Khan Academy

High School Chemistry

Unit 8: Solutions, acids, and bases

Overview

In this unit, students will explore properties of aqueous solutions, develop an understanding of solubility and concentration, and apply these concepts to analyze double replacement reactions and acids and bases.

Lesson 1: Students will describe characteristic properties of aqueous solutions.

Lesson 2: Students will **develop and use a model** to explain how interactions between solute and solvent particles, as well as temperature, affect the solubility of solids and gases in water. They will use reaction patterns to predict the products of double replacement reactions and apply solubility rules to identify precipitates.

Lesson 3: Hands-on science activity (see below)

Lesson 4: Students will describe solution concentration in terms of molarity. They will **use mathematics and computational thinking** to analyze scenarios and solve for grams of solute or the volume or molarity of a solution.

Lesson 5: Students will apply their understanding of aqueous solutions and concentration to identify acids and bases using the Arrhenius model and to analyze relative acidity using the pH scale.

Hands-on science activity

How can solubility principles help us detect and eliminate chemical contaminants in our water supply?

Students will use their knowledge of double replacement reaction patterns and solubility rules to predict the results of mixing aqueous solutions of ionic compounds. They will collect, **analyze, and interpret data** to test their predictions and **construct explanations** related to practical problems like hard water, agricultural run-off, and lead in drinking water. Click here for links to the activity.

Standards

Performance expectations: **HS-PS1-2 | HS-PS1-3**

Disciplinary core ideas: **HS-PS1.A.3 | HS-PS1.B.1 | HS-PS1.B.3 | HS-PS2.B.3**

Science and engineering practices:

- Developing and using models
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions

Crosscutting concepts:

- Structure and function
- Patterns
- Stability and change
- Energy and matter

Click here to read the full standards.

Essential questions

- What factors determine if a solute will dissolve in water to form an aqueous solution?
- How is molarity used to represent, calculate, and compare solute concentrations in aqueous solutions?
- What makes a solution acidic or basic, and how does the pH scale quantify acidity?

Lesson notes

Lesson 1: Aqueous solutions PEs: HS-PS1-3 DCIs: HS-PS1.A.3	Resources Video: 1 Exercise: 1
Objectives	**Teaching tips**

• Describe the properties of **aqueous solutions** using the terms **solute** and **solvent**.
• Compare the relative concentrations of solutions by classifying them as more **concentrated** or **dilute**.
• Identify aqueous solutions as **electrolytes** or **nonelectrolytes** based on the nature of the solute and/or whether the solution conducts electricity.
	• Introduce aqueous solutions by having students observe and analyze six beakers, one with pure water and five with water mixed with sand, vegetable oil, sodium chloride, sugar, or ethanol. Label the sodium chloride, sugar, and ethanol mixtures as "aqueous solutions."
	  ○ Ask students to describe properties they can observe for the *aqueous solutions* and how these differ from the mixtures of water with sand and oil.
	  ○ Introduce the terms *solute* and *solvent*, and ask students to identify the solute and solvent in each aqueous solution. While water is often called a "universal solvent," it is important to note that it does not dissolve *all* substances, as seen in this demo.
	  ○ Have students draw particle level diagrams to represent the contents of each beaker, and discuss how they compare. Emphasize that there is a uniform distribution of solute and solvent particles throughout a solution, which leads to consistent macroscopic properties.
	• Ask students what they think it means for a solution to be more *concentrated* or more *dilute*, and encourage them to share everyday examples where these terms are used. Prompt student thinking with examples like making fruit punch from drink mix or brewing coffee.
	• Next, have students draw or interpret particle level diagrams showing solutions with different relative concentrations (more/less concentrated or more/less dilute). Emphasize that concentration depends on *both* the amount of solute particles present and the total volume of the solution.
	• Demonstrate the behavior of electrolyte and nonelectrolyte solutions. Set up dilute solutions of sodium chloride (an electrolyte) and sucrose (a nonelectrolyte) with a conductivity meter in each solution or use the conductivity tester function in the *Macro* section of the PhET Sugar and Salt Solutions simulation.
	  ○ Gradually add solute to each solution to increase concentration, and discuss what students observe.
	  ○ Encourage students to recall the giant salt crystals of the Naica Caves from Unit 3 and what they learned about ionic and covalent compounds dissolving in water.
	  ○ Ask students to draw particle level diagrams representing an electrolyte and a nonelectrolyte dissolved in water.
	  ○ Challenge students to explain why the electrolyte conducts electricity more effectively as more solute is added and why the nonelectrolyte solution never conducts electricity, no matter how much solute is added.

