observe the color of the crease that is produced. 3. Record your observations.
Hardness	<ol style="list-style-type: none"> 1. Using the end of a paper clip, gently try to draw a line in the plastic strip. 2. Record your results. <p>Hint: You may want to rank the relative hardness of each plastic on a scale of 1–4, with 1 representing the piece that was scratched the least.</p>
Density relative to alcohol	<ol style="list-style-type: none"> 1. Place a plastic square in the vial labeled “Alcohol,” cap it, and gently shake the vial. 2. Observe whether the plastic floats or sinks. 3. Use forceps to remove the piece from the vial.
Density relative to alcohol-water mixture	<ol style="list-style-type: none"> 1. Shake the vial labeled “Alcohol-Water” well to create an alcohol-water mixture. 2. Place a plastic square in the vial, cap it, and gently shake the vial. 3. Observe whether the plastic floats or sinks. 4. Use forceps to remove the piece from the vial.
Density relative to water	<ol style="list-style-type: none"> 1. Place a plastic square in the vial labeled “Water,” cap the vial, and shake it gently to wet the plastic. 2. Observe whether the plastic floats or sinks. 3. Use forceps to remove the piece from the vial.
Density relative to saltwater	<ol style="list-style-type: none"> 1. Gently shake the vial labeled “Saltwater” until no salt crystals are visible in the water. 2. Place a plastic square in the vial, cap the vial, and shake it gently to wet the plastic. 3. Observe whether the plastic floats or sinks. 4. Use forceps to remove the piece from the vial.

5. Record the results of the tests in your data table.
6. Your teacher will demonstrate the effects of acetone and heat on each of the four types of plastic. As your teacher performs the tests, record your observations in your data table.

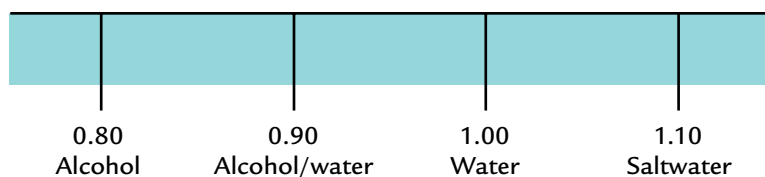
Part B: Identifying a “Mystery” Plastic

7. Your teacher will give you samples of an unknown plastic. With your group, decide which tests you will conduct to determine what type of plastic it is.
8. In your notebook, design a data table to record the results of your testing. Title the table “Properties of Different Plastics.”
9. Test the mystery plastic sample, and record the results in your data table.

ANALYSIS

1. Using evidence from your table, “Properties of Plastics,” identify the plastics which were scratched. How will this property affect their use?
2. Below is a scale showing the relative density of the four liquids you used to determine the density of the plastics.
 - a. Which plastic sample was the most dense? Explain your evidence.
 - b. Which plastic sample is the least dense? Explain your evidence.

Relative density



- c. In your science notebook, make a copy of the scale shown above. On it draw a labeled arrow that shows where each plastic falls on this scale of relative density.
3. What type of plastic is your mystery sample? Explain the evidence you used to come to this conclusion.



4. You are a materials scientist asked to recommend a type of plastic for manufacturing three products. Using the information in your table, “Properties of Plastics,” choose the best plastic for each of the following products. Be sure to include evidence from the activity in your answer.
- nail polish (high in acetone) container
 - dishwasher-safe food container
 - sports drink container

EXTENSION

Collect several different types of plastic products from home. Design your own investigation using the tests in this activity to determine the type of plastic the samples are made from. You may want to use additional tests or resources. Be sure to have your plan approved by your teacher before starting your investigation.

19 Creating New Materials



In the last activity, you observed that different types of plastics have specific properties. For example, the polyvinyl chloride (PVC) used to make food packaging softens and bends when exposed to heat or liquid acetone, but the high-density polyethylene (HDPE) used to make milk jugs does not. Their properties differ because they are made of different molecules. Materials engineers can use **chemical reactions** to create products with particular properties. A chemical reaction occurs when the atoms and molecules of two or more substances rearrange to form new substances.

In this activity you will mix two **reactants**, or inputs, which react chemically to create a new **product**, or output. Then you will compare the physical and chemical properties of the substances before and after they have reacted chemically.



How are reactants changed by a chemical reaction? How are the products different?



These materials scientists study the creation of new materials. The scientist above is preparing a material used to repair bones. The scientist on the right is testing a new form of bullet-proof glass to see if it meets safety requirements.



MATERIALS



For each group of four students

- 1 bottle of polyvinyl alcohol (PVA) solution
- 1 bottle of sodium borate solution



For each pair of students

- 4 white “hydrogen atoms”
- 2 black “carbon atoms”
- 1 red “oxygen atom”
- 7 white “bonds”
- 2 30-mL graduated cups
- 1 plastic spoon
- 1 stir stick
- paper towels
- warm soapy water



For each student

- 1 pair of safety goggles



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

1. In your science notebook, create a table to record your observations of the reactants before the reaction and the results after the reaction is completed.

Hint: Read through the entire procedure before making your table so you know what you will need to record.

2. Pour 10 mL of polyvinyl alcohol (PVA) into an empty 30-mL graduated cup. As you pour, be sure to observe the PVA and then record in your table its color, how well it pours, whether it can be stirred, and if it appears sticky.
3. Pour 2.5 mL of sodium borate into the other empty graduated cup. As you pour, be sure to observe its properties and record them in your table.

4. One partner should slowly add all of the sodium borate to the PVA while the other stirs constantly with the stir stick. Observe the changes, and keep stirring until nothing further happens. Record all changes that occurred as you stirred.
5. Observe the properties of the new substance that results. Record your observations in your data table.
6. Transfer your new product from the cup onto a paper towel using the spoon. Immediately wash the cups. Then investigate and describe additional properties, such as:

Stickiness: Does it stick to your hands? To the desk? To the paper towel?


Stretchiness: What happens when you pull it slowly? When you pull it quickly?

Bounciness: Try bouncing a small piece.



7. In your table summarize the properties of this new substance.
8. Follow your teacher's directions for cleanup.

ANALYSIS

1. How do the physical properties of the final product compare to the properties of:
 - a. polyvinyl alcohol (PVA), one of the reactants?
 - b. sodium borate, the second reactant, which you added to the PVA?
2. What evidence can you provide that a new substance formed?
3.  Plastics are a category of materials. Compare the plastics that you worked with in this activity to the properties of the plastics you tested in Activity 18, "Properties of Plastics." From these two investigations, what can you say about the properties of plastics?

20 Modeling Polymers



Plastics, including the substance you made in Activity 19, “Creating New Materials,” have different properties, but they all belong to a group of materials called polymers. **Polymers** are compounds made of thousands of repeating smaller molecules. The molecules that repeat in a polymer are called monomers. Notice their names. Monomer starts with the prefix *mono* which means “one” (in Greek). Polymer starts with the prefix *poly* meaning “many.” So, a polymer is made of many monomers.

In this activity you will construct paper-clip models to help you understand the properties of polymers. Scientists use models to help explain things we cannot see. But keep in mind that a scientific model, like the molecular model you have worked with, does not have to look like the real thing—it just has to act like it in one or more important ways.

CHALLENGE



How can you use models to represent changes that occur during a chemical reaction?

In what ways is this architectural model like the building it represents? In what ways does it differ?



MATERIALS



For each group of four students

- 1 wide-mouthed plastic bottle
- 48 silver paper clips
- 6 colored paper clips
- 2 clear plastic cups
- 1 plastic spoon



For each student

- 1 Student Sheet 20.2, "Polymers in Daily Life"

PROCEDURE

Part A: Examining a Monomer

1. In your science notebook, create a table to record how well a monomer, a polymer, and a cross-linked polymer can be poured, stirred, and pulled, as shown by the models you will make. Read through the entire procedure before constructing the table so you will know what you will need to record.
2. Work with your group to investigate the properties of the model monomers. Put 24 unconnected silver paper clips in the wide-mouthed bottle. Each paper clip represents one monomer.
3. Slowly pour the monomers from the bottle into the plastic cup. (If necessary, gently shake the bottle.) Repeat this two or three times. Describe how quickly the clips come out of the bottle. Record your observations in your data table.
4. Use the plastic spoon to stir the monomers in the cup. Record your observations.
5. Reach into the cup and pull out a single monomer. Record in your table your observations about pulling out the monomer.

