12 Recovering Copper

LABORATORY

2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students investigate the use of reactions with three metals for reducing copper waste and reclaiming copper from the used copper-etching solution produced in the first activity of the unit. Students use data from their investigation and text sources to develop an evidence-based argument for which metal is the best choice for recovering copper from the waste solution.

NGSS CORRELATIONS

Performance Expectations

Applying MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Applying MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

Disciplinary Core Ideas

MS-PS1.A Structure and Properties of Matter: Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.

MS-PS1.B Chemical Reactions: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze and interpret data to determine similarities and differences in findings.

Planning and Carrying Out Investigations: Conduct an investigation to produce data to serve as the basis for evidence that meet the goals of an investigation.

Engaging in Argument from Evidence: Construct and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

Crosscutting Concepts

Patterns: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Energy and Matter: Matter is conserved because atoms are conserved in physical and chemical processes.

Common Core State Standards—ELA/Literacy

WHST.6-8.1: Write arguments focused on discipline-specific content.

INVESTIGATIVE PHENOMENA AND SENSEMAKING

Sometimes when we make a product, we get side products that we don't want—but we can do something about it.

Students are introduced to a scenario in which chemicals are used to make a useful product, but they also produce unwanted wastes. Students discuss their ideas about solutions to the waste produced and develop questions that need to be answered before they can fully understand and figure out a solution to the problem in the scenario.

WHAT STUDENTS DO

Students compare the effectiveness of three different metals in extracting copper from the used copper chloride solution from the activity "Producing Circuit Boards." After determining which metals remove copper ions from the solution, they examine cost- and health-related information to inform their decision of which metal to use.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  - 1 Visual Aid 12.1, "Wastewater Discharge Limits"
  - 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T)
  - 1 SEPUP tray containing a serial dilution of 100,000 ppm copper chloride
    Teacher's Note: Directions for preparing a serial dilution are provided below.
  - 1 dropper bottle of 100,000 ppm copper chloride solution
  - 8 empty bottles labeled "Used Copper Chloride Solution"
  - 1 dropper

- 1 stir stick
- 1 permanent marker
- * 1 cup of rinse water
- * 1 cup of clean water
- * 1 10-mL (or smaller) graduated cylinder
- * 1 pair of disposable latex gloves
- * 1 pair of chemical splash goggles
- * paper towels
- * masking tape

■ *For the class*

- * 1 waste container

■ *For each group of four students*

- 1 dropper bottle of used copper chloride solution from the "Producing Circuit Boards" activity
- 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
- 1 pair of forceps
- * paper towels

■ *For each student*

- 1 Student Sheet 12.1, "Reclaiming Copper from Waste"
- 1 Student Sheet 12.2, "Writing Frame: Evidence and Trade-Offs" (optional)
- 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T) (optional)
- * 1 pair of chemical splash goggles

** not included in kit*

The EVIDENCE AND TRADE-OFFS (E&T) Scoring Guide can be found in the Assessment tab in the back of this Teacher Edition.

Fill the empty 30-mL dropper bottles labeled "Used Copper Chloride Solution" with the used etching solution produced in the activity "Producing Circuit Boards."

Prepare the serial dilution by placing 10 drops of 100,000-ppm copper chloride solution in Cup 1 of the SEPUP tray. Use a clean dropper to transfer 1 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 dropper. Add 9 drops of water to Cup 2. Stir the solution with the stir stick. Clean the stir stick. Use the dropper to transfer 1 drop from Cup 2 to Cup 3. Return any excess in the dropper to Cup 2, and rinse the dropper. Add 9 drops of water to Cup 3 and stir. Continue this dilution process through Cup 6.

SAFETY NOTE

Have students wear chemical splash goggles during the activity. The used copper chloride solution is toxic and corrosive. Make sure that they avoid contact with skin and eyes. People who have an allergic reaction to the copper chloride solution may experience itching and redness in the affected area for a short time. Wash any affected areas with water for 2–3 min. Rinse affected eyes for 15–30 min, and consult a doctor.

DISPOSAL

Have students scoop the solid metals from the cups of the SEPUP tray with forceps or plastic spoons onto paper towels, and put the paper towels in the waste container. Dispose of the metals according to local regulations. It is important that you dispose of the liquid waste generated in this activity in accordance with your local regulations as well. See the Safety Note in the first activity, "Producing Circuit Boards," for more information on disposal.

TEACHING SUMMARY

GET STARTED

1. Enhance students' sensemaking by eliciting their prior knowledge of chemical reactions and hazardous waste.
   a. Review common chemical reactions that create waste products.
   b. Demonstrate the problems associated with diluting hazardous waste.
   c. Introduce the the fifth driving question, and review the introduction and the guiding question for this activity.

DO THE ACTIVITY

2. Students reclaim copper using three different metals.
   a. Explain the experimental setup.
   b. Review with students the evidence that would indicate that copper had been removed from the used copper chloride solution.
   c. Students complete the Procedure.
   d. Have student clean up their equipment.

