High School Chemistry

Unit 3: Chemical bonding

Overview

In this unit, students will apply their knowledge of atomic structure and patterns in the periodic table to explore types of chemical bonding and to represent ionic and covalent compounds.

Lesson 1: Hands-on science activity (see below)

Lesson 2: Students will explore the nature of ionic bonds and learn about the octet rule. They will analyze patterns in the periodic table to predict chemical formulas and draw Lewis diagrams for simple ionic compounds.

Lesson 3: Students will expand their understanding of ionic compounds to include polyvalent metals and polyatomic ions. They will name ionic compounds and interpret these names to write chemical formulas.

Lesson 4: Students will explore the nature of covalent bonds and use the periodic table to predict the number of bonds an element will form. They will represent covalent compounds with formulas, names, and Lewis diagrams.

Lesson 5: Students will explore the nature of metallic bonds and synthesize their learning from all five lessons to identify a bond as ionic, covalent, or metallic based on the bonding elements' locations in the periodic table.

Hands-on science activity

What hidden trade-offs exist when we choose aluminum cans versus glass bottles for packaging?

Students will collect, **analyze, and interpret data** on the properties of substances with metallic, ionic, and covalent bonds in order to **develop models** for the relationship between types of bonds and macroscopic properties of substances. Students will use their models to make predictions and **construct explanations** about the advantages and disadvantages of different materials in specific applications.

Click here for links to the activity.

Standards

Performance expectations: **HS-PS1-1 | HS-PS1-3**

Disciplinary core ideas: **HS-PS1.A.2 | HS-PS1.A.3**

Science and engineering practices:

- Developing and using models
- Planning and carrying out investigations
- Constructing explanations and designing solutions
- Analyzing and interpreting data

Crosscutting concepts:

- Patterns
- Stability and change
- Structure and function
- Systems and system models

Click here to read the full standards.

Essential questions

- How are the properties of a substance related to the type of bonding between atoms in that substance?
- How can patterns in the periodic table be used to predict the way elements will bond with each other?
- How are compounds represented with chemical formulas, names, and Lewis diagrams?

Lesson notes

Lesson 1: Hands-on science activity

What hidden trade-offs exist when we choose aluminum cans versus glass bottles for packaging?

PEs: HS-PS1-3
DCIs: HS-PS1.A.3

Resources

Activity: 1

<table>
<tr><th>Description</th><th>Links</th></tr>
<tr><td>This activity is designed to help students connect the abstract concept of chemical bonds to observable properties of substances before they delve into the nature of bonding on an atomic level.

Students will collect, analyze, and interpret data on the properties of substances with metallic, ionic, and covalent bonds in order to develop models for the relationship between types of bonds and macroscopic properties of substances. Students will use their models to make predictions and construct explanations about the advantages and disadvantages of different materials in specific applications.</td><td>• Full activity overview (Khan Academy article)
• Student activity guide (Doc | PDF)
• Teacher guide (Doc | PDF)</td></tr>
</table>

Lesson 2: Ionic bonds

PEs: HS-PS1-1, HS-PS1-3
DCIs: HS-PS1.A.2, HS-PS1.A.3

Resources

Video: 3
Exercise: 2

<table>
<tr><th>Objectives</th><th>Teaching tips</th></tr>
<tr><td>• Describe the nature of an ionic bond, and use a particle model to represent the arrangement of cations and anions in an ionic solid.
• Predict which elements will bond ionically with each other based on their locations in the periodic table.
• Predict ion charges for main group elements based on their locations in the periodic table and the octet rule.</td><td>• Guide students to an understanding of the octet rule by reviewing and connecting the dots between several concepts from Unit 2. Prompt student recall by asking:
  ○ What is the pattern in the number of valence electrons for elements in groups 1-2 and 13-18?
  ○ What makes the elements in group 18 (noble gases) special?
  ○ What does it mean for an atom and an ion to be isoelectronic?
Note that atoms are more stable when they have full valence shells like the noble gases (8 electrons, or 2 for helium). One way they can achieve this stability is by gaining or losing electrons to become</td></tr>
</table>