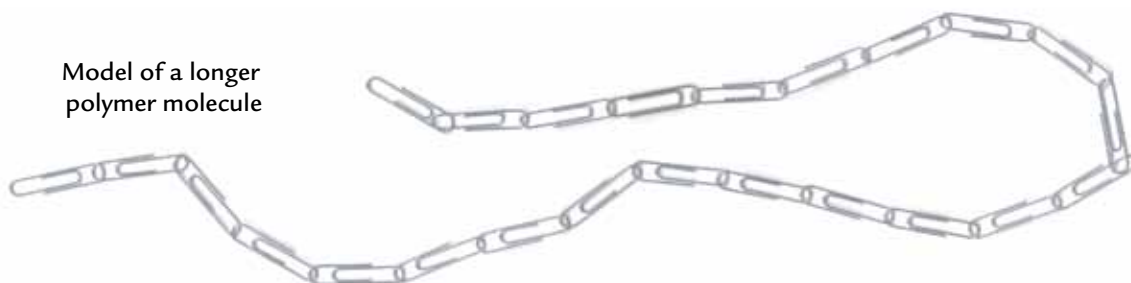
Part B: Forming a Polymer

6. Each member of your group will now link six paper clips from the remaining 24 clips into a straight chain, as shown in the diagram below. Each clip represents an individual monomer.



Model of a polymer

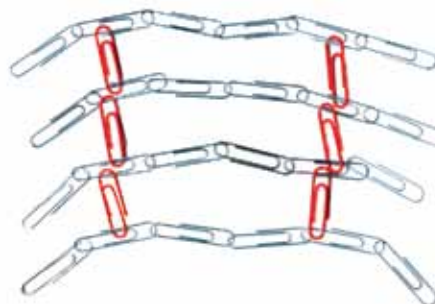
7. Link your four chains together to make one long chain of 24 paper clips. You have just made a model of a polymer like the polyvinyl alcohol (PVA) you used in Activity 19, "Designing New Materials." (You would need thousands of paper clip monomers to make a realistic paper clip polymer.)



8. Put your polymer in the wide-mouthed bottle. Leave one or two paper clips hanging out of the top. Now pour the polymer into a plastic cup two or three times. Record your observations.
9. Use the plastic spoon to stir the polymer in the cup. Record your observations.
10. Reach into the cup, and pull out a single paper clip. Record your observations.

Part C: Cross-Linking a Polymer

11. Separate the polymer back into four chains of six paper clips each. Each part represents individual polymer molecules. Place the chains in four parallel rows as shown in the diagram below.
12. Use two colored paper clips to connect, or cross-link, the first and second chain. Continue to do this with all four of the chains, as shown in the diagram below. You have just made a model of a cross-linked polymer, like cross-linked polyvinyl alcohol (PVA). You have constructed a model of a chemical reaction that chemically bonds polymers together into cross-linked polymers. The colored paper clips represent the sodium borate molecules that linked the polymer polyvinyl alcohol chains together in the chemical reaction in Activity 19, "Designing New Materials."



13. Test how well your cross-linked polymer can be stirred, pulled, and poured. Record your observations in your data table.
14. Separate all of the paper clips, and put the 24 silver paper clips back in the plastic cup.

ANALYSIS

1. Models provide ways to represent complex systems. In Activity 19, “Creating New Materials,” and this activity you made a total of three models of polymers. Analyze each of the models you built.
 - a. In your science notebook, make a table like the one below.
 - b. Fill in the table using observations from this activity.

Models of Polymers		
Type of Polymer Model	Strengths	Weaknesses
Paper clips linked together		
Classmates holding hands		
Class molecular model (in Activity 19)		

2. Compare the models you built in this activity:
 - a. Which was the most helpful when you analyzed the physical properties of a polymer?
 - b. Which was the most helpful when you analyzed the chemical reaction that occurred?
3. Using examples from this and Activity 19, “Designing New Materials,” explain the relationships between a monomer, a polymer, and a cross-linked polymer. Include a sketch to illustrate your explanation.
4. How does cross-linking affect the properties of a polymer?
5. All plastics are polymers. Based on what you observed with the models, what advantages do you think polymers have over monomers?

21 Polymer Parts



Can you imagine a world without plastics? Plastic soft drink containers, bags, pens, DVDs, and computer and television parts are just a few things made of plastics that would be different. For thousands of years, however, people lived without plastics. But today, materials scientists and engineers have created plastics to make everyday products that in the past were made from glass, metal, and wood. In this activity, you will read how a plastic, a synthetic polymer, is made through a chemical reaction.



What is the chemical structure of plastics?



Bakelite was the first synthetic plastic, invented by Belgian scientist Leo Baekeland in 1907. In the 1920s, the versatile Bakelite was manufactured to make all sorts of products from auditorium walls to radios.

MATERIALS



For each student

- 1 Student Sheet 21.1, “Three-Level Reading Guide: Polymer Parts”
- 1 Student Sheet 19.1, “Comparing Properties of Polymers”

READING

Use Student Sheet 21.1, “Three-Level Reading Guide: Polymer Parts,” to guide you as you complete the following reading.

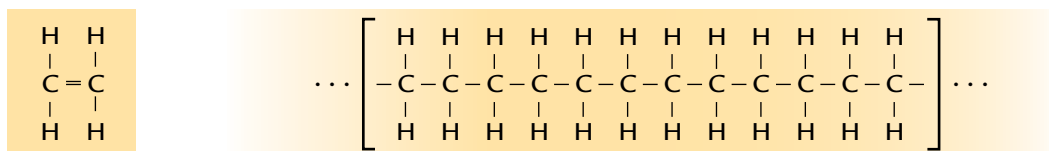
Plastics are Polymers

What makes plastics different from other materials such as glass and aluminum? The answer is found in the wide variety of plastic compounds that can be made from chains of carbon atoms. Scientists make new plastics by designing compounds with a wide variety of properties.

The majority of plastics used to make products are synthetic. This means that they are made in laboratories and factories, and do not exist in nature. The first plastic was developed in 1907. Some natural polymers include the cellulose that makes up wood and cotton, the protein that forms strands of human hair, and raw rubber that is collected from rubber trees.

Plastics are part of a larger category of compounds called polymers. A **polymer** is a substance made up of thousands of repeating small molecules. The prefix “poly-” means “many,” and the word “polymer” means “many parts.” The small molecules that repeat in a polymer are called monomers. The prefix “mono-” means “one,” and so a monomer is “one part.” You modeled the formation of a polymer from many monomers when you attached paper clips to make a long chain. Each paper clip represented the monomers that bond together to form a polymer. The long chain of paper clips represented the polymer.

Take polyethylene, for example. The plastic that was color-coded red in Activity 18, “Properties of Plastics,” was polyethylene. Polyethylene means “many ethylenes,” and it is a chain of ethylene molecules. The ethylene molecule is the monomer.



ethylene

- single molecule
- monomer

polyethelene

- thousands of the same molecule linked together
- polymer

Adding the prefix *poly-* to the name of a monomer forms the names of many synthetic polymers. Think about the other plastics you used in Activity 18: polystyrene—a chain of styrene molecules; polyvinyl chloride—a chain of vinyl chloride molecules; high-density polyethylene—a chemically bonded chain of ethylene molecules; and polypropylene—a chain of propylene molecules.

Synthetic plastics, like the four you investigated in Activity 18, have been in use for less than 100 years. However, people have been using natural polymers like wood, natural rubber, and wool for centuries.