BUILD UNDERSTANDING

3. The class discusses the results of the investigation.
   a. Have students share their observations and summarize the results.
   b. Explain that the aluminum, iron, and zinc metals not only removed the copper from solution, but they also formed new compounds that dissolved into the solution.
4. Students consider the trade-offs of selecting a metal for reclaiming copper.
   a. Discuss factors to consider before selecting a metal.
   b. Discuss wastewater limits for substances.
   c. (E&T ASSESSMENT) Introduce the EVIDENCE AND TRADE-OFFS (E&T) Scoring Guide.

TEACHING STEPS

GET STARTED

1. Enhance students' sensemaking by eliciting their prior knowledge of chemical reactions and hazardous waste.
   a. Review common chemical reactions that create waste products.

      Have students suggest chemical reactions that they have seen or learned about that are useful to manufacturing or to our daily lives. Students will likely suggest that chemical reactions are used to make circuit boards and to produce thermal and electrical energy. Remind students that when they made the circuit boards in the first activity of the unit, there was a waste solution left over that contained copper.
   b. Demonstrate the problems associated with diluting hazardous waste.

      Ask students how they think that waste might be disposed of. Students' suggestions will vary but will likely include the idea of pouring it down the drain, burying it, or mixing it to somehow change it. Ask students what they think would happen to the copper if they poured the waste down the drain. Students will likely say that it would get diluted or spread out into the water.

      Show students the serial dilution of copper chloride solution in the SEPUP tray. Note that the term *serial dilution* is not used in this unit, so students do not need to be familiar with this term. Explain the procedure you used to make the dilution. What they are seeing is copper chloride solution starting at 100,000 ppm (Cup 1), diluted tenfold in each cup, down to 1 ppm (Cup 6). Explain the unit *ppm* (parts per million) if your students are not familiar with it. Point out that we can no longer see any blue color in Cup 6, and ask students if they think the copper is truly gone. Students should recall that because mass is conserved, the copper cannot simply be "gotten rid of" by dilution or any other method; therefore, dilution is not an ideal way to handle toxic substances.

c. Introduce the fifth driving question, and review the introduction and guiding question for this activity.

Refer to the Driving Questions Board, and revisit the driving question from the first activity in the unit: What are the wastes from producing circuit boards, and is there anything we can do about them? Explain that students are returning to this driving question from the first activity for the final learning sequence of the unit. Ask students to add to or revise their responses to this question. Relate this driving question to the unit issue: How do people use chemical reactions to solve problems? Review the introduction and guiding question with the class. Explain that in this activity, the method of handling the waste produced in circuit board manufacturing is referred to as reclaiming the metal. This method is used to remove or reclaim the copper from the solution. This reduces the toxicity of the waste and provides a valuable material—copper metal—for reuse. Explain to students that they will use other metals to start a chemical reaction to try to remove the copper from the solution.

DO THE ACTIVITY

2. Students reclaim copper using three different metals.

a. Explain the experimental setup.

Point out that Cup 4, which contains only the copper chloride solution, acts not only as a control but also as a standard for comparing the color of the remaining liquids to that of the original. If your students are not familiar with the concept of a control, you may want to explain this idea further. You may also wish to have the serial dilution demonstration available for students to refer to throughout the Procedure. Leave the SEPUP tray on top of a piece of white paper in an area where students can come over and observe it.

b. Review with students the evidence that would indicate that copper had been removed from the used copper chloride solution.

Students will use ammonia to indicate the presence of copper in the solution. Emphasize that a change in the color of the solution indicates a chemical change. Also, the appearance of copper metal would be direct evidence that the copper was removed from the solution. Students will compare each cup to Cup 4, the control, to determine if a change has taken place. Suggest that students place the SEPUP tray over a sheet of white paper when comparing the liquids.

c. Students complete the Procedure.

Encourage students to discuss their observations with their partners as they do the experiment. When students conduct the ammonia test, you should point out that the ammonia shows the presence of copper in solution, but it gives only a broad estimation of how much copper is present. To help them obtain a more accurate estimation, have students compare the serial dilution of copper chloride to their results. Remind students that the used copper chloride solution had a concentration of about 100,000 ppm. Solutions that are lighter in color than the control have a lower copper concentration. Students can then compare their experimental results with the serial dilutions to evaluate the approximate copper concentration of the liquids remaining in Cups 1–3. Alternatively, students can remove the metals from Cups 1–3 and add ammonia to Cups 1–4 to compare the resulting reactions; a blue color indicates the presence of copper.

d. Have student clean up their equipment.

For cleanup, students should use a dropper and a plastic spoon to remove all solutions and solids from their containers, place them on paper towels, and place the paper towels in the waste container. They should blot any remaining liquid with a paper towel and dispose of it in the trash before washing all equipment.

BUILD UNDERSTANDING

3. The class discusses the results of the investigation.

a. Have students share their observations and summarize the results.