• Use the periodic table to predict chemical formulas for ionic compounds made up of main group elements.
• Draw Lewis diagrams to represent ionic compounds.
	isoelectronic with the nearest noble gas in the periodic table.
	To help students understand the pattern of ion formation, have them fill in a chart for the elements in the third row of the periodic table with the following information:
	  ○ Lewis diagram of the neutral atom
	  ○ Number of valence electrons lost or gained in ion formation
	  ○ Charge on the ion formed
	  ○ Lewis diagram of the ion formed
	  ○ Noble gas isoelectronic with the ion formed
	• Based on the information in their charts, ask students to develop an explanation for why sodium and chlorine bond and why they form a compound in a 1:1 ratio. Prompt students to remember what they learned about attractive forces between oppositely charged particles (Coulomb's law) in Unit 2, and emphasize that an ionic bond is an attractive force between a positively charged cation and a negatively charged anion.
	• Guide students to recognize that the ratio between ions in a compound will depend on the number of electrons that each atom needs to lose or gain to complete its valence shell. Ask students to determine the ratios of cations to anions in compounds formed between Mg and O, Ca and Cl, and Na and O. For each set of elements, have students:
	  ○ Draw Lewis diagrams for the neutral atoms.
	  ○ Circle electrons that will be lost on the metal atom's diagram, and place an "x" in each spot on the nonmetal atom's diagram where an electron is needed to complete the valence shell.
	  ○ Add more metal or nonmetal atom Lewis diagrams until it is possible to draw an arrow from each circled electron to each "x" without any left over.
	  ○ Use the ratio of metal to nonmetal atoms determined from the Lewis diagrams to write the chemical formula for the neutral compound.
	• Emphasize that ionic compounds are neutral, so the charges of the anions and cations in their chemical formulas must add up to zero. Ask students to develop a method for showing how the ion charges in the formulas they wrote add up to zero.
	• Review patterns in the chemical formulas and physical properties of substances with ionic bonding from Lesson 1. Guide students to make hypotheses explaining these patterns based on the nature of ionic bonds.
	  ○ Use physical 3-D models or online animation tools (e.g., MolView or ChemTube3D) to help students visualize the crystal lattice structures of ionic compounds.
	  ○ Use the PhET Sugar and Salt Solutions simulation to help students visualize what happens when an ionic compound dissolves in water.
	• Introduce students to the phenomenon of giant salt crystal formation in the Naica Cave of Crystals. (*See the "Related phenomena" section below for more information.*)

Lesson 3: Ionic nomenclature

PEs: HS-PS1-1, HS-PS1-3
DCIs: HS-PS1.A.2, HS-PS1.A.3

Resources

Video	Article	Exercise
2	2	2

Objectives

- Name ionic compounds from their chemical formulas, including compounds containing **polyvalent metals** and/or **polyatomic ions**.
- Write chemical formulas for ionic compounds from their names, including compounds containing polyvalent metals and/or polyatomic ions.

Teaching tips

- Introduce the rules for naming simple ionic compounds (without polyvalent metals and/or polyatomic ions), and provide students with several examples to practice, including some that have subscripts in their chemical formulas.
    - During this process, students may ask about using prefixes, such as *di* or *tri*, to indicate the number of each kind of ion in the chemical formula. If this doesn't come up organically, it is useful to raise the question directly.
    - Emphasize that prefixes are NOT used in ionic compound names, and ask students to explain *why* no prefixes or other methods are needed to indicate the number of each kind of ion in the chemical formula.
    - Prompt student thinking by providing the names of several simple ionic compounds and asking them if they can use what they learned in the previous lesson to determine the chemical formulas.
- Once students are comfortable with the idea that they can predict the ion charges of main group elements from the periodic table and use these to determine the ratio between the ions in a neutral compound, introduce compounds containing polyvalent metals.
    - Present students with the chemical formulas for two compounds where the metal ion has two different charges, such as $FeCl_2$ and $FeCl_3$.
    - Ask students how they could determine the charge on the iron ion in each compound.
    - Prompt students to think about what they know (chloride has a 1- charge and the ion charges must add to zero) and use this to solve for what they don't know (the charge on the iron ion).
- Introduce the Roman numeral naming system for ionic compounds containing polyvalent metals, and provide students with a variety of practice problems. Emphasize the following steps:
    - Identify that a polyvalent metal is present in the chemical formula *based on its location in the periodic table.*
    - Determine the charge on the polyvalent metal ion *using the known charge on the anion.*
    - Include a Roman numeral in the compound's name *to indicate the charge on the metal ion.*
- Provide students with a list of common polyatomic ions that they can reference throughout this unit and the rest of the course.
- Ask students to create a "roadmap" for naming ionic compounds, including those containing polyvalent metals and/or polyatomic ions. This might take the form of a flow chart or a series of questions to ask themselves in order to determine the name from a chemical formula.