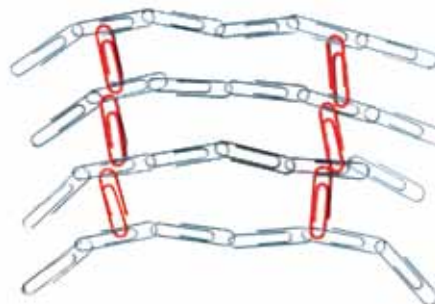
Investigating the Structure of Polymers

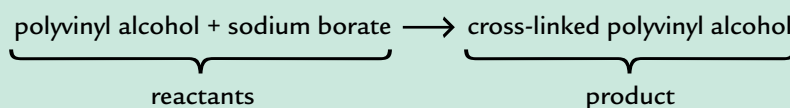


Herman Staudinger

Scientists began to investigate the atomic and molecule structure of natural polymers so they could learn how to make synthetic polymers. In 1920, the German chemist Herman Staudinger proposed that polymers were made of long chains of many small molecules. He thought that the length of the chain was related to the physical properties of the polymer. At the time, his ideas were considered radical, and many scientists did not take them seriously. But he continued to collect data that supported his ideas. From his work, and the work of other scientists, dozens of synthetic plastics were developed. Staudinger's research on the properties and structure of plastics was so important that he received the Nobel Prize in 1953.

Today, scientists know that changing the length of a polymer chain is not the only way to change its properties. Another way is to cross-link a polymer. You modeled this process in Activity 19, "Designing New Materials," when you mixed the polyvinyl alcohol with sodium borate. The sodium borate provided the cross-links. You also modeled cross-linking in Activity 20, "Modeling Polymers" when you cross-linked the paper clip chains with different-colored paper clips. Think about how the properties of polyvinyl alcohol and sodium borate were different from the properties of the cross-linked polymer.





Why does cross-linking a polymer change its properties? New chemical bonds form and change the structure of the molecules. The polyvinyl alcohol and sodium borate are reactants, and the result of their chemical reaction leads to the formation of a new product. The molecules and physical properties of the product are different than either of the reactants.

As Staudinger found, the number of cross-links is related to the physical properties of a cross-linked polymer, just as the length of the polymer chain was related to the physical properties of the polymer. If there are few cross-links, the cross-linked polymer has “memory.” After it is stretched, it “remembers” to return to its original shape, like a rubber band. If a plastic has more cross-links, the result is a harder substance that cannot be stretched and does not return to its original shape.

One problem with cross-linking is that it is often difficult to reverse. In fact, the more cross-links there are in a polymer, the harder it is to break down the polymer chemically. This means that cross-linked polymers are usually difficult to recycle.


A polymer that is commonly cross-linked to improve its uses is rubber. Natural rubber gets sticky in hot weather and brittle in cold weather, and it falls apart very easily. But when rubber is cross-linked, its properties change. Cross-linking rubber makes it more stable and elastic. Most of the rubber products in the world around you, from food containers to car tires, are made of cross-linked rubber. While this makes better products, a trade-off is that it causes disposal problems.



Cross-linked rubber is so stable that it does not degrade. This can make recycling cross-linked polymers difficult. However, there are ways to reuse the material. For example, old tires can be shredded and made into chips. These chips are used on playgrounds, running tracks, and in road construction. Scientists and engineers have also developed ways to use old tires as a source of energy.

It is estimated that two to three billion tires sit in landfills across the United States. Is this an environmental disaster or an opportunity to find new ways to deal with them?

ANALYSIS

1. What is the difference between a synthetic and a natural polymer? Give one example of each.
2. Why do two polymers, such as polystyrene and polyethylene, have different properties?
-  3. Explain why cross-linking a polymer like polyvinyl alcohol or rubber changes its properties. Include a diagram showing the relationships between a monomer, a polymer, and a cross-linked polymer.

22 Environmental Impact of Computers



In the beginning of this unit you considered materials used to make a single-material product, a drink container. But what about the materials that go into a more complex product—for example, a computer?

A computer contains many pieces that must be manufactured and put together. Think about all of the components—parts—in all of the computers in the world that make computers work. What raw materials are needed to make the components? How much waste is created? What impact does that waste have on our environment?

In this activity you will analyze the materials used and the amounts of waste produced to manufacture a computer.



What is the environmental impact of manufacturing a computer?

Manufacturing a computer requires assembling many parts, each made from unique materials.



MATERIALS



For each pair of students

- 1 set of colored pencils



For each student

- 1 sheet of graph paper or Student Sheet 22.1, “Pie-Chart Template”
- 1 Science Skills Student Sheet 3a and 3b, “Bar Graphing Checklist”

PROCEDURE

1. With your partner, read the information in Table 1, “Materials in a Desktop Computer,” below. Discuss the information in the table.

Table 1: Materials in a Desktop Computer
(weighing approximately 27 kg (60 lb))

	% of Total Weight	% Recyclable
Aluminum	14	80
Copper	7	90
Glass	24	0
Iron compounds	20	80
Lead	6	5
Plastic	25	20
Zinc	2	60
Other metals	2	—



2. With your partner read the information in Table 2, “Waste Products from Manufacturing Selected Computer Components,” below. Discuss the information in the table.

Table 2: Waste Products from Manufacturing Selected Computer Components

Component	Component Weight (kg)	Total Waste Produced during Manufacturing (kg)	Hazardous Waste Produced during Manufacturing (kg)
Computer chip	< 0.5	40	3
Circuit board	2	21	18
Monitor	20	1	0.9

3. With your partner decide which of you will construct a pie chart for the data in Table 1, and who will construct a bar graph for Table 2. You might want to try sketching ways to represent the information before constructing your final chart or graph. Be sure to label your work and give it a title.
4. Show your work to your partner. Together write down the conclusions that can be drawn from the information shown in the pie chart and the bar graph.

ANALYSIS

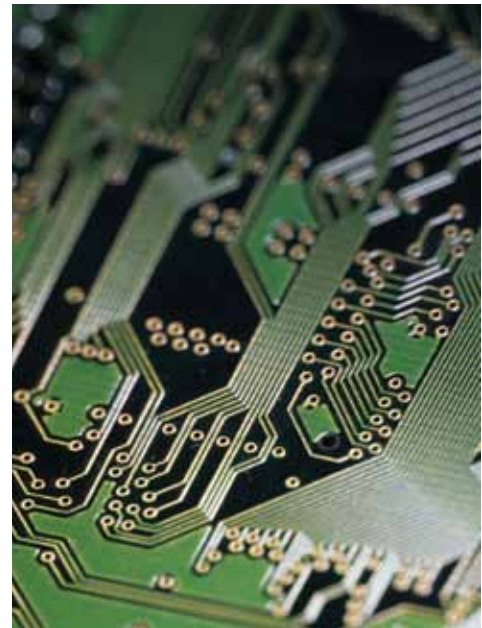
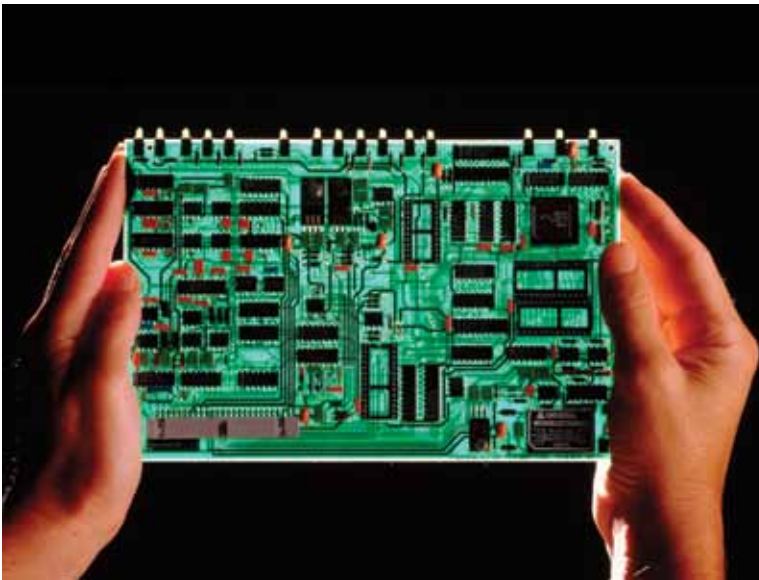
-  1. What are the top three materials by weight in a computer?
-  2. You are a materials scientist asked to present the information in Tables 1 and 2 to a group of computer manufacturers who want to reduce the effect of the computer life cycle on the environment. What information from your data would help them? Make a list of statements summarizing the information your graphs and charts show.
3. Based on your list from Analysis Question 2, what two statements do you think are the most important to discuss with the manufacturers? Explain why they are the most important.