Lesson 2: Solubility

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

Resources

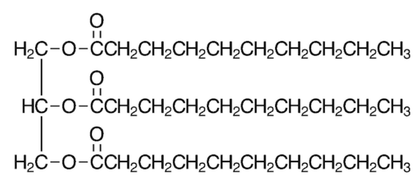
Video	Article	Exercise
2	1	3

Objectives

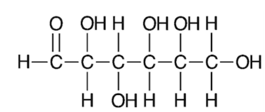
- Explain how the relative strengths of attractions between solute and solvent particles affect **solubility**.
- Predict the likelihood that a substance will dissolve in water by analyzing charge distribution in its molecules.
- Analyze **solubility curves** to identify and apply the relationship between temperature and solubility for solids and gases in water.
- Explain why the solubility of ionic solids in water increases as temperature increases.
- Use reaction patterns to predict the products and write balanced chemical equations for **double replacement reactions**.
- Interpret a **solubility chart** to determine if the predicted products of a double replacement reaction are soluble or insoluble (**precipitate**).

Teaching tips

- Connect solubility to polarity and intermolecular forces ([Unit 6]) by building on students' analysis of substances—sand (silicon dioxide), vegetable oil, sodium chloride, sugar, and ethanol—mixed with water in the introductory activity in [Lesson 1].
  - Have students analyze types of bonding and charge distribution in each substance using its molecular structure (water, oil, sugar, ethanol) or crystal structure (sand, sodium chloride). To simplify analysis, give students a general triglyceride molecule for oil and an open chain glucose molecule for sugar (see examples below). Students may need support recognizing sand (silicon dioxide) as a network covalent compound.



triglyceride



glucose

  - Have students work in small groups on whiteboards to identify the strongest type of intermolecular forces that exist between particles within each pure solute and between particles within the solvent (water). For substances that formed aqueous solutions, have students draw particle diagrams showing attractions between water molecules and solute particles. Encourage students to recall what they learned previously about ionic and covalent compounds dissolving in water.
  - Invite groups to share their diagrams with the class, and discuss how and why sodium chloride, sugar, and ethanol particles are attracted to water molecules and vice versa.
  - Ask students to hypothesize why oil and sand did not dissolve in water, then use these examples to help students unpack the concept of "like dissolves like."
    - Emphasize that solubility depends on the ***relative*** strengths of solute-solute attractions, solvent-solvent attractions, and solute-solvent attractions.
    - If attractions between the solute particles (as with sand and water) or the solvent particles (as with oil and water) are significantly stronger than the attractions between solvent and solute particles, a solution will not form.
- Engage students in an exploration of how surfactants in dish soap help remove greasy residue from pots and pans. (*See the "[Related phenomena]" section below for more information.*)
- Have students analyze two different solubility curves—one for gases and one for ionic solids. Ask them to describe and compare the

general trends they observe in the two graphs. Prompt student thinking by asking:
  - What variable is represented on each axis?
  - As temperature increases, how does solubility change?
  - Does every solute show the same trend?
- Guide students to connect the concepts of temperature, kinetic energy, and particle collisions (Unit 7), as well as the kinetic molecular theory of gases (Unit 6), to the topic of solubility. Ask students to use these concepts to explain why increasing temperature increases solubility of solids and decreases solubility of gases.
- Encourage students to become comfortable using solubility rules by giving them examples of ionic compounds and asking them to determine if each compound will be soluble in water. Note that soluble substances will be designated as aqueous (*aq*) in chemical equations and those that are insoluble will be designated as solid (*s*).
- Introduce double replacement reactions with a live demo or video of a precipitate reaction, such as silver nitrate reacting with sodium chloride or potassium iodide with lead(II) nitrate. Ask students to:
  - Write the reactants as their constituent ions dissociated in solution.
  - Predict the identities of the products if the ions "trade partners."
  - Write the reaction as a balanced chemical equation with appropriate state symbols, based on solubility rules.
  - Draw particle diagrams for the reactants and the products.
- Review how to balance ion charges when writing ionic compound formulas (Unit 3). Remind students that subscripts may differ between reactants and products and that any imbalance in atom counts will be addressed using coefficients as a final step (Unit 4).
- Implement the hands-on activity "*How can solubility principles help us detect and eliminate chemical contaminants in our water supply?*" in order for students to apply their understanding of double replacement reactions to data analysis and real-world problems (see Lesson 3).