- Give students example problems to test the effectiveness of their roadmaps.
- Have students trade roadmaps and give each other feedback.
- Discuss some of the key takeaways from the activity.

A similar strategy can be applied to writing formulas from names.

- Continue exploring the structure and formation of giant salt crystals. *(See the "Related phenomena" section below for more information.)*

Lesson 4: Covalent bonds

PEs: HS-PS1-1, HS-PS1-3
DCIs: HS-PS1.A.2, HS-PS1.A.3

Resources

Video	Article	Exercise
2	1	3

Objectives

- Describe the nature of a **covalent bond** and how it differs from an ionic bond.
- Predict which elements will bond covalently with each other based on their locations in the periodic table.
- Predict the number of covalent bonds a nonmetal will form based on its location in the periodic table and an understanding of the octet rule.
- Name covalent compounds from their chemical formulas.
- Write chemical formulas for covalent compounds from their names.
- Draw and interpret Lewis diagrams for simple molecules.

Teaching tips

- Use the analogy of a tug of war to help students understand the difference between ionic and covalent bonding. Explain that in ionic bonding, one team (atom) has a much stronger pull on the rope (attraction for electrons), so it "wins" (takes the electron(s) from the other atom). In a covalent bond, both teams (atoms) have a strong pull on the rope (attraction for electrons), so no one "wins." Instead, both atoms remain attracted to the same pair of electrons and stay together. Revisit this analogy when discussing bond polarity in Unit 6.
  - Guide students to understand that a *shared* pair of electrons is attracted to the nuclei of *both* atoms simultaneously.
  - Emphasize that this differs from an ionic bond, where one or more electrons are *transferred completely* from a metal atom to a nonmetal atom, and the transferred electrons are no longer attracted to the nucleus of the resulting metal cation.
  - Ask students to come up with their own analogies to explain the differences between the two types of bonding.
- Review patterns in the chemical formulas and physical properties of substances with covalent bonding from Lesson 1. Guide students to make hypotheses explaining these patterns based on the nature of covalent bonds.
- Use the PhET Sugar and Salt Solutions simulation to help students visualize what happens when a covalent compound, like sugar, dissolves in water. Compare this to NaCl dissolving in water.
- Use Lewis diagrams for simple molecules, like Cl_2, O_2, and N_2, to help students understand how the number of valence electrons an atom has relates to the number of covalent bonds it is likely to form.
- Give students the chemical formulas and names of several different covalent compounds, such as those listed below. Have them work in pairs or small groups to analyze patterns and develop a list of "rules" for naming covalent compounds based on their chemical formulas.
  - Example compounds: carbon monoxide (CO), carbon dioxide (CO_2), dinitrogen pentoxide (N_2O_5), tetraphosphorus trisulfide (P_4S_3), sulfur hexafluoride (SF_6)
  - Invite students to share their ideas, and guide them to develop a class list of naming rules for covalent compounds.

- Ask students to explain why it is necessary to use prefixes to indicate the number of atoms of each element present in the chemical formula for a covalent compound, while it is not necessary for an ionic compound.
- Have students work with their partners to practice using the rules to write compound names from chemical formulas and chemical formulas from names.