As you saw in the last activity, a computer is made of many parts, each manufactured from one or more materials. One essential part of a computer, and of many other electronic devices, is a **circuit board**. It works like a wiring system to transfer electricity to each operating part of the computer. To do this a circuit board contains a network of copper paths. These paths conduct the flow of electricity within the computer. A chemical process called **etching** is used to create the copper paths on the circuit board. In this activity you will find out how this works by etching your own circuit board.



How is a computer circuit board produced?



The large circuit board (left) holds many smaller circuit boards, one of which is magnified on the right.

MATERIALS



For each group of four students

- 1 felt-tip permanent marker
- 1 piece of copper-coated plastic
- 1 piece of steel wool
- 1 pair of forceps
- 1 battery harness with light bulb
- 1 9-volt alkaline battery



For each pair of students

- 1 piece of paper



For each student

- 1 Student Sheet 23.1, “Three-Level Reading Guide: Etching Circuit Boards”



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Designing and Etching a Circuit Board

1. Listen carefully as your teacher describes how a circuit board works.
2. Outline the shape of the copper-coated plastic on a piece of paper.
3. Using a pencil, work with your partner to create a circuit board design. It should be a pattern that will conduct electricity from one end of the board to the other. Create a sketch of your design, making sure to use thick lines.
4. Share your design with your group. Decide which design will be etched on the piece of copper-coated plastic.
5. Select someone in your group to clean the surface of the copper-coated plastic piece by rubbing the copper-coated side with steel wool. Cleaning will remove surface dirt and other impurities that might interfere with the etching reaction. Once you clean it, be careful not to touch the copper surface with your fingers. Oil from your fingers will interfere with the etching process.

6. Use the marker to draw your design on the copper-coated side of the circuit board and to write your initials on the plastic side. Be sure to make thick lines with the marker.
7. Let the ink dry for 1 minute.
8. Re-trace your design and your initials and again let the ink dry for 1 minute.
9. Look at the copper chloride etching solution your teacher has prepared and record your observations in your science notebook. Now place your circuit board in the tray. It will soak there overnight.

Part B: Examining the Circuit Board

10. Observe the used copper chloride after the etching process is completed. Describe your observations in your science notebook.
11. Obtain your circuit board from your teacher after it has been rinsed off with water.
12. Rub your circuit board with steel wool to remove any remaining ink.
13. Examine your circuit board, and then test it with the battery-and-lightbulb circuit. Record the results of your test.

Part C: Reading

Use Student Sheet 23.1, “Three Level Reading Guide: Etching Circuit Boards” to guide you as you complete the following reading.

READING: MAKE PRODUCTS, MAKE WASTE

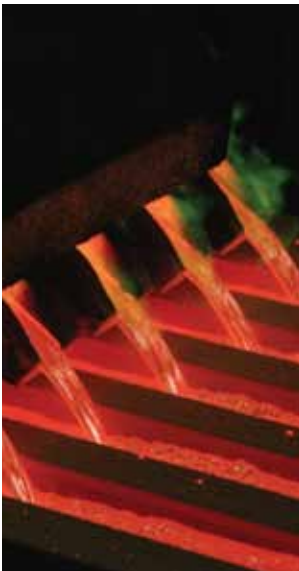
Making Everyday Products

We buy and use products every day. These products include drinks and items we consume and dispose of right away. But we also buy products that serve us for longer periods of time, like sneakers, cell phones, or computers. What happens before you buy a product? It has to be made from materials, and the materials have to come from somewhere.

Take, for example, a computer. To manufacture a computer the parts must be made first. To make the parts raw materials or recycled materials must be obtained. As you saw in the demonstration, copper is one of the raw materials that end up in a circuit board. Mining companies dig out copper-containing rocks, known as copper ore, from deposits in the earth. Refining companies then physically crush the rock and chemically remove the copper from the ore. The copper that is removed and purified is then sold to companies that use copper in their products.



Copper-containing rock can be mined from open pit mines (left) on the earth's surface or from tunnel mines (right) that are blasted into the surface.



Hot liquid metal copper is poured into molds where it will cool.

Making Circuit Boards

During the production of a circuit board, a chemical reaction etches a copper circuit on a piece of plastic. To etch means to use a corrosive solution to make a design in a material by dissolving the material not wanted. The copper that was protected from the etching solution is left on the board and creates a metal path. The metal path determines how electricity flows throughout the computer. This is a process that removes much of the copper on the board, leaving it in the etching solution.

Making Waste

Each step in the process from raw materials to finished circuit board creates some form of waste. After ore is mined to obtain copper, the copper-containing rock is extracted to be used in products. However, more than 98% of the ore does not contain any form of copper, so a lot of waste remains.

As you observed in this activity, after a circuit board is etched the used etching solution and rinse water contain copper. Other steps in the computer manufacturing process create yet more wastes that have copper in them. Solutions containing copper above a certain concentration are considered toxic. In fact, the U.S. Environmental Protection Agency (EPA) reported that in the year 2000, of all the toxic chemicals released by companies in the United States, the most common toxic substance was copper-containing waste. About 1.5 billion pounds of these chemicals were released into the environment that year.



A technician works with a machine (left) that etches copper circuit boards. Mining and manufacturing copper-containing substances can result in waterways that are polluted with copper waste.






Copper Isn't Always Bad

Like other living organisms, the human body needs small amounts of copper and other metals for it to work properly. That's why they are often among the ingredients of vitamin and mineral supplements. The U.S. Food and Drug Administration's (FDA) recommended daily intake of copper for adults is about 2 milligrams (mg). But in much larger amounts, copper, like many other metals, can be toxic. Drinking water that has high levels of copper can cause vomiting, diarrhea, stomach cramps, and nausea. Eating or drinking very high amounts of copper can cause liver and kidney damage. Inhaling copper dust over long periods of time can cause dizziness, headaches, diarrhea, and irritation of the nose, mouth, and eyes. Since high levels of copper can be toxic, proper disposal is crucial.

Today, the United States has laws that prevent companies and individuals from dumping toxic waste directly into the soil, waterways, and sewer systems. This helps keep our environment cleaner and safer. But manufacturing products that we have come to depend on, like circuit boards, still produces toxic waste. Figuring out how to handle this waste in ways that will not harm the environment is a problem many companies and government agencies face every day. If you consider the amount of waste produced by manufacturing products every year, that's a lot of toxic waste that is built up in the course of one year. It often costs companies a great deal of money to dispose of toxic waste safely.

ANALYSIS

-  1. Describe the changes that occurred during the etching process in:
 - your circuit board.
 - the copper chloride etching solution.
-  2. What do you think should be done with the used copper chloride etching solution?
-  3. Etching circuit boards creates large amounts of copper-containing toxic waste. What ways can you think of to reduce the amount of copper-containing waste produced in the United States?

Hint: You may want to look at Student Sheet 13.1, “Green Chemistry Guidelines,” to help you think of ways to improve methods of manufacturing.

24 Diluting the Problem



Manufacturing circuit boards produces water that contains copper compounds. The concentration of copper in the waste is one factor that will determine how the waste can be disposed. **Concentration** is the amount of one substance in another substance. In this activity you will determine the amount of copper compounds in the used copper chloride solution from Activity 23, “Producing Circuit Boards.” It is important to know the concentration of copper in the solution because there are local, state and federal laws that set limits on what types of wastes can be released and at what concentrations. For this reason, manufacturers need to dispose of the used copper chloride solution in ways that do not put high concentrations of copper in rivers or waterways.