Lesson 3: Hands-on science activity

How can solubility principles help us detect and eliminate chemical contaminants in our water supply?

PEs: HS-PS1-2, HS-PS1-3

DCIs: HS-PS1.A.3, HS-PS1.B.3

Resources

Activity

1

Description	Links
Students will use their knowledge of double replacement reaction patterns and solubility rules to predict the results of mixing aqueous solutions of ionic compounds. They will **carry out an investigation** and **analyze and interpret data** to test their predictions and **construct explanations** related to practical	• Full activity overview (**Khan Academy article**) • Student activity guide (**Doc** | **PDF**) • Teacher guide (**Doc** | **PDF**)

problems like hard water, agricultural run-off, and lead in drinking water.	

Lesson 4: Molarity

PEs: HS-PS1-3
DCIs: HS-PS1.A.3, HS-PS2.B.3

Resources

Video 2
Exercise 2

Objectives

- Describe solution concentration in terms of **molarity**, and explain how molarity changes as the moles of solute or volume of solution changes.
- Use the equation $M_1V_1 = M_2V_2$ to analyze **dilution** scenarios and calculate unknown molarity or volume values.
- Calculate the molarity of a solution given the grams of solute and total volume of solution.
- Calculate the grams of solute needed to make a solution of a given volume and molarity.

Teaching tips

- Review the concept of a mole from Unit 5, and ask students to brainstorm how moles could be used to describe solution concentration. Prompt student thinking by asking, "*If concentration is the amount of solute particles in a certain volume of solution, then what units could we use to quantify concentration?*" Emphasize that molarity is a *ratio* of moles of solute to liters of solution, which means it will be constant throughout a solution.
- Guide students in using the PhET Molarity simulation to explore how changes in the amount of solute and solvent affect molarity. Working in pairs or small groups, have students click on *Solution Values* (bottom left) to see quantitative data and follow prompts like those below.
    - Create 0.500 L of a 1.000 M solution of nickel(II) chloride.
    - Starting from this 1.000 M solution, predict what the new molarity value will be if you make each of the following changes. After you predict, use the simulation to test your predictions.
        - Increase the solution volume to 1.000 L
        - Decrease the solution volume to 0.250 L
        - Increase the moles of solute to 1.000 mol
        - Decrease the moles of solute to 0.250 mol
    - Use the relationship $M = \frac{moles\ of\ solute}{liters\ of\ solution}$ to answer the following questions, and then test your values using the simulation.
        - How many moles of potassium chromate solute are needed to make 0.300 L of a 2.000 M solution?
        - If you dissolve 0.100 moles of copper(II) sulfate in water to make a 0.125 M aqueous solution, what is the total volume of the solution?
- Remind students that we cannot measure substances directly in moles, so we must use grams. Encourage them to recall how we use molar mass (Unit 5) to convert between grams and moles, and provide some extra practice with this skill, if necessary.
- Challenge students, working in pairs or small groups, to develop procedures for making an aqueous solution of a specific volume and molarity (e.g., 100 mL of 0.05 M NaCl) both from the solid solute and from a more concentrated stock solution (e.g., 0.1 M NaCl). After reaching consensus about appropriate procedures, allow students to reinforce their understanding by carrying out the processes.
- Connect molarity to double replacement reactions (Lesson 2) and stoichiometry (Unit 5) by having students analyze reaction scenarios where the amounts of reactants are given in terms of solution molarity and volume. Guide students to recognize that they can use

the given information to solve for moles of each reactant and then apply established strategies to identify limiting reactants and calculate theoretical yields.

Lesson 5: Intro to acids and bases

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

Resources

Video	Article	Exercise
2	1	3

Objectives

- Identify substances as **acids** or **bases** using the **Arrhenius model**.
- Describe or identify a solution as acidic or basic using characteristic properties, such as taste, pH, effect on litmus paper, and reactivity.
- Characterize acids and bases as **strong** or **weak** based on the extent to which their constituent ions dissociate in solution.
- Predict the products of **acid-base neutralization reactions.**
- Name and write formulas for acids and bases using IUPAC rules.
- Classify solutions as acidic, basic, or neutral based on the ratio of dissolved H^+ to OH^- ions.
- Determine the relative pH values for different solutions by comparing their concentrations of H^+ ions in solution.
- Compare the acidities of different solutions based on their pH values and the logarithmic nature of the pH scale.
- Explain how and why the pH of a solution will change when the solution is diluted.

