HS CHEMISTRY

TEACHER RESOURCE GUIDE

THEME: The chemistry of our oceans is changing due to the influx of atmospheric carbon dioxide from human-induced carbon emissions.

CRITICAL ISSUE: Climate Change

CONTENTS:

AQUARIUM OF THE BAY

a division of bay.org

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MISSION STATEMENT:

Aquarium of the Bay's Education and Conservation Department's mission is to promote literacy in ocean and watershed health, climate change issues, and science career development through the lens of critical issues such as sustainable seafood, marine protected areas, marine debris and plastics, climate change and fresh water flows.

ACKNOWLEDGEMENTS:

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S. D. BECHTEL, JR. FOUNDATION
STEPHEN BECHTEL FUND

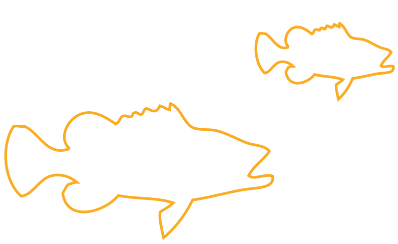
LESSON 1

ACIDS, BASES, AND OUR OCEANS

Enduring Understanding: Measuring the pH of a liquid or solution and balancing chemical equations are important steps to learning about changing ocean chemistry.

Materials

• "Acids, Bases, and Our Oceans" worksheet
• pH test strips (rated 0 to 14, available for purchase online)
• Purified water
• Lemon juice, vinegar, baking soda (dissolved in water), and Clorox or liquid bleach
• Eye droppers or pipettes
• Artificial seawater (optional) (See Instructor Background for preparation.)
• Small paper cups or glass beakers (recommended) to hold liquids



SETUP:

1. Make copies of the "Acids, Bases, and Our Oceans" worksheet for student groups.
2. Divide cups/beakers, droppers, and pH testing materials among groups.
3. Set up a color scale representing the pH color range for students to use as a visual reference.
4. Prepare artificial seawater.

PROGRAM OUTLINE:

What does the pH scale measure? (Teacher-led classroom discussion.)

- The pH scale measures how acidic or basic a substance is, ranging from 0 to 14. A pH of 7 is neutral, a pH less than 7 is acid, and a pH greater than 7 is basic.
  - The pH scale is logarithmic. Each whole pH value is 10 times more or less than the next unit. For example, a pH of 3 is ten times more acidic than a pH of 4 and 100 times more acidic than a pH of 5. Have students practice with these values until they're comfortable with a logarithmic scale.

What are the differences between acids and bases?

- "Acidic" and "basic" are terms that describe two extremes of chemical properties. All acids have similar properties to each other; conversely, all bases are similar.
  - Acids dissolve in water to release hydrogen ions (H^+).
  - Bases dissolve in water to release hydroxide ions (OH^-).
  - Acids and bases counteract each other. A base can make an acid weaker, and vice versa.
  - Adding an acid and a base together is called neutralization.

PROGRAM OUTLINE CONTINUED:

Investigating the pH scale (NOTE: Make certain your students understand safety concerns regarding bleach. It should not come into contact with eyes, skin, or clothing, nor should it be mixed with any solutions other than pure water.)

- Break the class into groups and hand out the “Acids, Bases, and Our Oceans” worksheet.
- What are some of the steps scientists take when investigating a question or new idea?
  - Identify the question.
    - What is the pH of the various substances?
  - Form a hypothesis.
    - Which solutions do they predict will be acidic, basic, or neutral?
  - Test the hypothesis.
    - Have students write out or orally explain to you how they will be testing each solution—lemon juice, baking soda, bleach, and vinegar—given the tools provided. Their measurements and methods should be controlled with standardized amounts while using proper safety precautions. They will be recording all their observations.
  - Analyze and discuss.
    - What results did the experiment show?
    - Why are these results important?
    - What do they help us understand about acids, bases, and the pH scale?
    - How will this help us better understand ocean acidification?

Balancing chemical equations

- Explain the law of the conservation of mass and the importance of balancing chemical equations.
  - Have your students practice balancing the equations on their worksheet. The equations represent the reactions that occurred during the experiment.