One way to dispose of the waste is to reduce the concentration of copper in the waste by diluting it, and then releasing it into a waterway. When waste is **diluted**, it is combined with water. This does not change the waste chemically, but decreases the concentration of waste per volume of water. Once the waste is diluted to below the limit set by law, it can be disposed of in a waterway. Depending on where the manufacturer is located, limits for the maximum concentration of copper that can be released in a single day from a single place may range from 1 to 10 parts per million (ppm). **Parts per million** is a way of expressing the concentration of a substance in one million parts of another substance.

In this activity you will determine the concentration of the used copper chloride solution in parts per million. Knowing the concentration will help you decide if dilution is a way to dispose of the waste.



How much copper is in the used copper chloride solution?



MATERIALS



For each group of four students

- 1 30-mL dropper bottle of each of the following:
 - 100,000 ppm copper chloride solution
 - water
 - 5% ammonia solution
 - used copper chloride solution from Activity 23, "Producing Circuit Boards"
- 1 cup of water



For each pair of students

- 1 SEPUP tray
- 1 dropper
- 1 stir stick
- 1 sheet of white paper
- paper towels
- 1 copy of Transparency 24.1, "Diluting and Testing Copper Chloride"



For each student

- 1 pair of safety goggles
- 1 Student Sheet 24.1, "Determining Concentration"
- 1 Student Sheet 24.2, "Treating Waste"



SAFETY

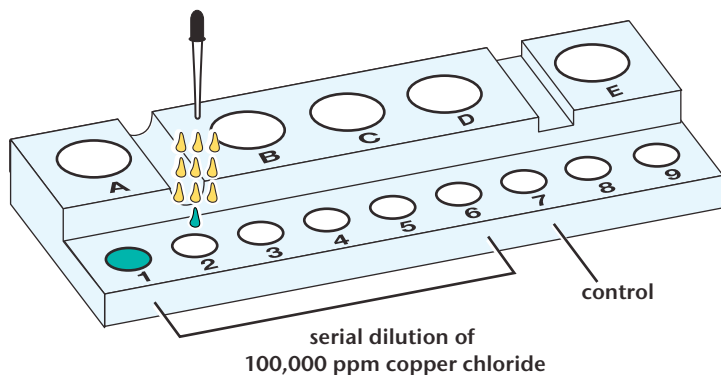
Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Preparing a Dilution of 100,000 ppm Copper Chloride

1. Place the copy of Transparency 24.1, "Diluting and Testing Copper Chloride" underneath your SEPUP tray. This will help you see the colors of the solutions as you perform the dilutions.
2. Put 10 drops of 100,000-ppm copper chloride solution in Cup 1 of the SEPUP tray.

Activity 24 • Diluting the Problem







- Use a clear dropper to transfer one drop of 100,000-ppm copper chloride solution from Cup 1 to Cup 2. Return any excess in the dropper to Cup 1, and rinse the inside of the dropper in the cup of water.
- Add 9 drops of water to Cup 2. Stir the solution with the stir stick. Clean the stir stick.
- Use the dropper to transfer one drop from Cup 2 to Cup 3. Return any excess in the dropper to Cup 2, and rinse the inside of the dropper.
- Add 9 drops of water to Cup 3, and stir.
- Continue this dilution process through Cup 6 by moving a drop of solution from the previous cup to the next cup, adding 9 drops of water, and stirring. Be sure to return any excess solution in the dropper to the previous cup, and rinse the dropper.
- Add 10 drops of water to Cup 7. This cup will act as a control to ensure that the water you added to Cups 1–6 does not contain copper.
- Record the color of the solutions in Cups 1–7 in the first column of the data table on Student Sheet 24.1, “Determining Concentration.”
- You will use ammonia solution to indicate if copper is present in the solution in each of the cups. Add 5 drops of ammonia to each of the seven cups, and stir. Be sure to clean the stir stick after mixing each cup to avoid contamination.
- If after adding ammonia, the solution is green, blue-green, or blue, copper is present in the solution. Record your observations in the second column of your data table.

Part B: Concentration of Copper in Used Copper Chloride Solution

- Place 10 drops of the used copper chloride solution into Cup 9. Add 5 drops of ammonia, and stir. Record your observations.
- Determine the concentration of copper in the used copper chloride solution. To do this, compare the color of the solution in Cup 9 to the colors in Cups 1–7. Record the concentration for the cup that has the closest concentration to Cup 9 on Student Sheet 24.1, “Determining Concentration.”
- Dispose of the solutions in your SEPUP tray as directed by your teacher.

ANALYSIS

-  1. Which contains a more dilute solution, Cup 1 or Cup 2? Explain.
-  2. Was there copper in Cups 1–6? How did you know it was or was not there? Explain, using evidence from this activity.
3. What is the concentration of copper in the used copper chloride solution from Activity 23, “Producing Circuit Boards”? Use the evidence from this activity to support your answer.
-  4. How many liters of water would you need to dilute 1 liter of used copper chloride solution from 100,000 ppm of copper to less than 1 ppm?
-  5. Based on your answers to Analysis Questions 3 and 4, how many liters of water would it take to dilute your waste from Activity 23 to 1 ppm, an acceptable concentration to pour down the drain?
6. Is dilution an acceptable way to dispose of the used copper chloride solution? Explain.

EXTENSION

Towns, cities, and states in the United States set limits on the amount of copper that can be disposed of down drains. Find out what the local limit is in your area.

25 Conservation of Mass



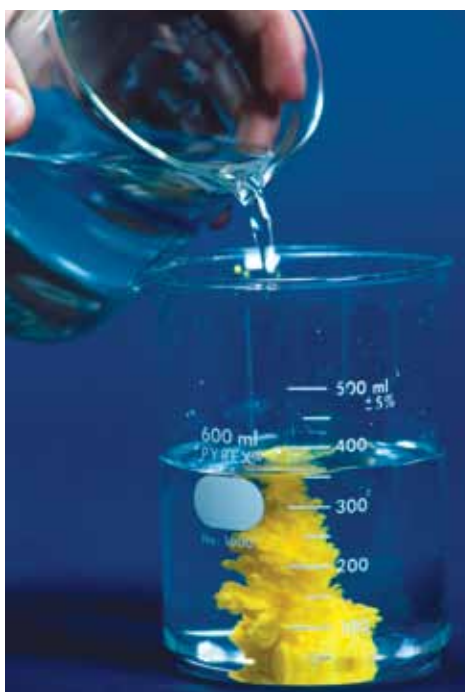
So far in this unit you have performed two chemical reactions. In Activity 19, “Creating New Materials,” you cross-linked polyvinyl alcohol in a chemical reaction that produced a new polymer. In Activity 23, “Producing Circuit Boards,” you observed a chemical reaction that etched copper. These are two examples of chemical reactions. You may be amazed to know that there are chemical reactions going on around you and inside of you every day. Whether you are cooking your dinner in a pan or releasing energy from food in your cells, chemical reactions are changing reactants into products. Understanding chemical reactions is helpful when creating materials and in deciding how to reduce the waste created at the same time.

In this activity you will conduct two chemical reactions in closed containers. Scientists call a container a **closed system** if none of the reactants or products can escape from the reaction container. If a chemical reaction takes place in a container that allows any reactants or products to escape, it is called an **open system**. You will investigate what changes and what stays the same when a chemical reaction takes place in a closed system.

CHALLENGE



How does the total mass of the reactants compare to the total mass of the products in a chemical reaction?



Two liquid reactants mix and undergo a chemical reaction that results in the creation of a yellow product.

MATERIALS



For each group of four students

- 1 balance
- 1 SEPUP tray to hold copper chloride bottles
- 1 30-mL bottle of 100,000-ppm copper chloride solution
- 1 30-mL bottle of sodium hydrogen phosphate solution



For each pair of students

- 1 10-mL graduated cylinder
- 1 aluminum washer
- 2 reaction bottles



For each student

- 1 Student Sheet 25.1, “Mass of Reactants and Products”
- 1 pair of safety goggles



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Chemical Reaction in an Closed System


1. With your partner, place an aluminum washer in the bottom of one of the reaction bottles.
2. Fill the dropper with 1 mL of 100,000-ppm copper chloride solution.
3. Being careful not to squeeze the dropper and mix the two reactants, place the top on the bottle and twist the lid securely.
4. Use the balance to measure the total mass of the bottle, dropper, and reactants to the nearest $\frac{1}{10}$ of a gram. Record this initial total mass on Student Sheet 25.1, “Mass of Reactants and Products.”
5. Observe the two reactants and record your observations on Student Sheet 25.1.
6. While holding the reaction bottle securely with one hand, use the other hand to squeeze the dropper, releasing the copper chloride solution into the bottle. Swirl the bottle to mix the copper chloride solution with the aluminum washer.