- Once students understand how to name and write formulas for covalent compounds, challenge them with problem sets containing a mix of ionic and covalent compounds. This provides practice identifying the bond type and applying the correct set of rules for naming and writing formulas.
- Encourage students to take a systematic approach to drawing Lewis structures for molecules by providing graphic organizers that break the process down into specific steps. For example:
    - Determine the total number of valence electrons available for all atoms in the molecule.
    - Identify the central atom.
    - Draw single bonds between the central atom and other atoms.
    - Add lone pairs of electrons to complete the valence shell of each atom until the total number available is reached.
    - Change lone pairs to bonded pairs if not every atom has a full valence shell.
- Have students build molecules with model kits to reinforce the connection between the number of electrons needed to complete an atom's valence shell and the number of bonds formed.
- Invite students to explore chemical structures and recycling of plastics. *(See the "Related phenomena" section below for more information.)*

Lesson 5: Metallic bonds

PEs: HS-PS1-1, HS-PS1-3
DCIs: HS-PS1.A.2, HS-PS1.A.3

Resources

Video	Exercise
2	1

Objectives

- Describe the nature of **metallic bonds**, and compare them to ionic and covalent bonds.
- Identify a bond as ionic, covalent, or metallic based on the locations of bonding elements in the periodic table.

Teaching tips

- Use a video to introduce metallic bonds as attractive forces resulting from metal cations sharing a "delocalized sea" of valence electrons.
- Have students work in pairs or small groups on whiteboards to draw models representing each of the three types of bonding. Ask students to share their models with the class, and discuss the key features for each type of bonding.
- Have students compare and contrast the three types of bonding with a Venn diagram.
- Review patterns in the chemical formulas and physical properties of substances with metallic bonding from Lesson 1. Guide students to make hypotheses explaining these patterns based on the nature of metallic bonds. This video provides a useful discussion of the connections between bonding and properties in metals.

Related phenomena

Example phenomenon

How do giant salt crystals form?

Background information

In 2000, miners near Naica, Mexico, discovered a cave 300 m (nearly 1000 feet) underground filled with enormous milky-white selenite crystals. The largest crystal measured nearly 12 m long and 1 m wide and had an estimated mass of 12,000 kg.

Since its discovery, the Cave of Crystals, as it became known, has attracted researchers from around the world interested in understanding the conditions under which these massive crystals formed.

Giant selenite crystals in the Cave of the Crystals. Image credit: "Cristales cueva de Naica" by Alexander Van Driessche, CC BY-SA 4.0.

Selenite is a form of the mineral gypsum with the chemical formula $CaSO_4 \cdot 2H_2O$ (calcium sulfate dihydrate).

Its crystals are composed of calcium cations, sulfate anions, and water molecules. Ionic compounds (salts) crystallize when oppositely charged ions in concentrated solutions become attracted at a nucleation site (a small cluster of ions that can act as a surface for further crystal growth) and begin to arrange themselves in a repeating three-dimensional lattice structure. As the crystals grow, cations are surrounded by anions and anions are surrounded by cations, which maximizes attractive forces and minimizes repulsive forces. When water molecules are incorporated into the crystal lattice in a specific ratio with the ions, the compound is called a *hydrate*.

The more slowly crystals grow, the larger they tend to be. The rate of crystallization depends on several factors, including temperature, solution concentration, and the presence of impurities that can act as nucleation sites. It turns out that conditions in the Cave of Crystals were ideal for growing very large crystals very slowly.

About 26 million years ago, magma from below the Earth's surface forced its way upward, creating a mountain near the town of Naica and pushing hot, mineral-rich water into gaps in the mountain's limestone, one of which would become the Cave of Crystals. As calcium sulfate-rich water in the cave cooled very, very slowly over millennia, eventually reaching below 58 °C, a few selenite crystals began to nucleate and grow.

Both the concentration of the dissolved calcium sulfate (just barely supersaturated) and the incremental rate of cooling favored the slow growth of large crystals at just a few nucleation sites. Based on laboratory experiments that recreated different crystallization conditions, scientists estimated that it would take about 990,000 years for one of the giant crystals to grow under the current conditions in the cave.