Determining if seawater is acidic or basic

- Students can form their own hypotheses about whether naturally occurring seawater is acidic or basic or where it lies on the pH scale. After writing down their hypotheses, they will then test them using the same methods they used earlier.
  - Historically, the oceans have been slightly basic on average—8.2 on the pH scale. However, they have come less basic over the last 200 years, since the beginning of the Industrial Revolution. The oceans now have an average pH of 8.1. The actual change is an average of 0.1 on the pH scale. This doesn’t sound like much, but since the pH scale is logarithmic, this change is on the scale of about a 30 percent increase in acidity.
  - The oceans are absorbing atmospheric carbon dioxide (CO_2) from carbon emissions, much like a sponge absorbs water. This huge input of CO_2 increases the acidity of ocean water. This can have a negative

impact on shelled organisms and many other effects we don't yet understand.

Why is learning how to test acids and bases important?

- Discovering where a solution lies on the pH scale can tell us about its chemical properties and how it may react with other substances and solutions. For us to understand the implications of ocean acidification and how it will impact organisms and ecosystems, we need to study the process on the molecular level.

Why is using proper scientific methods important?

- All experiments should be approached with proper scientific methodology so that we minimize bias or prejudice, which can impact the outcomes. The scientific method provides an objective, standardized approached to achieve results that are not influenced by the scientist.

TEACHER BACKGROUND:

Acids and Bases

Different household chemicals can be acidic or basic. They are easily tested for their variations on the pH scale, although the actual pH value depends on concentration. The pH is the measure of the concentration of free hydrogen ions (H^+) contained within a solution. Pure water is neutral at a pH of 7. Acids dissolve in water to release H+ ions and bases dissolve in water to release OH^- hydroxide ions. The pH scale is logarithmic, so each whole pH value is 10 times more or less than the next unit. For example, a pH of 3 is ten times more acidic than a pH of 4 and 100 times more acidic than a pH of 5.

Balancing Chemical Equations

A chemical equation is balanced when the number of atoms of each type is the same on each side of the equation. The law of the conservation of mass states that you cannot make or destroy atoms during a chemical reaction. Reagents are on the left side of an equation and products are on the right. In order to balance an equation, there must be the same number of atoms in the products as in the reagents.

Lemon juice (citric acid) reacting with water:

$$C_6H_8O_7 + 3H_2O \Leftarrow\Rightarrow C_6H_5O_7^{-3} + 3H_3O^{+1}$$

Vinegar (acetic acid) reacting with water:

$$C_2H_4O_2 + 4H_2O \Leftarrow\Rightarrow C_2H_3O_2^{-1} + 4H_3O^{+1}$$

Baking soda (sodium bicarbonate) reacting with water:

$$NaHCO_3 + H_2O \Leftarrow\Rightarrow NaOH + H_2CO_3$$

Bleach (sodium hypochlorite) reacting with water:

$$NaClO + H_2O \Longrightarrow HOCL + NaOH$$

These reactions provide a basic understanding of how acids and bases react with water.

Changing Ocean Chemistry

Before the industrial age the oceans were, on average, slightly basic, with a pH of 8.179. They have been changing over the last two decades and now have an average pH of 8.069 (less alkaline). Researchers believe this is because the oceans absorb atmospheric CO_2, which decreases the alkalinity of seawater. Seawater is slightly alkaline due to the presence of bicarbonates along with dissolved salts and other compounds. Bicarbonate comes from the weathering of rocks, but it does not enter the oceans at a fast enough rate to counteract the current influx of CO_2. There are some natural sources of atmospheric CO_2, such as volcanoes. However, human carbon emissions were calculated to have produced at least 9.7 billion metric tons per year in 2012, whereas volcanoes were estimated to produce about 200 million tons of CO_2.