Teaching tips

- Introduce acids and bases using common household substances, like lemon juice and vinegar (acidic) and glass cleaner and dish soap (basic). Allow students to describe and test the properties of these substances using pH paper or pH meters, litmus paper, and conductivity testers. Based on their observations, ask students to brainstorm other common substances that might be acidic or basic. If possible, allow students to test some of them. If they suggest solid substances, take the opportunity to demonstrate that substances must be in solution for their acidic or basic properties to be observed.
- Present students with the chemical formulas for several monoprotic acids (e.g., HCl, HNO_3, and $HC_2H_3O_2$) and several metal hydroxide bases (e.g., $NaOH$, KOH, and $Ca(OH)_2$). Have students write a dissociation equation for each compound. Ask them to look for patterns and come up with a way to define acids and bases according to how they dissociate in water. Use student ideas to introduce the Arrhenius model.
- Guide students in using the [PhET Acid-Base Solutions] simulation to explore the concept of acid and base strength. Have students work in pairs or small groups, using the *Intro* section of the simulation. Instruct them to select the *Particles* view option.
    - Provide a table to record the pH value and relative brightness of the conductivity tester bulb for each type of solution (water, strong acid, weak acid, strong base, and weak base). Ask students to summarize trends in their data in 2-3 sentences.
    - Have students compare the particle diagrams and dissociation equations for a strong acid and a weak acid, and ask them to explain how the diagrams and the equations are different. Students should notice that the dissociation equation for a weak acid has a double arrow. At this stage, it is enough to explain that this indicates the reaction is going in both directions simultaneously, meaning there will always be some undissociated particles. Equilibrium will be covered in Unit 9.
    - Guide students to recognize that strong acids and bases dissociate completely in water, while weak acids and bases dissociate only partially. Encourage them to connect this to their earlier learning about electrolyte strength.
- Present students with a live demonstration or video of a neutralization reaction. First, add a few drops of phenolphthalein solution to two test tubes containing 1M $NaOH$ and 1M HCl, so students can see how the indicator behaves in basic and acidic solutions. Next, add about 2 mL of 1M $NaOH$ to a test tube with 2-3

	drops of phenolphthalein. Add 1M HCl dropwise, shaking the test tube in between drops, until the color of the solution suddenly goes from magenta to clear. ○ Have students write a balanced chemical equation for the reaction, then ask them to hypothesize what caused the color of the solution to change so suddenly. ○ Ask students to predict what will happen if you continue adding drops of HCl to the solution or if you add drops of NaOH, then test their predictions. ○ Have students use their observations to summarize what happens in a neutralization reaction. ● Review rules for naming and writing formulas for ionic compounds ([Unit 3](#)), and emphasize that metal hydroxide bases follow these rules. ● Ask students to create a "roadmap" for naming acids. This could take the form of a flow chart, a series of questions to ask themselves, or any other format that helps them to go successfully from an acid's formula to its IUPAC name. Have students work in pairs or small groups and then share their roadmaps with the class. Give students example problems to test out the effectiveness of their roadmaps. A similar strategy can be applied to writing formulas from acid names. ● Guide students to summarize what they know so far about the pH scale. Emphasize that pH depends on the concentration of H^+ ions in solution, and every one integer decrease on the pH scale corresponds to a ten-fold increase in the concentration of H^+ ions. Ensure that students understand: ○ A solution with a pH of 7 is neutral and has equal concentrations of H^+ and OH^- ions. ○ A solution with a pH less than 7 is acidic and has a greater concentration of H^+ compared to OH^- ions. ○ A solution with a pH greater than 7 is basic and has a greater concentration of OH^- compared to H^+ ions. ● Provide students the opportunity to collect and analyze pH data for various solutions using universal indicators, pH paper, and/or pH meters. (This can be done as a short hands-on activity or as a teacher demonstration.) Have students organize the test solutions from most acidic to most basic and describe how they compare in terms of their H^+ ion concentrations. Invite students to observe how the pH of the most acidic solution changes as water is added gradually. ● Engage students in exploring the process of ocean acidification and its consequences for marine life. (*See the "Related phenomena" section below for more information.*)

Related phenomena

Example phenomenon

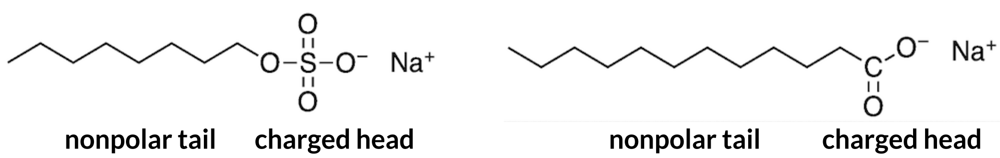
How does dish soap help clean a greasy pan?