Exploring this phenomenon helps students develop and master the following understandings:

- [ ] An ionic bond is an electrostatic attraction between a positively charged cation and a negatively charged anion.
- [ ] In an ionic solid, cations and anions are arranged in a crystal lattice formation that maximizes attraction between oppositely charged ions and minimizes repulsion between ions with like charges.

Tips for implementing phenomenon-based learning

- Introduce the phenomenon:
  - Show students a short National Geographic video about the Naica Crystal Cave to generate interest. Provide students with a template to take notes on the following questions:
    - How far beneath the Earth's surface is the cave?
    - What are the crystals in the cave made out of?
    - How much bigger are the crystals than any previously discovered?
    - What are some physical properties of the crystals that you notice?
    - What are the conditions needed for the crystals to grow?
    - Why is the cave considered "deadly?"
  - Discuss what students learned, and record a list of questions they have, based on seeing the video. Post the questions for easy reference throughout the unit, and use them as jumping off points for exploring aspects of the phenomenon or for assigning mini research projects.
- Explore the structure of the crystals:
  - Have students write the chemical formula and draw the Lewis diagram for calcium sulfate. Show the crystal structure for calcium sulfate dihydrate, and ask students what they notice about the arrangement of calcium and sulfate ions in the crystal.
  - Explain that a hydrate is an ionic compound with water molecules incorporated into the crystal lattice in a specific ratio with the ions. Show students how to name and represent the chemical formula of a hydrate. Introduce names and formulas of other hydrates to help students understand and apply the patterns.
  - Perform a simple demonstration to show that water is incorporated into the crystal lattice of a hydrate and can be removed through heating. Copper(II) sulfate pentahydrate is a good choice for the demonstration due to the deep blue color of the hydrate, which will change to a chalky light blue upon heating. Magnesium sulfate heptahydrate, commonly known as Epsom salt, is another readily available option.
    - Begin by measuring the combined mass of about 2 g of hydrate crystals and a small crucible or test tube. Record this initial mass value for reference later. Ask students to share their observations of the hydrate crystals (color, texture, luster, etc.).
    - Place the crystals in the crucible or test tube and heat them with a Bunsen burner flame. Periodically use a spatula to move the crystals around and break up clumps for more even heating. Ensure that students wear safety goggles and remain a safe distance from the burner throughout the demonstration.
    - Ask students to share their observations during the heating process. They may notice steam rising or condensing on the sides of the crucible or test tube, a popping sound as steam escapes from the crystals, and a change in the color and texture of the crystals.
    - When the crystals no longer appear to be changing, turn off the burner, and allow the sample to cool. While the sample cools, ask students to make inferences based on what they observed during the process of heating the hydrate. Have them predict how the mass of the sample after heating will compare with the mass before heating and use

evidence to support their predictions.

    - Once the sample cools, find the combined mass of the crystals and container. Compare the final mass to the initial mass, and ask students to explain how the change in mass provides evidence that water molecules were incorporated into the hydrate crystal.

- Explore the formation of the crystals:
  - Use the [PhET Sugar and Salt Solutions] simulation to help students understand how dissolved ions become attracted to each other and begin to form crystals.
    - Click on the *Micro* tab and add NaCl to the container of water. Ask students: *What happens to the Na^+ and Cl^- ions as the salt dissolves in the water?*
    - Move the evaporation slider on the bottom of the screen slightly to the right to gradually decrease the volume of the solution. Pause when the volume is about half of its starting value, and ask students: *How do the movement and interactions of the ions change as the water level slowly decreases?*
    - Decrease the volume of water by about half again until you see a few ions start to attract and form nucleation sites. If you stop it at just the right moment, you can see an equilibrium between crystals forming and dissolving. Asks students: *What causes groups of ions to begin clustering together?*
    - Decrease the volume of water until all of the ions have become attracted to form crystals. Ask students: *What do you notice about the way Na^+ and Cl^- ions are organized in the crystals? Which colored sphere represents which kind of ion, and what is your reasoning?*
  - Have students [grow their own sodium chloride crystals] under different conditions to investigate which conditions create the largest crystals.
    - Create a saturated salt solution by stirring sodium chloride into boiling water until no more will dissolve, then carefully pour the solution through a piece of filter paper into a beaker to remove undissolved salt crystals.
    - Tie one end of a piece of cotton string around a pencil, and set the pencil across the rim of the beaker, so that the other end of the string hangs down into the salt solution. Allow the solution to cool, and observe for the formation of crystals. Small crystals should appear in the first 1-2 days. These may be used as seed crystals in new experiments or allowed to continue growing.
    - Collect data on crystal size each day for a week or longer.
    - See [this resource] for an alternative procedure to grow salt crystals in petri dishes.
    - Experiment with different conditions:
      - Rate of cooling (room temperature, refrigerator, freezer)
      - Water purity (tap water versus distilled water and keeping the beaker uncovered versus covered to prevent dust particles from falling in)
      - Nucleation sites (different types of string, knots in the string, adding seed crystals)
      - Solution concentration (different amounts of salt in the same amount of water)

