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, Janice noticed a sign: "Turn in your old phone and get 10% off a new phone!"

"Wow!" She thought, "I have my old phone, so I can turn it in. That's an easy 10% discount!"

Just then the salesperson came by. Janice asked, "Why do you give a discount if I turn in my old phone?"

"The companies save money by recovering and reusing the materials from old phones to make new phones," replied the salesperson. "For example, there are metals like copper, silver, gold, and platinum in a cell phone. Although there isn't much in one phone, more than 2 billion people have smartphones! Recycling saves those metals and also reduces waste from the reactions used to purify the metals."

"What do all those metals in my phone do?" asked Janice.

The salesperson responded, "There are metals in the battery. Chemical reactions in the battery provide energy for the phone. Metals are also part of the electronics that make your cell phone smart!"

"I heard that the new cell phone batteries are better than the old ones. Right now my phone gets really hot sometimes. My dad says it's probably the battery heating up."

"Yup," said the salesperson. "Engineers are constantly designing improvements to every part of a cell phone, including the batteries, to make them work better for the customer and be better for the environment. Let me show you our new models."

• • •

Chemicals and chemical reactions are used to make and power many products, including the batteries and circuits in electronics. The reactions used to purify metals and produce cell phone parts, such as circuit boards, provide useful products, but they also create waste. How do these chemical reactions work? In this unit, you will analyze and interpret data to determine whether chemical reactions have taken place. You will develop models to describe what happens during a chemical reaction at the molecular scale and use your models to explain your observations of reactions in open and closed systems. You will also apply what you learn about energy and matter in chemical reactions to design, test, and modify a product and to develop methods to clean up chemical waste.