TEACHER BACKGROUND CONTINUED:

Artificial Seawater

You may choose to buy a premade artificial seawater mix from an aquarium store, or you can mix your own seawater using sea salt and distilled water. The advantage of a premade mix is that it contains additional minerals and salts that more accurately represent ocean chemistry. For this experiment, adding sea salt to distilled water may be more economical and practical. Seawater has a salinity of about 35 parts per million (ppm), equivalent to 35 grams of salt per one liter of water. The saturation level depends on temperature, but for the purposes of this experiment you can add 35 grams of sea salt to every liter (1000 grams) of distilled water you want to create.

GLOSSARY:

Acid: Chemical substance with pH less than 7; produces H^+ ions in aqueous solutions and neutralizes alkalis; typically corrosive; changes litmus from blue to red; common examples: citric acid (from fruits or vegetables), ascorbic acid (vitamin C), vinegar, carbonic acid (carbonation in soft drinks), lactic acid (in milk)

Base: Chemical substance with pH greater than 7; produces OH^- ions and accepts protons; typically turns red (acidified) litmus blue; common examples: detergents, soap, lye, ammonia

Carbon Dioxide (CO_2): Colorless, odorless, nonpoisonous gas formed by the combustion of carbon, as in the burning of fossil fuels, and in the respiration of living organisms

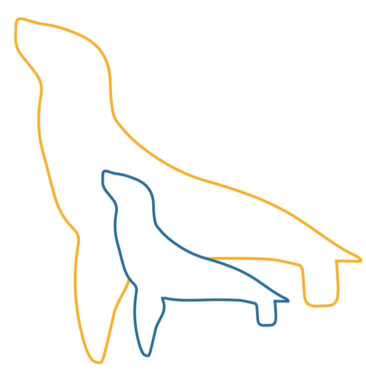
Carbon Emissions: Release of carbon dioxide into the atmosphere over a specified area and period of time

Carbonic Acid: Weak acid formed in solution when carbon dioxide dissolves in water

Ocean Acidification: Reduction in pH of seawater caused by the absorption of carbon dioxide (CO_2) from the atmosphere

pH Scale: Measure of how acidic or basic a substance is; approximates the activity and concentration of hydrogen ions

pH Test Strip: Simple tool for measuring the pH level of a liquid



HIGH SCHOOL STANDARDS:

California Common Core Standards

Mathematics

- HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

Chemistry

- 5.d. Students know how to use the pH scale to characterize acid and base solutions.
- 3.a. Students know how to describe chemical reactions by writing balanced equations.

California Next Generation Science Standards

- 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.
- 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.

PROGRAM MATERIALS:

- "Acids, Bases, and Our Oceans" worksheet

Name: ____________________

Date: ____________________

ACIDS, BASES, AND OUR OCEANS

What does the pH scale measure?

What are the differences between acids and bases?

What pH is purified water? What color shows on your pH test strips?

What is your procedure for testing the pH of the other solutions? Create a table for your experiment.

What is the importance of balancing equations?

Name: ______________________

Date: ______________________

ACIDS, BASES, AND OUR OCEANS CONTINUED

Balance the reactions of your experiment:

Lemon juice (citric acid) reacting with water:

$$C_6H_8O_7 + H_2O \Leftrightarrow C_6H_5O_7^{-3} + H_3O^{+1}$$

Vinegar (acetic acid) reacting with water:

$$C_2H_4O_2 + H_2O \Leftrightarrow C_2H_3O_2^{-1} + H_3O^{+1}$$

Baking soda (sodium bicarbonate) reacting with water:

$$NaHCO_3 + H_2O \Leftrightarrow NaOH + H_2CO_3$$

Bleach (sodium hypochlorite) reacting with water:

$$NaClO + H_2O \Rightarrow HOCL + NaOH$$

Write down your hypothesis about the pH of seawater:

What was the pH of the artificial seawater?

LESSON 2

THE CHEMISTRY OF OCEAN ACIDIFICATION

Enduring Understanding: The chemistry of our oceans is changing on a molecular level, and it is important to understand the process.