Teacher Resources

Science and Engineering Practices

Explain that students will use evidence from the investigation to *engage in argument from evidence* about the best way to treat the copper waste from circuit board production. Summarize students' data on the board, and help them compare the outcomes for each metal. You may wish to do this by displaying sample student data tables and discussing if the entire class acquired similar results. Students should observe that in comparison with Cup 4, which was the control, each of the three metals removed copper but to a different degree. The aluminum and zinc seemed to react the most; students may cite the vigorous bubbling, rapid deposition of copper metal, and rapid disappearance of the blue color from solution as evidence. Be sure to reinforce that the brown particles are pieces of copper metal. One common student misconception is that the brown solid is rust. If students have trouble understanding that it is not rust, remind them that rust, or iron oxide, is the result of a chemical reaction (corrosion reaction) that takes place when iron reacts chemically with oxygen and water.

b. Explain that the aluminum, iron, and zinc metals not only removed the copper from solution, but they also formed new compounds that dissolved into the solution.

The three reactions students observed in this investigation are all chemically similar. In each case, the solid metal (aluminum, iron, or zinc) replaces the copper in the copper chloride, which precipitates out as solid copper. Bubbles of hydrogen gas are produced, and energy is released in the exothermic reaction. In each reaction, the added metal reacts to form a soluble metal compound, whereas the copper compound reacts to form solid copper metal.

4. Students consider the trade-offs of selecting a metal for reclaiming copper.

a. Discuss factors to consider before selecting a metal.

Ask students what factors they think should be considered when selecting a metal to use to reclaim copper. List and discuss their suggestions. In addition to the reactivity of the metal, students may be concerned about the toxicity, cost, availability, and health effects of disposal of a replacement metal. Ask students which of these factors they think is the most important when deciding which metal to use. Point out that making such a decision requires considering the trade-offs.

b. Discuss wastewater limits for substances.

Remind students that copper is only one of many substances that are regulated as toxic waste. The waste students produced using the different metals to reclaim the copper also needs to be handled according to federal laws and local regulations.

Display Visual Aid 12.1, "Wastewater Discharge Limits," which compares the limits for three different municipal water districts. (Note that the data from Oswego, Illinois, are the basis for the maximum wastewater concentrations found in the table under Analysis item 3.) Point out that the maximum concentration of iron allowed in wastewater varies considerably among the three districts. While the federal government provides guidelines based on the current body of scientific knowledge, individual states and local districts decide how to implement these guidelines.

Some cities and counties take a conservative approach and establish wastewater restrictions in the absence of conclusive studies showing negative health effects. For example, although ingesting low levels of iron is not known to have any negative health effects (in fact, iron is a necessary daily mineral), two of the three districts shown on the Visual Aid restrict the disposal of solutions containing iron. Notice that aluminum is not included on the list of restricted substances. Ingesting low levels of aluminum is not known to cause any negative health effects. Large amounts of aluminum ingested over long periods of time may cause bone disease, but because there has been little research conducted in this area, no conclusive link has been established.

While showing the Visual Aid, discuss with the class how living organisms might be exposed to the chemicals released in wastewater. Wastewater that meets the regulations might be released into rivers, lakes, and other bodies of water, exposing animals and other organisms that live in those environments to these substances. Students may not know that public drinking water is usually water from natural sources in which toxic materials could be present. This is why drinking water is carefully treated and tested. Emphasize the cyclical nature of this use and reuse. Many factories generate wastewater during the production of consumer goods. This wastewater must be treated and disposed of, usually back into the local environment that communities rely on to meet their water needs.

c. (E&T ASSESSMENT) Introduce the EVIDENCE AND TRADE-OFFS (E&T) Scoring Guide.

SEPUP Scoring Guides

Analysis item 3 in this activity is the first use of the EVIDENCE AND TRADE-OFFS (E&T) Scoring Guide. Optionally project or distribute the Scoring Guide. Point out how it has the same levels as other Scoring Guides but different descriptions for each level. Review the levels as needed. A sample Level 4 response is provided in Samples Responses to Analysis.

If you wish, distribute to students Student Sheet 12.2, "Writing Frame: Evidence and Trade-Offs," to help them construct their responses. Before students complete Analysis item 3, be sure to discuss or reinforce the concept of a trade-off, which was introduced in the first activity of this unit. For this question, you may want students to work in pairs. This will allow them to practice together constructing an evidence and trade-offs answer. You may need to explain the phrase *trace amounts* to students. This phrase is used to describe amounts that are able to be detected but not measured or quantified.

Teacher's Note: If you emphasize writing formal lab reports in your class, you may want to use Analysis item 2 as the basis for a formal lab report.

EXTENSION

Students might want to investigate other ways that metals can be used to reclaim copper from the used copper chloride solution. Encourage them to design a procedure to conduct such an experiment. Ask them to detail what they will look for in their investigation and how they will interpret their results. Ensure that their proposed procedures incorporate safety protocols. If you feel secure that they will be safe and you will be able to oversee their investigation, allow them to conduct the tests and share the results with the class.

STRATEGIES FOR TEACHING DIVERSE LEARNERS

Below are suggestions for differentiating instruction and assessment in this activity for diverse learners in your classroom:

- Students with learning disabilities: Model for students how to fill in the first row of the data table on Student Sheet 12.1. Students may use the Writing Frame on optional Student Sheet 12.2 to help them answer Analysis item 3.
- English learners: Consider having students use the Writing Frame on optional Student Sheet 12.2 to help them answer Analysis item 3.