1 Producing Circuit Boards

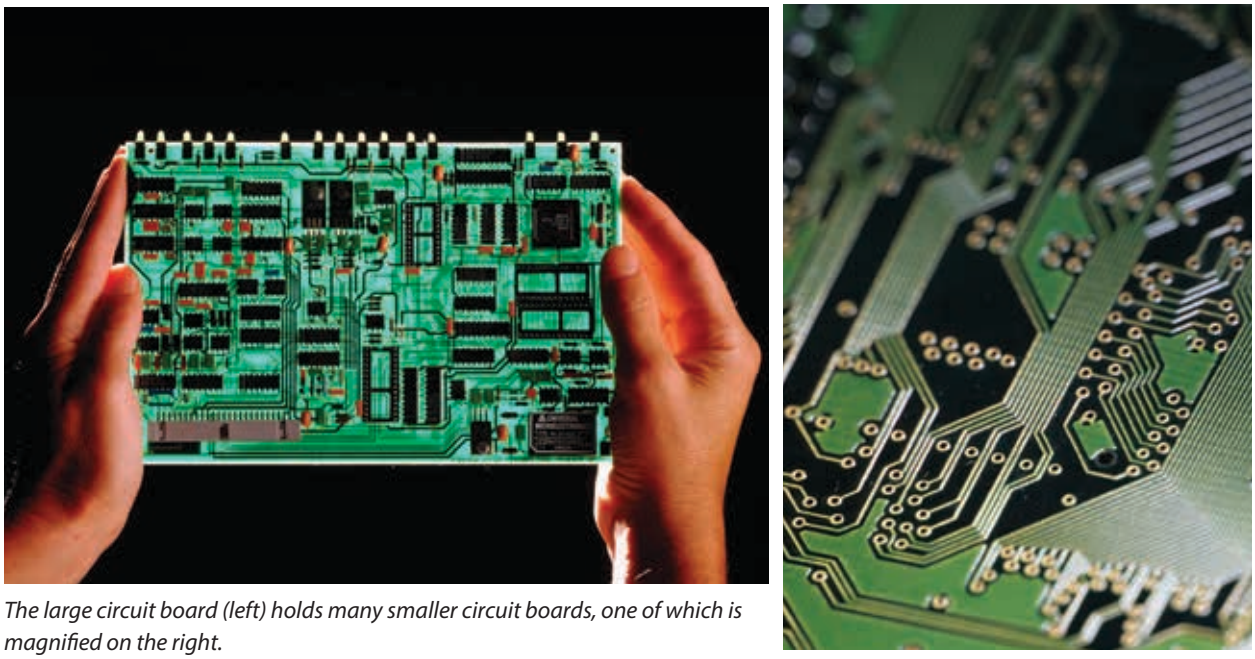
INVESTIGATION

CHEMICAL PROCESSES ARE used to make many of the products you use every day. These products include the food you eat, the clothing you wear, and electronic devices such as computers, cell phones, and televisions.

One essential part of a computer and many other electronic devices is a circuit board**.** A **circuit board** is a thin board with copper lines on the surface. It works like a wiring system to transfer electricity to the electronic parts of a computer or other device. The copper lines form paths for the flow of electricity. A chemical process called *etching* is used to create the copper paths on the circuit board. In this activity, you will find out how etching works by etching your own circuit board.

GUIDING QUESTION

How are chemical processes used to produce circuit boards?



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 piece of copper-coated plastic
- 1 felt-tip permanent marker
- 1 piece of steel wool
- 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 1.1, "Three-level Reading Guide: Etching Circuit Boards"
- 1 pair of chemical splash goggles

SAFETY

Wear chemical splash goggles at all times during this lab investigation. 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. Wash your hands thoroughly with soap and water after you finish the activity.

PROCEDURE

Part A: Designing and Etching a Circuit Board

1. Listen carefully as your teacher describes how a circuit board works.
2. Plan your circuit board design.
   a. Outline the shape of the copper-coated plastic on a piece of paper.
   b. Discuss with your partner how you will design your circuit. It should be a pattern that will conduct electricity (allow electricity to flow) from one end of the board to the other.
   c. Using a pencil, sketch your design on the paper, making sure to use thick lines.
   d. Share your design with the other pair in your group. Decide which design will be etched on the piece of copper-coated plastic.

3. Prepare your circuit board for etching.
   a. 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 process. 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.
   b. 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.
   c. Let the ink dry for 1 minute (min).
   d. Re-trace your design and your initials, and again let the ink dry for 1 min.
4. Begin the etching process.
   a. First, make a table in your science notebook to record the properties of the copper on the circuit board and the copper chloride etching solution before and after you place the board in the solution for etching.
   b. Look at the circuit board and the copper chloride etching solution. Record your observations in the table in your science notebook.
   c. Your teacher will place your circuit board in the tray. It will soak there overnight.

Part B: Examining the Circuit Board

5. Observe the used copper chloride after the etching process has completed. Describe your observations in your science notebook.
6. Obtain your circuit board from your teacher after it has been rinsed off with water.
7. Rub your circuit board with steel wool to remove any remaining ink.
8. Examine your circuit board, and then test it with the battery-and-light-bulb circuit. Record the results of your test.

Part C: Reading

Refer to Student Sheet 1.1, "Three-level Reading Guide: Etching Circuit Boards," to guide you as you complete the following reading. Be sure to pay attention to the illustrations and relate them to the text and your experience producing a circuit board.