Background information

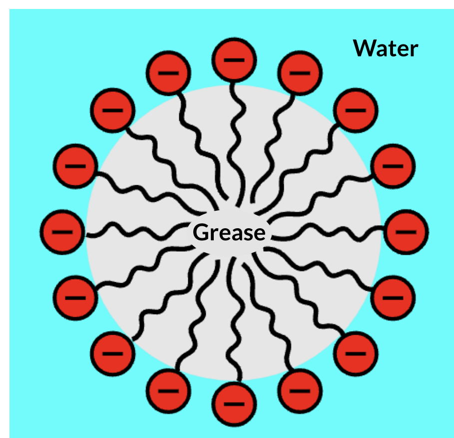
Cleaning a frying pan with soap and water

Dish soaps contain *surfactants*, which are molecules that have an ionic "head" and a nonpolar "tail." This dual nature enables them to facilitate the mixing of nonpolar substances, like grease and oil, with water, which is necessary for cleaning greasy residue off of pots, pans, and dishes.

Anionic surfactants, where the head is negatively charged, are the most widely used type of surfactants for dishwashing liquid. Common examples contain a nonpolar hydrocarbon chain bonded to a sulfate or carboxylate anion (see below).



When surfactants mix with water, the molecules organize into *micelles*. These are spherical structures in which all the nonpolar parts of the molecules (the tails) point inward, and the charged parts of the molecules (the heads) are organized on the outside, where they can attract polar water molecules. The nonpolar tails of the surfactant molecules dissolve into grease on the surface of a pan and pull nonpolar grease particles into the centers of micelles. In this way, the grease particles become suspended in the water and can be rinsed away.



Surfactant molecules forming a micelle

The surfactant molecules also arrange themselves at the surface of the water-air boundary with their nonpolar tails pointing out into the air and their charged heads interacting with water molecules. As a result, the surfactant molecules interrupt attractions between water molecules and decrease surface tension, allowing the water to spread out more easily across the surface of a pan for cleaning.

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

- ☐ Solubility depends on the relative strengths of solute-solute attractions, solvent-solvent attractions, and solute-solvent attractions.
- ☐ Nonpolar solutes generally don't dissolve in water because attractions between polar water molecules are stronger than attractions between water molecules and nonpolar solute molecules.
- ☐ Polar and ionic solutes generally dissolve in water because their particles have an uneven distribution of charge, which allows them to attract the partial positive or negative ends of water molecules.

Tips for implementing phenomenon-based learning

- Ideas to encourage student engagement:
  - Review the property of surface tension that students explored in the hands-on activity "*How does water form droplets on surfaces?*" in Unit 6. Ask students to draw particle level diagrams modeling surface tension in water and to describe how intermolecular forces cause water to form droplets on surfaces.
  - Ask students to observe and explain what happens when water and vegetable oil are combined. First, fill a beaker with water, and add vegetable oil slowly, one drop at a time. Next, repeat the process with a beaker of vegetable oil, adding water dropwise. Lastly, coat a pan or shallow dish with oil, then add drops of water in several different locations. Gently tilt the container to show how the water droplets come together, rather than spreading out across the surface.
    - Have students work in pairs or small groups on whiteboards to explain, using words and particle level diagrams, why the oil droplets stay together and don't spread out in the water, and why the water droplets stay together and don't spread out in the oil. Remind students to think about the relative strengths of the intermolecular forces.
    - Invite students to share their diagrams and thinking with the class. Emphasize that the *greater strength of attractions between the water molecules* is responsible for keeping the oil and water separate in both cases. Students may have heard that oil and other nonpolar substances are "hydrophobic," meaning "afraid of water." This can lead to the misconception that oil actively moves away from water, but in reality, the water molecules are so much more strongly attracted to each other that they *exclude* the oil molecules, leaving them attracted to each other by default.
  - Demonstrate how surfactants in dish soap decrease the surface tension of water by disrupting intermolecular forces.
    - Have students repeat the procedure from the Unit 6 hands-on activity to place a paperclip on the surface of a container of water. They should bend one end of the clip slightly upward so that they can place it gently on the surface of the water without touching the liquid with their hands. (Brass push pins also work well for this application. Students can hold the pin end while placing the flat end on the surface of the water.)
    - After discussing why the paperclip or push pin floats, ask students to predict what will happen when they add a drop of dish soap to the container.
    - Invite students to add a small amount of dish soap to the water, away from the paperclip or push pin. This can be done with a dropper or by putting a small amount of soap on a finger or cotton swab and touching it to the surface of the water.
    - Ask students to hypothesize why the paperclip or push pin sank when soap was added.
    - Use the Milk Rainbow Experiment or the Pepper and Soap Experiment to further demonstrate the effect of surfactants on the surface tension of water.
  - Show students the chemical structures of common anionic surfactants, like those in the background above. Ask them to work in pairs or small groups to create a model showing how surfactant molecules could interact with *both* water and oil molecules to aid the process of cleaning dishes. Use student ideas to introduce the concept of micelles. If students have