Example phenomenon

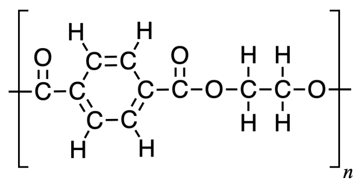
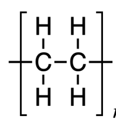
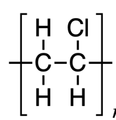
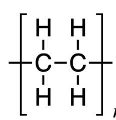
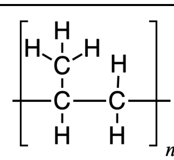
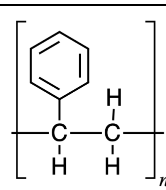
Why is it necessary to separate plastics for recycling?

Plastic bottles collected for recycling

Background information

Plastic materials are found everywhere in our daily lives. Their applications range from building materials to food and drink containers due to their ability to be molded into a variety of shapes and their lightweight, durable, and chemical resistant properties. All plastics are polymers—substances made of many repeating units bonded together. They are composed of long chains of carbon and hydrogen (and sometimes oxygen and chlorine) atoms bonded covalently in repeating patterns. Differences in the number of atoms of each kind of element and their bonding arrangements in the polymer chains lead to distinct properties that make different types of plastics more useful for particular applications.

The six most commonly recycled plastics have code numbers, which can be found inside the recycling symbol on containers. Their names, chemical structures, and common uses are shown in the table below.

Number	Name	Chemical structure of polymer*	Common uses
1	Polyethylene terephthalate (PETE)		Bottles and caps for soft drinks and water
2	High-density polyethylene		Milk jugs, squeeze bottles, and furniture
3	Polyvinyl chloride (PVC)		Construction and plumbing materials and bottles for cleaning products
4	Low-density polyethylene (LDPE)		Shopping bags, plastic wrap, and clear food containers
5	Polypropylene (PP)		Yogurt cups, heavy-duty microwaveable containers, and laboratory equipment
6	Polystyrene (PS)		Foam coffee cups and food containers, plastic utensils, and toys

**The Lewis diagram of the repeating unit in the polymer structure is shown inside brackets. This unit repeats n times, depending on the length of the polymer chain.*

While over 400 million metric tons of plastic are now produced globally each year, less than 10% of discarded plastic products get recycled. The rest gets incinerated, goes into landfills, or ends up as pollution in the environment. A number of factors contribute to the low recycling rate, starting with ineffective collection practices, but even after plastic trash is collected, the process of recycling the materials is complex.

One challenge is separating the different types of plastics from each other after collection. This is necessary, because each type of plastic has a different chemical structure, leading to different properties and applications. Two common techniques used for separation are sink-float sorting and optical sorting. In sink-float sorting, mixed plastics are placed in a water tank. High-density plastics (those with a density greater than 1 g/cm^3) sink to the bottom of the tank, and low-density plastics (those with a density less than 1 g/cm^3) float. Optical sorting uses near-infrared spectroscopy (NIR). When near-infrared light shines on plastic items, different types of plastic absorb and reflect this light in characteristic ways based on their different molecular structures. By analyzing the spectra produced, sensors can identify the type of plastic in an item.