SAMPLE RESPONSES TO ANALYSIS

1. Explain the purpose of including Cup 4 and Cup 9 in your investigation.

   The purpose of Cup 4 and Cup 9 was to act as a control, to compare a cup where no metal was added to the cups where metal was added. Cup 9 also showed how much copper was in the starting used copper chloride solution.

2. Explain, using evidence from this investigation, which metal seemed to work best at removing the copper from solution.

   The aluminum and zinc were the best at removing the copper from solution. Both of these reactions bubbled a lot, the copper precipitate formed quickly, and the blue color of the solution disappeared quickly.

3. (E&T ASSESSMENT) **Revisit the issue:** Companies that make circuit boards often reclaim copper from copper-containing solutions. This allows them to reuse the copper or to sell it. Based on your results from this investigation and the information in the following table, which metal would you recommend that 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 2017 (U.S. dollars)	Maximum wastewater concentration (ppm)	Health benefits	Health hazards
Aluminum	$0.93	Not restricted	Trace amounts may help important chemical reactions in the human body.	High levels may cause bone disease.
Copper	$3.09	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	$0.03	100	Essential for formation of red blood cells; the recommended daily intake for an average adult is 18 mg.	Large amounts ingested over time may cause inflammation and damage to organs.
Zinc	$1.47	2.4	Small amounts are needed for functioning 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.

SAMPLE LEVEL 4 RESPONSE

There is a lot of discussion about the issue of which metal is best for reclaiming copper from wastewater. My decision is that aluminum is the best choice to reclaim the copper. My decision is based on the following evidence. First, aluminum removed a lot of the copper from the solution, more than iron. Second, even though zinc worked well to reclaim the copper, it is more regulated than aluminum. Third, replacing the copper with aluminum makes the waste less toxic. Humans can take in more aluminum every day than they can copper, so if someone accidentally drinks water containing aluminum, they should be okay. People who disagree with my decision might say that the waste still has to be disposed of carefully since high amounts of aluminum can still hurt humans. A trade-off of using aluminum is that it is not the cheapest metal.

REVISIT THE GUIDING QUESTION

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

Review with students the choices they made in Analysis item 3 for which metal they think is best. Encourage students to discuss how they made their decision and what trade-offs they considered. Have students share if they had an easy or difficult time deciding which metal to choose, and if any other information might have been helpful to them in making their decision.

ACTIVITY RESOURCES

KEY VOCABULARY

chemical reaction

evidence

product

reactant

reclaim, reclaimed, reclamation

trade-off

BACKGROUND INFORMATION

RECLAIMING METALS FROM HAZARDOUS WASTES

The overall aluminum–copper-chloride reaction in this activity is written as follows:

$6\ CuCl_2\ (aq) + 6\ H_2O\ (l) + 6\ Al\ (s) \rightarrow 3\ H_2\ (g) + 4\ AlCl_3\ (aq) + 6\ Cu\ (s) + 2\ Al(OH)_3\ (aq)$

The iron–copper and zinc–copper reactions are similar in that each of the three reactions is a type of single-replacement reaction. In the aluminum–copper reaction, the chloride ions help remove the aluminum oxide coating so that a reaction can take place through the oxidation of aluminum (loss of electrons) and the reduction of copper ions (gain of electrons). The aluminum–copper-chloride reaction is a simplified version of a waste reclamation and reduction strategy for handling toxic waste materials. One of the ultimate goals of green chemistry is to modify industrial processes in ways that eliminate the production of waste. But, if this is not accomplished and metal waste is produced, reclaiming the metal is one way to treat the waste.

REFERENCES

City of San Jose Environmental Services. (2007). New local limits adopted for industrial users. *Tributary Tribune*. http://www.sanjoseca.gov/ArchiveCenter/ViewFile/Item/1366

Fox Metro Water Reclamation District. (2017). *Discharge limits & levels (Ordinance #864)*. http://www.foxmetro.org/departments/pretreatment/discharge-limits/

King County Industrial Waste Program. (2017). *Discharge limits and prohibited discharges*. http://www.kingcounty.gov/services/environment/wastewater/industrial-waste/limits-regulations/limits-prohibited.aspx

Name____ Date__________

STUDENT SHEET 12.1

RECLAIMING COPPER FROM WASTE

Cup	Metal	Initial observations of metal	Final observations of metal	Observations of reaction	Observations of remaining liquid	Observations of ammonia test	Copper present?
1							
2							
3							
4							

Name____ Date__________

STUDENT SHEET 12.2

WRITING FRAME: EVIDENCE AND TRADE-OFFS

There is a lot of discussion about the issue of ______________________________

____

My decision is that ____

____

My decision is based on the following evidence:

First, ____

____

____

Second, ____

____

____

Third, ____

____

____

The trade-off is ____

____

____

People who disagree with my decision might say that ________________________

____

____

Name *Sample student response* Date

STUDENT SHEET 12.1

RECLAIMING COPPER FROM WASTE

Cup	Metal	Initial observations of metal	Final observations of metal	Observations of reaction	Observations of remaining liquid	Observations of ammonia test	Copper present?
1	*Aluminum*	*Dull gray color*	*Brown-black coating, thinner*	*Fast bubbling, brown solid forming in dish; gas rising*	*Clear in color, contains black and brown solids*	*Gray gel-like precipitate forms*	*No*
2	*Iron*	*Black-gray color*	*Red-brown coating*	*Brown solid forming on metal*	*A lighter green than original solution*	*Brown precipitate forms*	*No*
3	*Zinc*	*Shiny silver color*	*Red-brown coating*	*Brown solid forming on metal*	*Light-green to clear in color*	*White precipitate forms*	*Some*
4	*Control/ none*	*No solid metal visible in solution*	*No solid metal visible in solution*	*No reaction occurred*	*Original blue-green color*	*Bluish green to dark blue precipitate forms*	*Yes*

Name *Sample student response* Date

STUDENT SHEET 12.2

WRITING FRAME: EVIDENCE AND TRADE-OFFS

There is a lot of discussion about the issue of

which metal is best for reclaiming copper from wastewater.

My decision is that

aluminum is the best choice to reclaim the copper.

My decision is based on the following evidence:

First,

aluminum removed a lot of the copper from the solution, more than iron.

Second,

even though zinc worked well to reclaim the copper, it is more regulated than aluminum.

Third,

replacing the copper with aluminum makes the waste less toxic. Humans can take in more aluminum every day than they can copper, so if someone accidentally drinks water containing aluminum, they should be okay.

The trade-off is *that aluminum is not the cheapest metal.*

People who disagree with my decision might say that

the waste still has to be disposed of carefully since high amounts of aluminum can still hurt humans.

VISUAL AID 12.1

RECLAIMING COPPER FROM WASTE

Maximum Daily Concentration (ppm) Considered Safe

	King County, Washington	Oswego, Illinois	San Jose, California
Arsenic	4.0	0.145	1.0
Cadmium	0.6	0.04	0.7
Chromium	5.0	1.0	1.0
Copper	8.0	2.4	2.3
Iron	—	100.0	—
Lead	4.0	0.4	0.4
Mercury	0.2	0.0005	0.010
Nickel	5.0	0.4	0.5
Silver	3.9	0.7	0.7
Zinc	10.0	2.4	2.6

Other disposal restrictions include limits on the following:

- temperature
- pH
- flammable and/or explosive materials
- solids that harden
- organic pollutants
- corrosive substances
- fats, oils, and grease

EVIDENCE AND TRADE-OFFS (E&T)

When to use this Scoring Guide:

This Scoring Guide is used when students are making a choice or developing an argument about a socioscientific issue, where arguments may include judgments based on nonscientific factors.

What to look for:

- Response uses relevant evidence, disciplinary core ideas, and crosscutting concepts to compare multiple options in order to make a choice.
- Response takes a position supported by evidence and describes what is given up (traded off) for the chosen option.

Level	Description
Level 4 Complete and correct	The student provides a clear and relevant choice with appropriate evidence and reasoning, including BOTH of the following: • a thorough description of the trade-offs of the decision • reasons why an alternative choice was rejected
Level 3 Almost there	The student provides a clear and relevant choice with appropriate and sufficient evidence and reasoning, BUT one or both of the following are insufficient: • the description of the trade-offs • reasons why an alternate choice was rejected
Level 2 On the way	The student provides a clear and relevant choice BUT evidence and reasoning are incomplete.
Level 1 Getting started	The student provides a clear and relevant choice BUT provides reasons that are subjective, inaccurate, or unscientific.
Level 0	The student's response is missing, illegible, or irrelevant.
x	The student had no opportunity to respond.

NGSS OVERVIEW

CHEMICAL REACTIONS

Performance Expectation MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Performance Expectation MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

Performance Expectation MS-PS1-6*: Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

Performance Expectation MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Performance Expectation MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

* *Performance expectations marked with an asterisk integrate traditional science content with engineering through a Science and Engineering Practice or Disciplinary Core Idea.*

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
1. **Investigation: Producing Circuit Boards** Students analyze and interpret data to compare the initial and final substances when a copper-coated circuit board is etched. This begins a series of activities that reveal patterns of changes indicating that chemical reactions have taken place.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 RST.6-8.9
2. **Laboratory: Evidence of Chemical Change** Students carry out an investigation and analyze the results to identify evidence that may indicate that a chemical change has taken place. In later activities, the patterns they observe at the macroscopic level will be explained in terms of changes at the atomic/molecular level.	MS-PS1.A MS-PS1.B	Planning and Carrying Out Investigations Analyzing and Interpreting Data Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.3
3. **Reading: Physical Changes and Chemical Reactions** Students read about observable (macroscopic) and atomic/molecular-level patterns of changes in physical and chemical properties and how they can be signs of chemical reactions. They also read about how to use logical reasoning to avoid mistaking physical changes for chemical changes. They integrate ideas in the reading with their observations of chemical changes in the previous investigation, and analyze and interpret several examples to determine whether a change is physical or chemical.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Obtaining, Evaluating, and Communicating Information Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 RST.6-8.4 RST.6-8.7 WH.6-8.9