Materials

- "The Chemistry of Ocean Acidification" worksheet
- Whiteboard or blackboard
- Writing materials

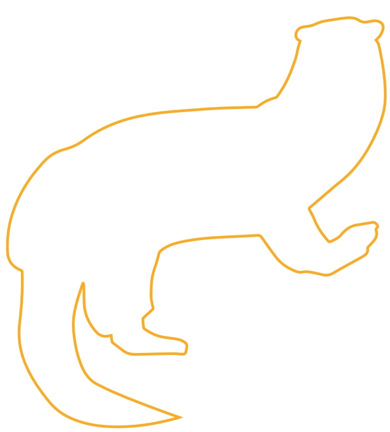
SETUP:

1. Make copies of "The Chemistry of Ocean Acidification" worksheet.
2. Write Le Chatelier's principle on the board (see Glossary).
3. Prepare writing materials.

PROGRAM OUTLINE:

What is ocean acidification? (Teacher-led classroom discussion.)

- Ocean acidification is the term given to the changing chemistry of our oceans. Human carbon emissions have increased the concentration of CO_2 in the atmosphere. Have your students read Le Chatelier's principle and describe what they believe occurs as the atmospheric CO_2 concentration increases.
  - Because the concentration of CO_2 in the atmosphere is higher than it is in the oceans, this extra CO_2 is absorbed by seawater. As a result, the oceans are becoming more acidic and less alkaline.



Chemical equations of ocean acidification

- Introduce the chemistry behind ocean acidification by having your students write out and balance the equation below, as well as predict the products when only given the reagents, or vice versa. Verbally explain the process and then give them the equation with missing elements so that they can fill in the blanks and describe the equation in their own words. To simplify the process, you may want to break down each of the equations rather than giving it as a whole.

PROGRAM OUTLINE CONTINUED:

- Ocean acidification chemical equations

$$CO_{2\,(aq)} + H_2O <=> H_2CO_3 <=> HCO_3^- + H+ <=> CO_3 2^- + 2\ H^+$$

- Step by step explanation
  - o Carbon dioxide (CO_2) from the atmosphere reacts with water (H_2O) to form carbonic acid (H_2CO_3), which then dissociates to form bicarbonate (HCO_3^-) and hydrogen ions (H^+).
  - o Seawater is naturally saturated with carbonate ions (CO_3^{2-}), a base that acts like an antacid to neutralize the H^+, forming more bicarbonate.
- Example problems

$$CO_{2\,(aq)} + \_\_\_\_\_ <=> H_2CO_3 <=> HCO_3^- + \_\_\_\_\_ <=> CO_3^{2-} + \_\_\_\_\_\ H^+$$

$$CO_{2\,(aq)} + \_\_\_\_\_ <=> H_2CO_3$$

$$H_2CO_3 <=> HCO_3^- + \_\_\_\_\_$$

$$HCO_3^- + H^+ <=> CO_3^{2-} + \_\_\_\_\_\ H^+$$

$$HCO_3^- + H^+ <=> \_\_\_\_\_\_ + 2\ H^+$$

Understanding the steps

$$CO_{2\,(aq)} + H_2O <=> H_2CO_3$$

- When CO_2 is added to seawater, the carbonic acid is an intermediate step and is present only in small amounts. Therefore, we can represent this first part of the equation as

$$CO_{2\,(aq)} + H_2O <=> HCO_3^- + H^+$$

- What happens when we increase the concentration of CO_2 in this reaction (such as when the atmospheric CO_2 increases)?
  - The forward reaction is favored in order to maintain equilibrium. Seawater is weakly buffered with respect to changes in hydrogen ions, and there will be a much larger proportional change in the concentration of H^+ than HCO_3^-.
  - The excess H^+ is used up in another reaction:

$$CO_3^{2-} + H^+ <=> HCO_3^-$$

- What is the net effect when CO_2 is added to seawater?
  - The concentration of H^+ and HCO_3^- increases, while the concentration of CO_3^{2-} decreases.

PROGRAM OUTLINE CONTINUED:

- This net reaction for all the equations above can be represented by the following equation.

$$CO_{2\,(aq)} + H_2O + CO_3^{2-} <=> 2HCO_3^-$$

- It's important to remember that the H^+ increases proportionally to the ratio between the concentrations of HCO_3^- and CO_3^{2-}. The increase in H^+ concentration is what causes ocean acidification, where the decrease in concentration of naturally occurring CO_3^{2-} is the main threat to calcifying marine organisms (see Lesson 4).