previously taken biology, this could offer an opportunity to make connections to what they learned about cell membranes.
    - Assign students to research the names of different types of surfactants and their chemical structures, then have them look at the labels of dish soap, shampoo, liquid hand soap, and other products in their classroom or their homes to identify the surfactants present.
    - Invite students to experience the effect of surfactants *firsthand*. Start by having students coat their hands with a small amount of vegetable oil. Next, have them try to rinse the oil off their hands using only water. Lastly, have them use soap to remove the oil. Discuss how it felt different when the soap was added.
    - Have students create an infographic explaining how surfactants in dish soap make it possible to clean greasy residue off of pots and pans with water.
- Sample prompts to elicit student ideas and encourage discussion:
    - How do intermolecular forces lead to surface tension in water?
    - Why does a drop of oil stay together, rather than spreading out in a container of water?
    - Why does water bead up, rather than spreading out on a greasy surface?
    - Why doesn't oil dissolve in water?
    - How do surfactant molecules attract both oil and water molecules?
    - How do surfactants allow oil particles to disperse in water so that they can be rinsed away?

Example phenomenon

How do rising levels of carbon dioxide in our atmosphere make the ocean more acidic, and what are the consequences for marine life?

Coral reef

Background information

When carbon dioxide in our atmosphere interacts with the ocean surface, some of it dissolves into the seawater. In this way, the ocean acts as a "carbon sink" by decreasing the concentration of carbon dioxide in the atmosphere and reducing its greenhouse effect. At the same time, however, increasing levels of dissolved carbon dioxide lead to changes in the acidity of seawater and cause disruptions to marine ecosystems.

Once dissolved, carbon dioxide combines with water to form carbonic acid, some of which dissociates into hydrogen and bicarbonate ions. As the hydrogen ion concentration increases, acidity increases, and pH decreases. Carbon dioxide levels in the atmosphere have risen sharply since the 1950s, due to combustion of fossil fuels and other human activities, leading to more and more carbon dioxide being absorbed by the ocean. As a result, global surface ocean pH has already decreased from a pre-industrial value of 8.2 to 8.1, and values of 7.8-7.9 are predicted by the year 2100. Since the pH scale is logarithmic, even a seemingly small decrease of 0.1 corresponds to an increase in acidity of about 30%.

Organisms like oysters and coral that build hard shells and skeletons by forming crystals from calcium and carbonate ions in seawater (a process called "biogenic calcification") are particularly sensitive to ocean acidification. Dissociated hydrogen ions react with carbonate ions to produce bicarbonate ions, so as the concentration of hydrogen ions in the ocean goes up, the concentration of carbonate ions goes down. As a result, marine organisms are less able to create the shells and reefs that function as protection and shelter and create some of the most biodiverse habitats in the world.

Chemical reactions related to ocean acidification:

(1) Dissolved carbon dioxide reacts with water to form carbonic acid: $CO_2(aq) + H_2O\ (l) \leftrightarrows H_2CO_3\ (aq)$

(2) Carbonic acid partially dissociates: $H_2CO_3\ (aq) \leftrightarrows H^+(aq) + HCO_3^-(aq)$

(3) Hydrogen ions react with carbonate ions to form bicarbonate ions: $H^+(aq) + CO_3^{2-}(aq) \leftrightarrows HCO_3^-(aq)$

Cold water reefs and shelled creatures may be particularly vulnerable to ocean acidification. Since gases are more soluble in water at lower temperatures, the ocean near the poles and areas where there is a natural upwelling of colder deep water, such as the west coast of North America, can dissolve higher concentrations of carbon dioxide, leading to greater local impacts on acidity.