After sorting, plastic waste must be washed to remove contaminants, shredded into smaller pieces, and sorted again to improve purity. It is then melted down and formed into pellets that are sold to manufacturers for making new products. Despite all of this effort, recycled plastics often are not entirely pure due to the presence of contaminants and some breakdown of the polymer structures. As a result, they often are used in applications where purity is less important and where they become less recyclable. For example, PETE recovered from water bottles may be spun into fibers for clothing, and HDPE from milk jugs can be made into plastic “lumber” used in outdoor furniture.

Exploring this phenomenon helps students develop and master the following understandings:

- [ ] Nonmetal atoms form covalent bonds with other nonmetal atoms.
- [ ] Lewis diagrams can be used to represent the arrangement of bonded atoms in covalent compounds.
- [ ] The same elements can form multiple different covalent compounds with distinct properties, depending on the number of atoms of each kind of element and their bonding arrangement in a molecule.

Tips for implementing phenomenon-based learning

- Ideas to encourage student engagement:
    - Ask students to bring in empty plastic containers from home or to collect some from school recycling bins with a variety of recycling code numbers. Water or soda bottles, yogurt cups, milk jugs, shampoo bottles, cleaning product bottles, and plastic bags are good examples. Have students sort the plastics by number, then make note of the types of containers that fall into each category and describe their properties. Use this as a way to introduce the names and chemical structures of the different types of plastics.
    - Provide students with Lewis diagrams for the different types of plastic. Have them use molecular model sets to build the polymers, then ask them to compare the models, noting how they are similar and how they are different. Emphasize that the same elements can form multiple covalent compounds with distinct properties, depending on the number of atoms of each kind of element and their bonding arrangement in a molecule.
    - Have students simulate a sink-float test to separate different types of plastics by their relative densities. Have them cut small pieces out of different types of containers, place the pieces in a beaker of water, and observe which types of plastic float or sink. Those that float can be

recovered and further separated using a beaker of rubbing alcohol. Those that float in the alcohol can be separated using a beaker of vegetable oil. Have students create a flow chart showing how different types of plastic behave and are separated at each step.

- Ask students to make connections between the optical sorting technique and what they learned about the electromagnetic spectrum and atomic emission spectra in Unit 2.
- Take a field trip to a plastic recovery facility and/or have students research plastic collection and recycling processes in their area.

- Sample prompts to elicit student ideas and encourage discussion:
  - Why is it necessary to identify different types of plastic by code numbers on containers?
  - Based on the elements present in plastics, what type of bonding do you expect to be present in the polymer molecules?
  - If many different types of plastic contain the same kinds of atoms, why do they have different properties?
  - What is similar, and what is different about the Lewis structures of different types of plastic?
  - What are some challenges to effective recycling of waste plastic?

Common student misconceptions

Possible misconception: *Prefixes, such as di and tri, are necessary for writing the names of ionic compounds.*

Students may have heard prefixes used in common chemical names, like carbon dioxide and carbon monoxide, and therefore, assume that they are used in naming all types of compounds.

Critical concepts

- The ratio between ions in a compound can be predicted based on the number of electrons that each atom needs to lose or gain to complete its valence shell.
- Ion charges for main group elements can be determined by their periodic table group numbers, and the ion charge for a polyvalent metal can be determined from a compound's formula and the anion charge.
- Ionic compounds are neutral, so the charges of the anions and cations in their chemical formulas must add up to zero.

How to address this misconception

When introducing the system for naming ionic compounds, spend time exploring *why* there is nothing in the name to indicate the number of each kind of ion in the chemical formula. Ask students to explain how they are able to write the chemical formula for an ionic compound without this information in the name. Later, when discussing why prefixes are necessary for naming covalent compounds, present examples like carbon dioxide vs carbon monoxide to emphasize that, unlike ionic compounds, ratios between elements in covalent compounds cannot be predicted easily from their locations in the periodic table. As a result, prefixes must be used.

Possible misconception: *The Roman numeral in an ionic compound's name refers to the number of metal ions in the compound's chemical formula.*

Since subscripts in chemical formulas and prefixes in names of covalent compounds refer to the number of atoms or ions in a molecule or formula unit, students may think that Roman numerals serve the same purpose.