TEACHER BACKGROUND:

Chemistry of Ocean Acidification

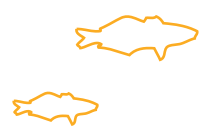
Atmospheric CO_2 is absorbed by ocean water. It reacts with H_2O to form carbonic acid, a corrosive chemical that can degrade the shells of marine organisms. The more immediate concern with ocean acidification is the availability of carbonate. Numerous marine species rely on naturally occurring carbonate to build their calcareous structures. Ocean acidification decreases the availability of carbonate, making it harder for these organisms to produce a calcareous structure. Their shells and skeletons become thinner and weaker, making them more vulnerable to predation, competition, and harsh elements. They use more metabolic energy to try and build shells, so they have less energy available for basic survival needs, such as finding food and shelter. Many scientists fear that ocean acidification could eventually decrease marine biodiversity on a large scale.

Ocean acidification equation:

$$CO_{2\,(aq)} + H_2O <=> H_2CO_3 <=> HCO_3^- + H^+ <=> CO_3^{2-} + 2\ H^+$$

Carbon dioxide (CO_2) reacts with water (H_2O) to form carbonic acid (H_2CO_3), which then dissociates to form bicarbonate (HCO_3^-) and hydrogen ions (H^+). Seawater is naturally saturated with carbonate ions (CO_3^{2-}) a base that acts like an antacid to neutralize the H^+, forming more bicarbonate.

The net reaction for this equation:



$$CO_{2\,(aq)} + H_2O + CO_3^{2-} <=> 2HCO_3^-$$

where H^+ increases proportionally to the ratio between the concentrations of HCO_3^- and of CO_3^{2-}. The increase in H^+ concentration is what causes ocean acidification, where the decrease in concentration of naturally occurring CO_3^{2-} is the main threat to calcifying marine organisms.

Balancing Chemical Equations

A chemical equation is balanced when the number of atoms of each type is the same on each side of the equation. The law of the conservation of mass states that you cannot make or destroy atoms during a chemical reaction. Reagents are on the left side of an equation and products are on the right. In order to balance an equation, you must have the same number of atoms in the products as in the reagents.

GLOSSARY:

Calcareous: Adjective meaning mostly or partly composed of calcium carbonate

Calcification: Process by which marine organisms sequester carbonate and calcium to form calcium carbonate shells and skeletons

Chemical Equation: Written representation of a chemical reaction in which the symbols and amounts of the reactants are separated from those of the products by an equal sign, arrow, or a set of opposing arrows

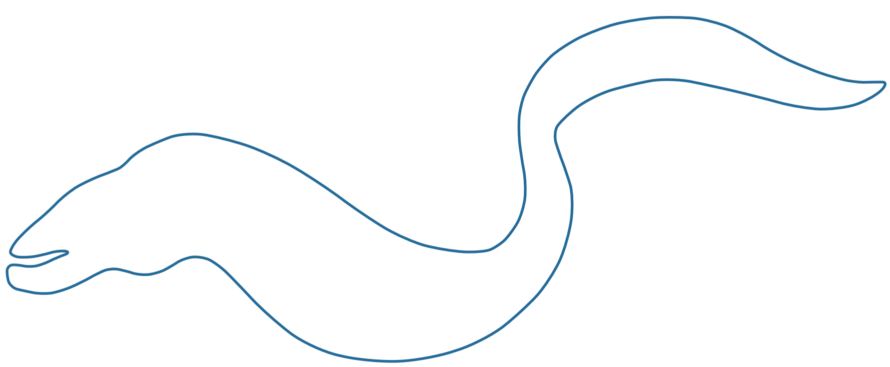
Le Chatelier's Principle: When a system at equilibrium is subjected to change in concentration, temperature, volume, or pressure, then the equilibrium readjusts itself to counteract the effect of the applied change and a new equilibrium is established; also known as "The Equilibrium Law."