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
4. **Modeling: Chemical Reactions at the Molecular Scale** Students use molecular models to explore the kinds and numbers of each kind of atom, as well as the arrangements of atoms, in the reactants and products of several chemical reactions. The patterns they observe demonstrate the concept of conservation of atoms in chemical reactions, as well as the relationship between changes at the atomic/molecular scale and changes in the observable properties of substances.	MS-PS1.B	Developing and Using Models Connections to Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Scale, Proportion, and Quantity Structure and Function	ELA/Literacy: RST.6-8.3
5. **Talking It Over: Physical or Chemical Change?** Students analyze and interpret information on the observable properties of substances before and after a change to determine whether the change is a physical change or a chemical reaction. This activity provides an assessment opportunity for Performance Expectation MS-PS1-2.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Systems and System Models Engaging in Argument from Evidence Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 SL.8.1
6. **Laboratory: Comparing the Masses of Reactants and Products** Students investigate conservation of mass on a macroscopic scale. Students analyze and interpret data from two reactions to determine how the total mass of the products of a chemical reaction compares to the total mass of the reactants.	MS-PS1.B	Analyzing and Interpreting Data Connections to Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Systems and System Models Scale, Proportion, and Quantity	ELA/Literacy: RST.6-8.3
7. **Modeling: Explaining Conservation of Mass** Students use a combination of molecular modeling and mathematical computation to describe the atomic/molecular basis for mass conservation in chemical reactions. They are introduced to the law of conservation of mass and the relevance of this law to various natural phenomena. This activity provides an assessment opportunity for Performance Expectation MS-PS1-5.	MS-PS1.B	Developing and Using Models Systems and System Models Connections to the Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Systems and System Models Scale, Proportion, and Quantity	

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
8. **Investigation: Chemical Batteries** Students investigate how chemical energy can be transformed via a chemical process into electrical energy. After building a prototype wet cell, students brainstorm improvements and build, test, and evaluate new prototypes to meet a set of predetermined criteria within specified constraints.	MS-PS1.B MS-ETS1.B MS-ETS1.C	Constructing Explanations and Designing Solutions	Energy and Matter	ELA/Literacy: RST.6-8.3
9. **Laboratory: Thermal Energy and Reactions** Students explore chemical reactions that absorb or release thermal energy. Through classroom discussion, students are introduced to the crosscutting concept that energy and matter are conserved but can transfer within a system between reactants, products, and the environment. They are also introduced to the idea that the absorption or release of energy is caused by the rearrangement of atoms during a reaction. Some rearrangements require energy; others release it.	MS-PS1.B MS-PS3.A	Analyzing and Interpreting Data	Energy and Matter	ELA/Literacy: RST.6-8.3
10. **Design: Developing a Prototype** Students undertake a design challenge to construct and test a hand warmer device that uses the thermal energy released from an iron exothermic reaction. When testing their designs, students analyze their results and brainstorm ideas for further modification.	MS-PS1.B MS-ETS1.B MS-ETS1.C MS-PS3.A	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions Developing and Using Models	Energy and Matter	
11. **Design: Refining the Design** Students use the thermal energy release from combining iron, calcium chloride, and water to design a hand warmer. Students redesign, construct, test, and evaluate their hand warmer designs from the "Developing a Prototype" activity. A new criterion is introduced— students must consider how to control the start of the chemical reaction in their design modifications. This activity provides an assessment opportunity for Performance Expectation MS-PS1-6.	MS-PS1.B MS-ETS1.B MS-ETS1.C MS-PS3.A	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions	Energy and Matter	

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
12. **Laboratory: Recovering Copper** Students investigate the use of reactions with three metals for reducing copper waste and reclaiming copper from the used copper-etching solution produced in the first activity of the unit. Students use data from their investigation and text sources to develop an evidence- based argument for which metal is the best choice for recovering copper from the waste solution.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Planning and Carrying Out Investigations Engaging in Argument from Evidence	Patterns Energy and Matter	ELA/Literacy: WHST.6-8.1
13. **Laboratory: Another Approach to Recovering Copper** Students close the unit by applying what they have learned in previous activities to conduct a final investigation to figure out which precipitation reaction works best to remove copper from wastewater. Students analyze and interpret their data from this activity and previous activities to develop their evidence-based argument for the best choice of reactions.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Planning and Carrying Out Investigations Engaging in Argument from Evidence	Patterns Energy and Matter	ELA/Literacy: WHST.6-8.1

PHENOMENA, DRIVING QUESTIONS AND SEPUP STORYLINE

CHEMICAL REACTIONS

CHEMICAL REACTIONS

Unit Issue: The use of chemical reactions to solve problems.

Anchoring Phenomenon: Chemical reactions can be used to solve problems but can also create problems. Examples explored include combining certain substances releases a gas, combining certain substances releases energy (such thermal energy, light, electricity), and combining certain liquids results in a color change or formation of a solid. Students generate and answer questions such as: What happens when new materials are formed? How do particles combine into new substances? How can chemical reactions solve and create problems?