Critical concepts

- A Roman numeral in the name of an ionic compound refers to the charge on the metal cation.
- Since ionic compounds are neutral, their chemical formulas can be written by determining the ratio in which the ion charges add up to zero.

How to address this misconception

Establish a firm connection between the polyvalent metal cation charge and the Roman numeral. When writing chemical formulas for compounds with polyvalent metals, encourage students to circle the Roman numeral in the name and write the corresponding ion charge above it. For example, the (II) in iron(II) chloride is rewritten as a 2+ charge on iron. When translating chemical formulas into names, remind students to check for the presence of a polyvalent metal by looking at the metal's location in the periodic table. Emphasize that if a polyvalent metal is present, they will need to determine its charge based on the chemical formula and the anion charge. Have students write out the charges on the anion and cation, circle the charge on the polyvalent metal ion and write above it the corresponding Roman numeral, which will become part of the compound's name.

Unit resources

Student resources

- Unit 2 (Atomic models and periodicity): Use the resources in this Khan Academy unit to review patterns for valence electrons and properties of elements in the periodic table, as well as the electromagnetic spectrum and atomic emission spectra.
- MolView and ChemTube3D: Use these online tools to visualize the crystal lattice structures of ionic compounds.
- PhET Sugar and Salt Solutions: Use this simulation to visualize what happens when an ionic or covalent compound dissolves in water.
- Unit 6 (States of matter): Use the resources in this Khan Academy unit to learn about polar covalent bonds.
- Metallic Bonding and its Properties and Metallic Bonding and Metallic Properties Explained: Use these videos to make connections between bonding and properties in metals.
- Deadly Crystal Cave: Use this short National Geographic video as an introduction to the phenomenon of giant crystal formation in the Naica cave.
- Cave of Crystals (video), Naica Cave of Crystals Mexico (video), Naica's crystal cave captivates chemists (C&EN article): Use these resources to learn more about the Naica Crystal Cave.
- How to Grow Salt Crystals and How to Grow Big Table Salt or Sodium Chloride Crystals at Home: Use these references for simple procedures to grow salt crystals.
- Article and video note taking template (Doc | PDF): Use this printable template for structured note taking on the articles and videos in this unit.
- Venn diagram template (Doc | PDF): Use this printable template for comparing and contrasting concepts.

Classroom implementation resources

- PubChem Periodic Table of Elements and Printable Periodic Tables: Download various versions of the periodic table, including a blank template.
- Weekly Khan Academy quick planning guide (Doc | PDF): Use this template to easily plan your week.
- Using Khan Academy in the classroom (Doc | PDF): Learn about teaching strategies and structures to support your students in their learning with Khan Academy.
- Differentiation strategies for the classroom (Doc | PDF): Read about strategies to support the learning of all students.
- Using phenomena with the NGSS: Learn more about how to incorporate phenomena into NGSS-aligned lessons.
- Hands-on science activities from Khan Academy: Choose from Khan Academy's collection of high-quality, ready-to-use, and free hands-on science activities. Each one is engaging, three-dimensional, phenomenon-based, and simple to implement.

NGSS standards reference guide

Performance expectations

- **HS-PS1-1:** Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
- **HS-PS1-3:** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Disciplinary core ideas

- **HS-PS1.A.2:** The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.
- **HS-PS1.A.3:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Science and engineering practices (SEPs)

- **Developing and using models**: Students progress to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
- **Planning and carrying out investigations:** Students progress to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
- **Analyzing and interpreting data:** Students progress to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
- **Constructing explanations and designing solutions:** Students progress to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

Crosscutting concepts (CCCs) and their implementation

Crosscutting concept	Unit implementation
Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	Students apply patterns in the periodic table to predict bonding behavior, write chemical formulas, and name compounds.
Structure and function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.	Students make connections between atomic structure, chemical bonding, and macroscopic properties of substances.
Stability and change: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.	Students predict bonding patterns based on an atom's tendency to achieve greater stability by completing its valence shell.
Systems and system models: Defining the system under study—specifying its boundaries and making explicitly a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.	Students describe and apply different models of chemical bonding.