MAKE PRODUCTS, MAKE WASTE

Making Everyday Products

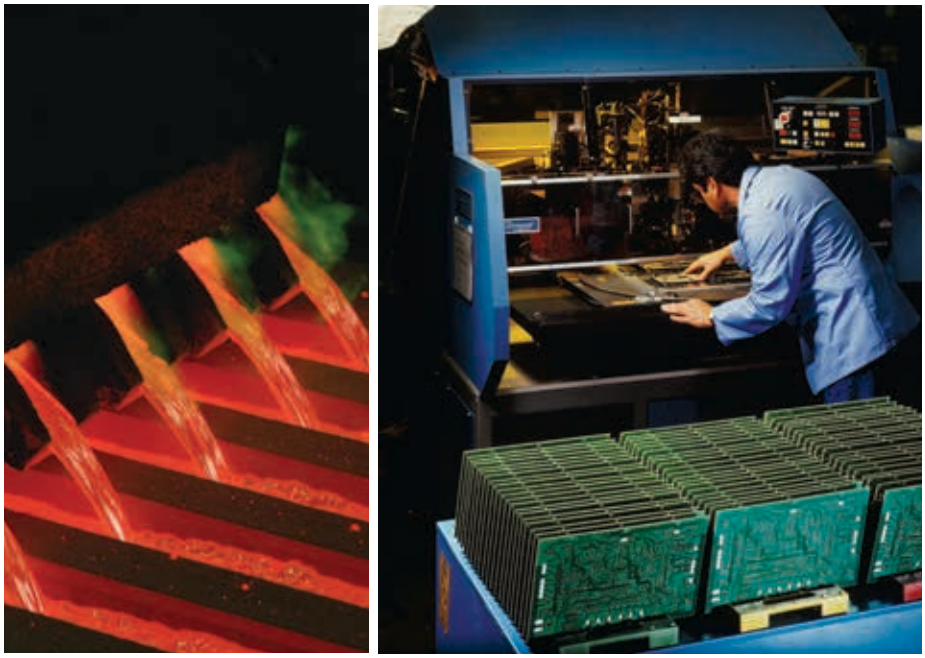
People buy and use products every day. These products include items we consume and dispose of right away. But we also buy products that serve us for longer periods of time, like sneakers, cell phones, or computers. What happens before you buy a product? It has to be made from materials, and those materials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

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

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

Making Circuit Boards

To make your circuit board, you used a process very similar to that used in the circuit board industry. This process is based on the chemical characteristics of copper. A chemical process etches a copper circuit on a piece of plastic. To **etch** a copper circuit board means to use a corrosive solution to create a circuit for the flow of electricity. The corrosive solution removes any unwanted copper. The copper that is protected from the etching solution (in your investigation, the copper below the permanent marker) is left on the board and creates a metal path. The metal path of a circuit board determines how electricity flows throughout the computer. This process removes much of the copper on the board, leaving it in the etching solution.



Hot liquid metal copper is poured into molds where it will cool (left). A technician works with a machine that etches copper circuit boards (right).

Making Waste

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

As you observed in this activity, after a circuit board is etched, the used etching solution and rinse water contain copper in a different form than you began with. Other steps in the computer manufacturing process create yet more wastes that have copper in them. Solutions

Mining and manufacturing copper-containing substances can result in waterways that are polluted with copper waste.

containing copper above a certain level are considered toxic. The U. S. Environmental Protection Agency (EPA) reports on yearly releases of chemicals. In 2015, they reported that copper made up about 5% of all the toxic chemicals released into the environment. That's about 76,000 metric tons of copper.

Copper Isn't Always Bad

The human body needs small amounts of copper and other metals to function properly. That is why they are often among the ingredients of vitamin and mineral supplements. The U.S. Food and Drug Administration (FDA) recommends adults get about 2 milligrams (mg) of copper each day. But in much larger amounts, copper and other metals can be toxic. High levels of copper in drinking water can cause

vomiting, diarrhea, stomach cramps, and nausea. Eating or drinking even higher 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, water, and sewer systems. This helps keep the environment cleaner and safer. But manufacturing products that people want, 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 scientists and engineers face every day. It often costs companies a great deal of money to dispose of toxic waste safely. But, even though some chemical processes produce wastes, other chemical processes have been designed to clean up wastes.

ANALYSIS

1. Describe the changes that occurred to the properties of the following during the etching process:
   a. your circuit board
   b. the copper chloride etching solution
2. **Evidence** is factual information or data that support or refute a claim. How does your answer to item 1 provide evidence about whether the starting and final substances change during the etching process?
3. The etching process produced waste etching solution.
   a. What do you think should be done with this waste?
   b. A **trade-off** is an exchange of one outcome for another—giving up something that is a benefit or advantage in exchange for something that may be more desirable. What is one trade-off of your suggestion in 3a?
4. 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?