7. Set the bottle on the table, and observe. On Student Sheet 25.1, record your observations both as the reaction happens and after there are no more signs of a reaction.
8. Determine the total final mass of the reaction bottle to the nearest $\frac{1}{10}$ gram. Record this final mass on your student sheet.
9. Calculate the change in total mass.

Part B: Another Chemical Reaction in a Closed Chamber

10. Now conduct a second chemical reaction in a closed system. With your partner, pour 4 mL of 0.8 M sodium hydrogen phosphate into the bottom of the second reaction bottle.
11. Fill the dropper with 1-mL of 100,000-ppm copper chloride solution.
12. Being careful not to bump or drop any of the copper chloride into the bottle, carefully twist the dropper top securely onto the bottle.
13. Use the balance to measure the total mass of the bottle, dropper, and reactants to the nearest $\frac{1}{10}$ of a gram. Record this initial total mass on Student Sheet 25.1, "Mass of Reactants and Products."
14. Observe the two reactants and record your observations on Student Sheet 25.1.
15. While holding the reaction bottle securely with one hand, use the other hand to squeeze the dropper, releasing the copper chloride solution into the bottle. Swirl the bottle to mix the copper chloride solution with the sodium hydrogen phosphate solution.
16. Set the bottle on the table, and observe. On Student Sheet 25.1, record your observations both as the reaction happens and after there are no more signs of a reaction.
17. Determine the total mass of the reaction bottle to the nearest $\frac{1}{10}$ gram. Record this final mass on your student sheet.
18. Calculate the change in total mass.
19. Clean up according to your teacher's directions.

ANALYSIS

1. What evidence do you have that a chemical reaction took place between:
 - a. copper chloride solution and aluminum?
 - b. copper chloride solution and sodium hydrogen phosphate?
2. What can you conclude about the effect of a chemical reaction on the mass of reactants in a closed system? Support your answer with evidence from this activity.
-  3. Using what you now know about the Law of Conservation of Mass, how would you respond if a company said it had developed a way to make hazardous materials and wastes “disappear”?

26 Incinerating the Waste



When the wastebasket is full, what do you do with the waste? Take it out to the garbage can? Most likely this is the easiest option. In Activity 23, “Producing Circuit Boards,” you saw that the chemical reaction that produces a circuit board also produces copper chloride waste. What do large manufacturing companies do with waste? What is the best choice for the environment? For years, people have gotten rid of waste through incineration. **Incineration** is the burning of wastes at very high temperatures—greater than 650°C (1,200°F). In this activity, you will explore how well incineration works to eliminate the copper-containing toxic waste.



When waste is incinerated, what happens to potentially toxic heavy metals?

A toxic waste incineration facility.



MATERIALS



For each group of four students

- 1 dropper bottle of water
- 1 dropper bottle of ammonia



For each pair of students

- 1 sample of ash from metal paper
- 1 sample of ash from nonmetal paper
- 1 SEPUP tray
- 1 stir stick
- 1 dropper
- 1 piece of white paper
- 1 paper towel



For each student

- 1 pair of safety goggles
- 1 Student Sheet 24.2, "Treating Waste"



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Observing Incineration

1. In your science notebook, make a table like the one shown below.




Testing for Copper		Color after Adding Ammonia	
		Metal Paper	Nonmetal Paper (control)
Substance			
Unburned paper			
Smoke			
Ash			

2. Watch as your teacher uses ammonia to test two pieces of paper—one metal and one nonmetal—for copper. Record your observations in your table. The nonmetal paper is being tested as a control.
3. To simulate incineration, your teacher will burn both pieces of paper. Observe as your teacher uses ammonia to test the smoke, one of the products of incineration, for the presence of copper. Record your observations in your table.

Part B: Testing Ash for Copper

4. Place your SEPUP tray on a piece of white paper.
5. Use your stir stick to put one scoop of ash from the metal paper into Cup 1.
6. With your stir stick, break the ash into smaller pieces.
7. Add 20 drops of water to Cup 1, and stir. Clean the stir stick.
8. Use your stir stick to put one scoop of ash from the nonmetal paper into Cup 2.
9. Add 20 drops of water to Cup 2, and stir. Clean the stir stick.
10. Add 5 drops of ammonia to Cups 1 and 2 to test for the presence of copper. Stir Cup 1, clean the stir stick, and stir Cup 2. Record your observations in your table.
11. Dispose of the substances in your SEPUP tray as directed by your teacher.

ANALYSIS

1. Which of the three items in your table, “Testing for Copper,”—paper, smoke, or ash—are products of incineration?
-  2. Which of the products of incineration contained copper? Explain your evidence.
3. How did incineration change the metal paper?
-  4. What are the advantages and disadvantages of using incineration to dispose of heavy metal wastes?
-  5. Look at the information on Transparency 26.1, “Municipal Waste Disposal in the U.S. and Japan,” and Transparency 26.2, “Relative Landmasses of the U.S. and Japan.” Based on what you know about incineration and the information shown, why do you think these two countries handle waste disposal differently?

27 Reclaiming the Metal

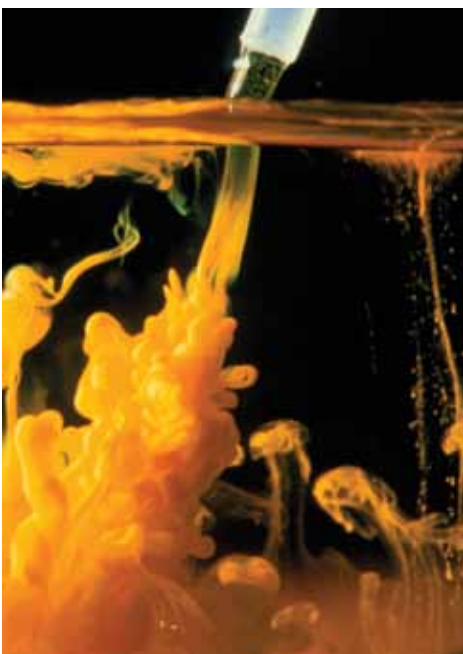


Deciding how to handle waste produced from manufacturing is challenging. It can be diluted or incinerated, as you saw in previous activities. In some cases, it contains valuable materials that can be **reclaimed** and then reused. To reclaim metal means to get it back so it can be used again. Reclaiming metal from waste reduces the amount of new metal needed for manufacturing.

One way to reclaim copper from used copper chloride is to combine the waste with a solution that **precipitates** the copper. The metal copper precipitates, or falls out of solution because of a chemical reaction. Reclaiming the copper can be a useful way to deal with waste because it reduces the amount of toxic waste that is discarded, and provides copper that can be used again to make new products. Chemists have found that other types of metal are particularly effective in removing copper from waste products. In this activity you will test three metals to find out which one is best at reclaiming copper from waste.

CHALLENGE

Which metal is best at reclaiming copper from the used copper chloride solution?



Mixing two chemicals (left) results in a chemical reaction that creates an orange precipitate. Test tubes (right) hold the results of several metal precipitation reactions.

MATERIALS



For each group of four students

- 1 dropper bottle of used copper chloride solution from Activity 23, “Producing Circuit Boards”
- 1 dropper bottle of 5% ammonia solution
- 1 cup of water



For each pair of students

- 1 SEPUP tray
- 1 aluminum washer
- 1 iron washer
- 1 zinc washer
- 1 plastic spoon
- 1 dropper
- paper towels



For each student

- 1 pair of safety goggles
- 1 Student Sheet 24.2, “Treating Waste”



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.


PROCEDURE

Read through the entire procedure before you begin, and in your science notebook prepare a data table for recording your observations and results.