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

- ☐ An aqueous solution forms when a solid, liquid, or gaseous solute dissolves in water (the solvent).
- ☐ A solution is more concentrated when there are more moles of solute particles dissolved in a given volume of solution.
- ☐ Gases are more soluble in water at lower temperatures.
- ☐ According to the Arrhenius model, an acid is a substance that produces H^+ ions when dissolved in water.
- ☐ Strong acids dissociate completely in solution, while weak acids dissociate only partially.
- ☐ Increasing the concentration of H^+ ions in solution leads to a decrease in pH and a more acidic solution.

Tips for implementing phenomenon-based learning

- Ideas to encourage student engagement:
  - Engage students with a simple demonstration that shows how carbon dioxide gas can dissolve in water to increase its acidity:
    - Mix 100 mL water with 5 mL bromothymol blue indicator, then divide the solution between two clear cups. Explain to students that the indicator is blue-green in tap water and changes to yellow when the solution becomes acidic.
    - Place a drinking straw in one of the cups and blow into the solution until the color changes to yellow. The solution in the other cup will remain blue-green.
    - Ask students to use their observations to explain what happened to the pH of the solution and to the concentration of hydrogen ions as the teacher blew into the straw.
    - Ask students to hypothesize what gas in the teacher's breath is responsible for the change in acidity of the solution. Build on student ideas to explain that carbon dioxide reacts with water to form carbonic acid.
    - Have students write the chemical formula and the dissociation equation for carbonic acid. Ask students to explain what it means for carbonic acid to be a "weak" acid.
    - If time allows, invite students to continue exploring the acidification of water by carbon dioxide with quick experiments like those in this [American Chemical Society resource](#).

- Introduce the phenomenon of ocean acidification with this video. Have students take notes and then discuss the following questions:
    - Where does the carbon dioxide absorbed by the ocean come from? Why is the ocean called "the planet's biggest carbon sink?"
    - How and why does a change in temperature affect the amount of carbon dioxide that can dissolve into the ocean?
    - What polyatomic ions dissolved in seawater are used by marine organisms, like clams, oysters, and coral, as building blocks for their shells and skeletons? And how is the concentration of these ions affected by the reaction of carbon dioxide with water?
    - How much more acidic has the ocean become as a result of human activities, like burning fossil fuels, that release carbon dioxide into the atmosphere?
    - How can the negative impacts of ocean acidification on organisms like clams, oysters, and coral lead to broader impacts on marine ecosystems and human beings?
- Have students model the process and consequences of ocean acidification by designing creative posters for the classroom.
- Students also can explore effects on diverse ecosystems through case studies from the Great Barrier Reef to the Arctic Ocean. If students were assigned to research popular dive sites for the scuba-related phenomenon in Unit 6, have them go back and investigate the effects of ocean acidification on marine life in those locations.
- Reach out to an aquarium or marine research department in your area to arrange a virtual or in-person visit focusing on some aspect of ocean acidification and its effects on marine ecosystems. NOAA also offers a number of relevant educational resources, including videos in which researchers and communities talk about ocean acidification impacts and solutions.

- Sample prompts to elicit student ideas and encourage discussion:
    - How does carbon dioxide dissolving into seawater affect the pH of our ocean?
    - What is the chemical formula for carbonic acid, and why is it considered a weak acid?
    - How does carbonic acid act as an acid under the Arrhenius definition when dissolved in water?
    - How does ocean acidification negatively impact marine organisms, like oysters and coral, that build hard shells and skeletons?
    - Why are cold water reefs particularly vulnerable to ocean acidification?
    - How does an increase in ocean acidity affect the overall health of marine ecosystems, and what are the potential long-term impacts on global biodiversity and climate systems?