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
Sometimes when we make a product, we get side products that we don't want.	What are the wastes from producing circuit boards, and is there anything we can do about them?	What happens when chemical processes are used to produce electronic devices? (Activity 1)	1 (12, 13)	MS-PS1-2 MS-PS1-5	Chemical reactions are used to produce desirable products (circuit boards), but they also lead to production of wastes (by-products) from chemical processes. (Substances can be identified by their properties and can't be made to just "go away.")
When you mix some substances, they do things like fizz, change color, disappear or change temperature.	What is happening when substances appear to change?	How can you tell if a chemical change has occurred? (Activity 2)	2, 3, 5	MS-PS1-2 MS-PS1-5 MS-PS1-6	Four common signs may frequently indicate that chemical reactions have taken place.
		What is the difference between a physical and a chemical change? (Activity 3)			Careful observation of properties is needed to distinguish physical and chemical changes. These macroscopic changes can be explained by what is happening at the level of atoms and molecules.
		Is the phenomenon observed a physical change or a chemical change (reaction)? (Activity 5)			In this activity, students apply what they have learned about physical and chemical changes to several scenarios.

PHENOMENA, DRIVING QUESTIONS AND SEPUP STORYLINE

CHEMICAL REACTIONS (continued)

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
In chemical reactions, the total amount of matter after the reaction is the same as the total amount of matter before the reaction.	How is mass conserved during a chemical reaction?	What happens to atoms and molecules during a chemical reaction? (Activity 4)	4, 6, 7	MS-PS1-2 MS-PS1-5	Atoms are reorganized and conserved in chemical reactions. Changes in the organization of particles at the atomic/ molecular scale helps to explain physical and chemical changes and to distinguish one from the other.
		What happens to the mass of the reactants during a chemical reaction? (Activity 6)			The total mass of the products of a reaction equals the total mass of the reactants.
		Why is mass always conserved in chemical reactions? (Activity 7)			The conservation of atoms during reactions explains the conservation of mass.
When you mix some chemicals, they get hot or cold or give off electricity or light.	How can chemical reactions be used to provide energy?	How can we improve the design of a chemical battery? (Activity 8)	8, 9, 10, 11	MS-PS1-2 MS-PS1-6 MS-ETS1-3 MS-ETS1-4	Changing certain variables can affect how much energy is produced from a reaction.
		What does thermal energy have to do with chemical reactions? (Activity 9)			Chemical reactions can be used to release or absorb thermal energy.
		How do engineers design and test a prototype hand warmer? (Activity 10)			Variables can be modified as a device, such as a cold pack, is designed and refined through testing.
		How can the hand warmer design prototypes be redesigned and improved? (Activity 11)			

PHENOMENA, DRIVING QUESTIONS AND SEPUP STORYLINE

CHEMICAL REACTIONS (continued)

Investigative Phenomena	Driving Questions	Guiding Questions	Activities	PE	Storyline
Sometimes when we make a product, we get side products that we don't want— but we can do something about it.	What are the wastes from producing circuit boards, and is there anything we can do about them?	Which metal is best at reclaiming copper from the used copper chloride solution? (Activity 12) What is the best option for reclaiming copper metal from the used copper chloride solution? (Activity 13)	12, 13	MS-PS1-2 MS-PS1-5	Several chemical reactions can be used to reclaim copper from circuit board production, and the best reaction to use can be evaluated based on several criteria.

UNIT OVERVIEW

CHEMICAL REACTIONS

Unit Issue: The use of chemical reactions to solve problems.

Anchoring Phenomenon: Chemical reactions can be used to solve problems but can also create problems.

Listed below is a summary of the activities in this unit. Note that the total teaching time is listed as 19–25 periods of approximately 45–50 minutes (approximately 4–5 weeks). If you find you cannot finish in this time frame, consider skipping Activity 8, especially if students are familiar with development of a prototype.

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
1. **Investigation: Producing Circuit Boards** After a brief introduction to the function of a circuit board in a computer and other electronic devices, students mask a circuit board and etch it with an acidic copper-etching solution. They then read about the etching process and consider the copper-containing waste it produces.	Properties of substances, circuit boards, evidence, trade-offs LITERACY	Obtain circuit board sample (optional); fill a beaker with water; prepare Student Sheet.		2–3
2. **Laboratory: Evidence of Chemical Change** The class reviews the safety guidelines for working with chemicals in the science classroom. They investigate five chemical changes. For each one, they identify the signs of chemical change and the elements present before and after the reactions. Students discover that in a chemical change, new substances form that have different properties from the starting substances. They are introduced to the idea that the elements in the substances at the beginning and end of the reaction are the same, but they have rearranged into new chemical combinations.	Properties of substances, chemical change, chemical reactions, evidence of reactions LITERACY	Prepare materials for the demonstrations; prepare Student Sheets.	AID A3	2
3. **Reading: Physical Changes and Chemical Reactions** Students read about both physical and chemical changes. They learn how to distinguish these two phenomena at the observable level and begin to describe how they are different at the atomic/molecular scale.	Physical vs. chemical changes at macroscopic and atomic/molecular levels, evidence of reactions, dissolving, precipitate formation LITERACY SENSEMAKING	Prepare Student Sheet.	AID A4	2