1. With your partner carefully examine each of the three metal washers: aluminum, zinc, and iron. Record your observations in your data table.
2. Add 10 drops of used copper chloride solution to Cups 1–4 of the SEPUP tray.
3. Using forceps, place the aluminum washer in Cup 1, the iron washer in Cup 2, and the zinc washer in Cup 3. Cup 4 will serve as a control for comparison purposes.
4. Observe the reaction in each cup for 5–10 minutes. Record your observations of each reaction in your data table. Be sure to include a comparison of the results obtained with each of the different metals.

- Using the plastic spoon, remove the pieces of metal from the cups, and place them on a paper towel. Clean the spoon with a paper towel after each piece is removed.
- In your data table, record your final observations of each metal.
- Record your observations of the solutions left in each cup.
- Using a dropper, put 5 drops of each of the solutions into a clean cup in the SEPUP tray. Do this by transferring 5 drops from Cup 1 to Cup A, from Cup 2 to Cup B, from Cup 3 to Cup C, and from Cup 4 to Cup D. Be sure to clean the dropper with water after each transfer so the solutions do not mix.
- Test for copper in each solution by adding 2 drops of ammonia solution to Cups A–D. If copper is present in the solution, a deep blue color or a blue-green precipitate will form when ammonia is added.
- Record your observations of the ammonia test in your data table. Dispose of the metals and solutions in your SEPUP tray as directed by your teacher.

ANALYSIS

- Explain the purpose of including Cup 4 and Cup D in your investigation.
-  Prepare a written report summarizing your investigation. Put your report on a clean sheet of paper. Include your name, the date, and a title for your report. Your report should have the following three components:
 - A statement of the problem you were trying to resolve.
 - A description of the materials and procedure you used to solve the problem.
 - An analysis of the results, which should include:
 - a copy of your data table.
 - a summary of the results shown by the data in your data table.
 - an answer to this question: Which metal seemed to work best at removing the copper from solution? (Describe your evidence completely in your answer.)
 - any problems you may have had with the investigation.
 - any additional questions related to the problem that you would like to investigate.

Activity 27 • Reclaiming the Metal



3. Companies that make circuit boards often reclaim copper from copper-containing solutions. This allows them to reuse the copper, or sell it. Based on your results from this investigation and the information below, which metal would you recommend a company use to reclaim copper? Support your answer with evidence, and identify the trade-offs of your decision.

More Information on Metals				
Metal	Approximate Cost per Pound in 2012 (U.S. dollars)	Maximum Wastewater Concentration (ppm)	Health Benefits	Health Hazards
Aluminum	\$1.00	Not Restricted	Trace amounts may help enzymes function.	High levels may cause bone disease.
Copper	\$3.80	1	Essential for nervous system functions and energy metabolism, the recommended daily intake for an average adult is 2 mg.	Large amounts ingested over time cause liver and kidney damage.
Iron	\$0.06	100	Essential for formation of red blood cells, the recommended daily intake is 18 mg for an average adult.	Large amounts ingested over time may cause inflammation and damage to organs.
Zinc	\$0.90	2.4	Small amounts are needed for functioning of enzymes and forming proteins. The recommended daily intake for an average adult is 15 mg.	Large amounts ingested over time may cause inflammation and damage to organs.

EXTENSION

What other metals can precipitate copper from the used copper chloride solution? Design an experiment to find out. After your teacher approves your investigation, conduct the experiment, and present the results to the class.

28 Another Approach to Metal Reclamation



In the last activity, you conducted a chemical reaction with solid metals to precipitate copper metal from the used copper chloride solution. The brown deposit that formed was solid copper. Reclaiming copper from waste solutions has two advantages. First, it reduces the volume of toxic copper compounds that are thrown away as copper is replaced in solution with another, less toxic metal. Second, copper is a valuable metal that can be reused or sold.

Solid metals are not the only reactants that precipitate copper. Certain solutions can also form copper precipitates when they react with the used copper chloride solution. As you work to determine the best way to treat the waste from circuit-board manufacturing, you will evaluate two more chemical reactions that reclaim copper from the used copper chloride solution.



Which compound in solution is best for reclaiming copper metal from the used copper chloride solution?

A goldsmith sorts printed computer circuit boards to reclaim the precious metal before the boards are recycled.



MATERIALS



For each group of four students

- 5 dropper bottles, each containing one of the following:
 - used copper chloride solution from Activity 23, “Producing Circuit Boards”
 - sodium carbonate solution
 - sodium hydrogen phosphate solution
 - 5% ammonia solution
 - water
- 1 cup of water



For each pair of students

- 1 SEPUP tray
- 1 SEPUP funnel
- 2 pieces of filter paper
- 1 dropper
- 1 stir stick
- 1 pair of forceps



For each student

- 1 pair of safety goggles
- 1 Student Sheet 24.2, “Treating Waste”
- Answer to Analysis Question 2 from Activity 23, “Producing Circuit Boards”



SAFETY

Wear safety goggles at all times during this lab. Do not allow solutions to touch your skin or clothing. Clean up any spills immediately. If accidental contact occurs, inform your teacher, and rinse exposed areas.

PROCEDURE

Part A: Precipitation of Metals

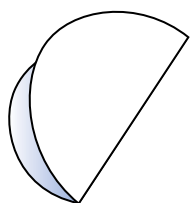
1. In your science notebook, prepare a data table like the one shown on the next page.
2. Add 15 drops of used copper chloride solution to Cups 1 and 2 of the SEPUP tray.

Cup		Reactants	Observation of Products		
			Precipitate in Filter	Filtrate	Color after Adding Ammonia
A		Used copper chloride + sodium carbonate solution			
B		Used copper chloride + sodium hydrogen phosphate solution			

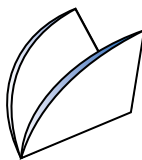
- Add 20 drops of sodium carbonate solution to Cup 1, and stir. Rinse the stir stick.
- Add 20 drops of sodium phosphate solution to Cup 2, and stir.
- Examine the results of the reaction in Cups 1 and 2.

Part B: Filtration

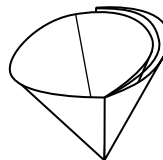
- Now you will filter out the copper precipitate. Use the illustration below as a guide to fold the filter paper and set up the funnel.
- Place the funnel over large Cups A and B of the SEPUP tray.



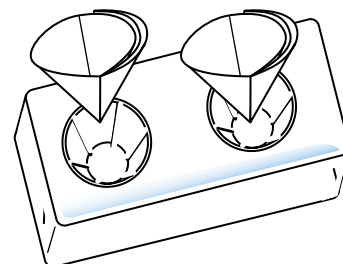
Step 1
Fold filter paper in half.



Step 2
Fold filter paper in half again.



Step 3
Open with three thicknesses of paper on one side of the cone and one thickness on the other.



Step 4
Place in funnel and add 3–5 drops of water from the dropper bottle to hold it in place.

8. The solid that formed when you mixed the liquids in Steps 3 and 4 is a precipitate. It can be removed by filtering. Use a clean dropper to transfer both the precipitate and the solution from Cup 1 to the filter paper above Cup A. Rinse the dropper thoroughly.

Hint: If the solid is difficult to remove, add a few drops of water to Cup 1. Use the dropper to remove the water and the precipitate, and transfer it to the filter paper.

9. Use a clean dropper to transfer the precipitate and solution from Cup 2 to the filter paper above Cup B.

10. Wait a few minutes as the solutions pass through the filter paper. After most of the liquid has filtered through, move the funnel so that it rests over Cups C and D.


11. Use forceps to gently pick up the filter paper in Cups A and B, and inspect the precipitate. Record your observations of the precipitate.


12. The filtered liquids left in Cups A and B are now called the filtrates. In your data table, record your observations of the filtrates.

13. Add 5 drops of ammonia to Cups A and B, and stir. Record your observations and the results of the ammonia test in your table.

14. Dispose of the filter papers and solutions in your SEPUP tray as directed by your teacher.


ANALYSIS

 1. Which solution was most effective at removing copper from the used copper chloride solution—sodium carbonate or sodium phosphate? Explain your evidence.