Common student misconceptions

Possible misconception: *All ionic compounds dissolve in water.* Based on their experience with common ionic compounds that readily dissolve in water, such as table salt, students may assume that all ionic compounds are soluble in water. This may lead to confusion when talking about precipitate formation in double replacement reactions.
Critical concepts • Solubility depends on the relative strengths of solute-solute attractions, solvent-solvent attractions, and solute-solvent attractions. • If attractions between the solute particles or the solvent particles are significantly stronger than the attractions between solvent and solute particles, a solution will not form. • A solubility chart can be used to predict the solubility of a given ionic compound in water at 25 °C.
How to address this misconception Spend time developing a model that connects the relative strength of intermolecular attractions to solubility. Emphasize that, while many ionic compounds are soluble in water, some do not dissolve due to relatively strong ionic bonds and lattice structures that cannot be overcome by attractions to polar water molecules. Allow students to observe this by testing the solubility of various ionic compounds, like sodium chloride and potassium bromide (soluble) and calcium carbonate and barium sulfate (insoluble).

Possible misconception: *The "strength" of an acid or base refers to its concentration.* Students often conflate the concepts of acid or base *strength* and *concentration*. They may find it challenging to accept, for example, that hydrochloric acid is considered "strong," even at very low concentrations.
Critical concepts • Concentration describes the number of solute particles in a given volume of solution. • A strong acid or base dissociates completely into its constituent ions in solution, while a weak acid or base dissociates only partially when it dissolves. • pH is a measure of the concentration of dissociated hydrogen ions in solution.
How to address this misconception Demonstrate the difference between acid or base *strength* and *concentration* with a simple experiment. Start with 1 M solutions of a strong acid and a weak acid, such as hydrochloric acid and acetic acid. Use a pH meter or pH paper to show that the strong acid has a lower pH due to a higher concentration of dissociated H^+ ions. Guide students to draw particle diagrams to represent the two different solutions. The diagram of the strong acid should show only H^+ and Cl^- ions mixed in with water molecules, while the diagram of the weak acid should show only a few of the acid molecules dissociated into H^+ and acetate ions. Gradually dilute the strong acid solution, while monitoring pH changes, to show that the pH of the strong acid solution remains lower than that of the weak acid, even as its concentration decreases (because the concentration of dissociated H^+ ions is still greater for the strong acid).

Unit resources

Student resources

- PhET Sugar and Salt Solutions: Use this simulation to investigate the behavior of electrolytes and nonelectrolytes.
- PhET Molarity: Use this simulation to explore how changes in the amount of solute and solvent affect molarity.
- PhET Acid-Base Solutions: Use this simulation to explore the concept of acid and base strength.
- Unit 3 (Chemical bonding): Use the resources in this Khan Academy unit to review how to name and write formulas for ionic compounds.
- Balancing chemical equations: Use this Khan Academy video to review balancing equations.
- Unit 5 (Stoichiometry and the mole): Use the resources in this Khan Academy unit to review the concepts of a mole, molar mass, and stoichiometry.
- Unit 6 (States of matter): Use the resources in this Khan Academy unit to review the concepts of polarity, intermolecular forces, and the kinetic molecular theory of gases.
- Unit 7 (Thermochemistry): Use the resources in this Khan Academy unit to review the concepts of temperature and kinetic energy.
- How does water form droplets on surfaces?: Review the property of surface tension with this hands-on activity from Unit 6.
- Milk Rainbow Experiment and Pepper and Soap Experiment: Use these demonstrations to show how surfactants affect the surface tension of water.
- Fluid mosaic model of cell membranes: Use this Khan Academy video to make connections between surfactant micelles and cell membranes.
- Carbon Dioxide Can Make a Solution Acidic: Use this resource from the American Chemical Society for quick experiments to explore the acidification of water by carbon dioxide.
- What is Ocean Acidification?: Use this video to introduce the phenomenon of ocean acidification.
- NOAA Ocean Acidification Program: Explore educational resources related to ocean acidification.
- Article and video note taking template (Doc | PDF): Use this printable template for structured note taking on the articles and videos in this unit.

Classroom implementation resources

- 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-PS1-2:** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.
- **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.3:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- **HS-PS1.B.1:** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- **HS-PS1.B.3:** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- **HS-PS2.B.3:** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Science and engineering practices (SEPs)

- **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
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 use molecular structure and distribution of charge to determine the relative strengths of interactions between solute and solvent particles.
Energy and matter (Flows, cycles, and conservation): Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.	Students explain how changes in temperature affect the solubility of solids and gases in aqueous solutions.
Stability and change: For natural and built systems alike,	Students observe changes from reactants

conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.	to products and represent them with balanced chemical equations.
Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	Students use patterns in reactivity to predict the outcomes of chemical reactions.