CHEMICAL REACTIONS (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
4. **Modeling: Chemical Reactions at the Molecular Scale** Students use molecular models to investigate the reactants and products of chemical reactions. They apply their experiences with the models to develop the idea that kinds of atoms and the number of each kind of atom in the reactants and products are identical.	Chemical equations, conservation of atoms, reactants, products	Prepare modeling sets.	MOD QUICK CHECK A1	1–2
5. **Talking It Over: Physical or Chemical Change?** Student groups consider six scenarios that describe changes in matter. They apply evidence and logical reasoning to develop arguments about whether each scenario describes a physical change or a chemical reaction.	Properties of substances, chemical and physical changes, chemical reactions SENSEMAKING	Prepare Student Sheets.	AID A3 (Assessment of PE MS-PS1-2)	2–3
6. **Laboratory: Comparing the Masses of Reactants and Products** Students explore the law of conservation of mass. They conduct a precipitation reaction and measure the total mass before and after the reaction. Future activities will build on this concept as students are asked to think about the implications of conservation of atoms and mass in their investigations of chemical methods of waste treatment.	Chemical reactions, mass, reactants, products	Set up electronic balances.	QUICK CHECK A2	1
7. **Modeling: Explaining Conservation of Mass** Students are given evidence about the masses of atoms. They use this to model mass conservation as an outcome of conservation of atoms. This is tied to the concept that the copper from the "Producing Circuit Boards" activity has not gone away; it is just in a different form.	Conservation of atoms, conservation of mass	Prepare modeling sets.	MOD A1 (Assessment of PE MS-PS1-5)	1
8. **Investigation: Chemical Batteries** Students build a chemical battery that transforms chemical energy into electrical energy, which in turn powers a motor. After building an initial prototype battery, students are given a set of criteria and constraints and asked to design a chemical battery that spins faster than the initial prototype for at least 5 min. Students brainstorm, build, test, and evaluate their prototypes.	Energy transformation, batteries, design criteria and constraints	Prepare Student Sheet.		1–2

CHEMICAL REACTIONS (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
9. **Laboratory: Thermal Energy and Reactions** Students set up two chemical reactions, measuring the temperature of the reactants and products. They use their measurements to identify which reaction releases and which absorbs energy.	Thermal energy, energy change as evidence of reactions, endothermic and exothermic reactions		AID A1	1
10. **Design: Developing a Prototype** Students design a hand warmer and then construct, test, and evaluate a prototype.	Engineering design, criteria, constraints, prototypes, thermal energy, energy transfer, exothermic reactions	Prepare the demonstration hand warmer; prepare the pre-swelled beads 24 hours in advance; prepare Student Sheet.	QUICK CHECK A4	1–2
11. **Design: Refining the Design** Students brainstorm new designs that will allow users to start the chemical reaction when they want to use the hand warmer. These designs may be redesigns of those developed in the previous activity or may be totally new. Students discuss designs and choose one to build as a prototype. Pairs of students exchange prototypes, and test and evaluate them. Students then think about how to further modify their designs.	Engineering design, criteria, constraints, prototypes, thermal energy, energy transfer, exothermic reactions	Prepare the demonstration hand warmer; prepare more pre-swelled beads 24 hours in advance, if needed; prepare Student Sheet.	ENG A3 (Assessment of PE MS-PS1-6)	2–3
12. **Laboratory: Recovering Copper** Students compare the effectiveness of three different metals in extracting copper from the used copper chloride solution from the activity "Producing Circuit Boards." After determining which of the metals removes copper ions from the solution, they examine cost- and health- related information to inform their decisions of which metal to use.	Metal replacement, chemical waste, reclaiming metal waste LITERACY	Fill empty labeled dropper bottles with used etching solution; set up the copper dilutions series; prepare Student Sheet.	E&T A3	2
13. **Laboratory: Another Approach to Recovering Copper** Students compare two double-replacement reactions for recovering the copper waste. They apply what they have learned in this activity and the previous activity to decide which reaction works best to reclaim the copper.	Metal replacement, chemical waste, reclaiming metal waste LITERACY	Refill dropper bottles with used etching solution; set up the control filtration; prepare Student Sheet.	E&T A2	1

This book is part of SEPUP's *Issues and Science* 17-unit multi-year course. The units are designed to allow for custom sequencing to meet local needs. For more information about these units, see the SEPUP and Lab-Aids websites listed at the bottom of this page.

- Land, Water, and Human Interactions
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- Earth's Resources
- Weather and Climate
- Solar System and Beyond
- Ecology
- Body Systems
- From Cells to Organisms
- Reproduction
- Evolution
- Biomedical Engineering
- Energy
- Chemistry of Materials
- Chemical Reactions
- Force and Motion
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Additional SEPUP instructional materials include:

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