 2. The table, “Summary of Precipitation Reactions,” on the next page, shows information about each of the substances you used to precipitate copper. Based on your answer to Analysis Question 1, your results from Activity 27, and the information on the next page, which precipitation reaction would you recommend a company use to reclaim copper?

Be sure to support your answer with evidence, and discuss the trade-offs.

Summary of Precipitation Reactions			
Metal	Approximate Cost per Pound (U.S. dollars in 2012)	What Are the Products of the Reaction?	What Can Be Done with these Products?
Aluminum	\$1.00	Copper Aluminum chloride	Reuse copper Easy disposal of aluminum chloride through release into environment
Iron	\$0.06	Copper Iron chloride	Reuse copper Restricted disposal of iron chloride—must be treated, stored, or diluted
Zinc	\$0.90	Copper Zinc chloride	Reuse copper Highly restricted disposal of zinc chloride—must be treated or stored
Sodium Carbonate	\$0.10	Copper carbonate Dissolved salt	Reuse copper carbonate Easy disposal of dissolved salt through release into environment
Sodium Phosphate	\$0.30	Copper phosphate Dissolved salt	Reuse copper phosphate Easy disposal of dissolved salt through release into environment

- 
 3. Making 1,000 circuit boards can produce more than 18,500 liters (5,000 gallons) of copper-containing wastes. How do you think this toxic waste should be handled? Review your results from Activities 24–28, and the information you have collected on Student Sheet 24.2, “Treating Waste,” and support your answer with evidence. Be sure to consider dilution, incineration, precipitation, and any other option that would reduce the environmental harm from the production of circuit boards.
4. **Reflection:** Look back at your answer to Analysis Question 2 from Activity 23, “Producing Circuit Boards.” Now that you’ve completed the unit, has your idea of what to do with the waste changed? Explain.

29 The Green Computer Decision



The Sunnyvale school district has been awarded a Green Computer Grant. To use the grant money, the school district must purchase “green” computers. The term “green” describes activities or products that disturb our environment less than current activities or products do. “Green” houses, for example, would have solar panels for energy, and be made from recycled building materials. “Green” electronics have been engineered in ways that produce less waste and thus reduce the environmental impact of their product life cycle. The Sunnyvale school district must show how the computers they decide to purchase have “green” features.

You are a materials scientist asked by the Sunnyvale school district to analyze proposals from computer companies about their products. You will recommend which computers to purchase based on the computer’s green features and your knowledge of the products’ life cycles.



Which “green” computers should the school district purchase?



Deciding which computer to buy can be based not only on the computer’s features, but also the environmental impact of the entire computer life cycle.

MATERIALS



For each group of four students

- 1 transparency of Student Sheet 29.1, “Life Cycle of a Computer”
- 1 poster board or chart paper
- assorted markers
- tape
- transparency marker



For each student

- 1 Student Sheet 29.2, “Analyzing a Computer Proposal”
- 1 Student Sheet 29.3, “Comparing Computer Proposals”
- 1 Student Sheet 13.2, “Principles of Green Chemistry”

PROCEDURE

1. With your group review Transparency 29.1, “Life Cycle of a Computer” and identify each of the life cycle stages listed below. Use a transparency marker to label each stage on the transparency.
 - raw materials
 - manufacturing
 - useful life
 - end of life
 - recycling
2. With your group you will perform a life cycle analysis for a hypothetical new material. To analyze this proposed change, you will predict how using the new material will affect each stage of the life cycle. To do this
 - Read the news flash that follows.

NEWS FLASH

New Polymer to Revolutionize Computer Manufacturing

Scientists and engineers have announced the creation of a new plastic made from plant-based polymers. It is hoped that this material will replace the synthetic polymers currently used to make computer monitors. Since the

new plastic is made from plant-based materials, this would reduce the need for the raw material, petroleum. When recycled, the polymer can be broken down into a material that can be used to make computer monitors a

second and third time, much like the process used to recycle glass bottles. This is an improvement over plastics currently used to make computer monitors since the current plastics cannot be reused to manufacture new monitors.

Activity 29 • The Green Computer Decision

- With your group use a transparency of Student Sheet 29.1, “Life Cycle of a Computer,” to think about which step(s) would change using the new material. Share your ideas with the class.
3. Now you will perform a life-cycle analysis for “green” computers. Your teacher will assign your group one of the four computer proposals described on the pages that follow.
 4. With your group, read your assigned proposal. Fill out Student Sheet 29.2, “Analyzing a Computer Proposal,” to help you identify how each feature of the proposal will change the life cycle of the computer.
 5. Your group will work together to present a life-cycle analysis to the class. In your presentation you should be prepared to:
 - Describe each feature of the computer proposal.
 - Point out on your transparency of Student Sheet 29.1, “Life Cycle of a Computer,” how your proposal would modify the life cycle of a computer.
 - Explain how each feature changes the life cycle and reduces the environmental impact of the computer.
 - Explain which “Principles of Green Chemistry” are incorporated in the proposal.

Hint: Refer to Student Sheet 13.2

6. Make your presentation to the class, and listen to those of the other groups. As you listen to each presentation, record information on Student Sheet 29.3, “Comparing Computer Proposals.” You will use this information to choose a proposal.

Note: For each of the four computer plans presented below, the system specifications are the same. That means that the memory, processing speed, and software programs are identical.

Proposal A Features

- Each computer has a cathode ray tube (CRT) monitor.
- The glass used in the monitor is from recycled glass products.
- Company reuses copper from circuit-board etching to produce more circuit boards.



- Computers are shipped in bulk. This reduces the amount of packing material needed to individually ship each computer.

Proposal B Features

- Each computer has a cathode ray tube (CRT) monitor.
- Old computers are shipped back to the computer company. The company takes apart the old computers and reclaims metal components, such as the copper from the circuit board and the wires, to reuse in new computers.
- Nontoxic manufacturing wastes are sent to landfills. Hazardous materials are labeled, packaged, and sent to hazardous-materials facilities.
- The plastic cases that hold the monitors are made from a plant-based plastic.



Proposal C Features

- Each computer has a flat screen liquid-crystal display (LCD) monitor that uses about 50% less electricity and 30% less materials than the standard CRT monitor.
- Reclaimable metals are precipitated from waste solutions and are reused in the manufacturing process.



- 15% of the plastic components of the computer are made of recycled plastic.
- The company will take back the computers once they are no longer being used, dismantle them, and use the metal components for further computer manufacture.

Proposal D Features

- Each computer has a flat screen liquid-crystal display (LCD) monitor that uses about 50% less electricity and 30% less materials than the standard CRT monitor.
- Computers are shipped in bulk, reducing the amount of packing material needed to individually ship each computer.
- 15% of the metal components of the computer are made of recycled metal.
- The company offers a coupon for 50% off a new computer if the current computer is kept and upgraded for at least eight years (instead of buying new computers).



ANALYSIS

1. Which proposal would you recommend the district choose for its Green Computer Grant? State your opinion, citing evidence from Student Sheet 29.3, “Comparing Computer Proposals,” and previous activities. Include a discussion of the trade-offs involved in your decision.
2. With your group, explain how the science you learned in this unit helped you analyze your proposal. To do this, choose one feature of your proposal and explain which concept you learned helped you to understand that this feature would improve the life cycle of a computer.
3. The proposals your group analyzed did not include the cost of each computer. The school board members did not provide this information earlier because they wanted you to evaluate the plans based only on the chemistry of the materials and the products’ life cycles.
 - Read the list price for each computer proposal below.
 - Knowing the price of each computer, does your answer to Analysis Question 1 change? Explain.

Proposal Costs		
Proposal	Cost per Computer	Purchase Plan
A	\$1,250	Year one—120 computers purchased
B	\$1,650	Year one—60 computers purchased Year two—30 computers purchased Year three—30 computers purchased The price is locked in for all three years.
C	\$2,450	Year one—120 computers purchased
D	\$1,800	Year one—120 computers purchased

4. **Reflection:** Do you think that there should be green guidelines for families and individuals when they buy products, such as computers?