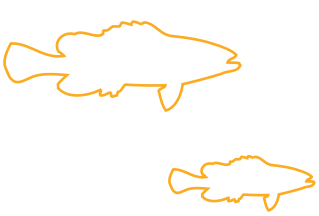
Ocean Acidification: Reduction in pH of seawater caused by the absorption of carbon dioxide (CO_2) from the atmosphere

Products: Substance that is formed as the result of a chemical reaction

Reactants: Substance that takes part in and undergoes change during a chemical reaction

Sequester: The act of forming a chelate or other stable compound with an ion, atom, or molecule so that it is no longer available for reactions





HIGH SCHOOL STANDARDS:

California Common Core Standards

Mathematics

- MP.2. Reason abstractly and quantitatively.

California Science Content Standards

Chemistry

- 3.a. Students know how to describe chemical reactions by writing balanced equations.
- 9.b. Students know equilibrium is established when forward and reverse reaction rates are equal.

California Next Generation Science Standards

- HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
  - 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.

PROGRAM MATERIALS:

- "The Chemistry of Ocean Acidification" worksheet

Name: ______________________

Date: ______________________

THE CHEMISTRY OF OCEAN ACIDIFICATION

According to our classroom discussion, what does ocean acidification mean? Why is it occurring?

Determine the missing reactants and products and balance the following equations:

$$CO_{2\,(aq)} + \_\_\_\_\_\_ <=> H_2CO_3$$

$$H_2CO_3 <=> HCO_3^- + \_\_\_\_\_\_$$

$$HCO_3^- + H^+ <=> CO_3^{2-} + \_\_\_\_\_\_ H^+$$

$$HCO_3^- + H^+ <=> \_\_\_\_\_\_\_ + 2\,H^+$$

Using proper nomenclature, describe the chemical equations above.

Breaking down the steps:

$$CO_{2\,(aq)} + H_2O <=> HCO_3^- + H^+$$

Using Le Chatelier's principle, describe what happens when we increase the concentration of CO_2 in the reaction above.

Where does the excess H^+ end up?

What is the net reaction for ocean acidification?

LESSON 3

OCEANS ABSORBING OUR CARBON

Enduring Understanding: Every person produces a certain amount of carbon emissions through common everyday activities. This carbon contributes to atmospheric carbon dioxide, which is absorbed by the oceans. We can reduce this carbon footprint by taking conservation actions.

Materials

- "Oceans Absorbing Our Carbon" worksheet
- Computer with Internet access
- Projector and screen
- Whiteboard or blackboard
- Dry ice (available at many grocery stores at low cost)
- Cooler
- Small glass beaker with wide mouth
- Large glass container (big enough to hold the small glass beaker)
- Purified (distilled) water
- Red cabbage juice or bromothymol blue pH indicator (available at Science Company or Amazon)
- Dropper or pipette
- Stirring stick
- Prongs, kitchen gloves, and goggles (for handling dry ice)
- Writing materials

SETUP:

1. Make copies of the "Oceans Absorbing Our Carbon" worksheet.
2. Familiarize yourself with the free Carbon Footprint Calculator provided by The Nature Conservancy.
3. Connect a computer with Internet access to a projector and screen visible to your class.
4. Put a small (less than one pound) piece of dry ice in an ice cooler.
   - As dry ice sublimates very quickly if not kept in a dry-ice cooler, try to buy it as close to the time of your program as possible. If you're keeping it overnight, buy one to two pounds and place it in your freezer, then transfer it to a cooler the morning of your program.
5. Place the small glass beaker, large glass container, water, pH indicator, dropper, stirring stick, cooler with dry ice, prongs, and kitchen gloves on a demonstration table
6. Verify the purified water is neutral by adding pH indicator to a small amount.
7. If you're using red cabbage juice as your pH indicator, prepare this the night before your class (see "How to Make Red Cabbage Juice pH Indicator" in Instructor Background)
8. Write the chemical equation for ocean acidification on the board:

$$CO_{2\,(aq)} + H_2O \iff H_2CO_3 \iff HCO_3^- + H^+ \iff CO_3^{2-} + 2H^+$$

PROGRAM OUTLINE:

Calculating a carbon footprint

- What is a carbon footprint?
  - Many of our daily activities use fossil fuels, which produce a certain amount of CO_2 when burned. Using electricity, driving cars, flying on planes, recycling, even the types of food one eats all contribute to an individual's carbon footprint.
  - Hand out the "Oceans Absorbing Our Carbon" worksheets.
- Demonstrate how to use the Carbon Footprint Calculator.
  - Assign students the task of determining the carbon footprint for their households. As they may need to consult with their families, you may either assign this as homework or reserve your school's computer lab for the day after handing out the worksheets so that they can gather the relevant information from their household.
  - Provide your students with the link to the EPA's website on carbon emissions, "Overview of Greenhouse Gases": http://www.epa.gov/climatechange/ghgemissions/gases/co2.html
    - o They should use this website to answer the questions in the first section of their worksheet.
    - o Collect each student's carbon footprint anonymously and write the numbers on the board (i.e., have your students write down their carbon footprint on a scrap of paper and place it in a bowl).
  - Discuss how each section of the Carbon Footprint Calculator contributes to or takes away from our overall carbon footprint and why. Ask your students what actions they can take to reduce their carbon footprint.
  - Add together all the carbon footprint calculations from the entire class. Ask them to consider what that number might be if we add all the classes in the school, all the schools in the district, all the districts in the state, and finally, all 50 states.
    - o The EPA has calculated that the United States produced 5,400 million metric tons of carbon dioxide in 2012.
  - Explain that the oceans absorb atmospheric CO_2, much like a sponge absorbs water. At first, scientists believed this was a good thing, as it took away CO_2 from the atmosphere and helped protect against climate change, but now we know that the large input of CO_2 is changing the chemistry of our oceans.
  - Allow time for students to complete the first part of their "Oceans Absorbing Our Carbon" worksheet individually or in groups.

Dry-ice demonstrations and observations

- If you have enough materials, you may choose to break your students into smaller groups and have them participate in the experiment. Otherwise, conduct it as a demonstration. Only the instructor should handle the dry ice.
- Create an artificial ocean
  - Add about one inch of water to the bottom of the large glass container. Using the dropper, add a small amount of the pH indicator to the water until it clearly shows a neutral color (red-purple for cabbage juice, green for bromothymol blue). Explain that this represents the ocean. For a more realistic effect, add a small amount of a household base, such as dish soap, to the water so that it represents a slightly basic solution like our oceans.

PROGRAM OUTLINE CONTINUED:

- How atmospheric CO_2 is absorbed by seawater
  - Refer to the ocean acidification chemical equation you wrote on the board earlier. Using their worksheets, have students predict what will happen when the dry ice is added to the small beaker and placed inside the artificial ocean (larger beaker). Their prediction needs to include which part of the chemical equation happens at what point and what color the pH indicator will turn.
  - Add about one inch of water to the bottom of the small glass beaker and add pH indicator until the neutral color appears clearly.
  - Using gloves and tongs, drop a small piece of dry ice into the small beaker. The water should immediately turn yellow and the dry ice begin to sublimate. Explain that this demonstrates the burning of fossil fuels that produces CO_2.
  - Very carefully place the small beaker (with sublimating dry ice) into the large glass container with pH indicator. The sides of the large container will "trap" the heavy CO_2 gas and keep it contained. The class will observe how the surface of the artificial seawater slowly begins to turn yellow as the CO_2 gas from the dry ice touches the surface of the water.
    - o What is the chemical process behind the change in pH indicator colors? How does this represent our actual atmosphere and oceans?
  - It represents how seawater absorbs atmospheric CO_2 emitted by humans and, subsequently, the chemistry of the oceans becomes slightly more acidic (less alkaline) due to the excess H+ ions.
    - o Why does the exchange of molecules between the gas and liquid occur?
  - Chemical systems in nature obey Le Chatelier's principle and work toward equilibrium, meaning that the molecules will flow in the direction where they are less concentrated. Therefore, the CO_2 gas flows from the atmosphere (where it is more concentrated) into the ocean (where it is less concentrated).
  - Using the stirring stick, stir the water in the large container to distribute the more acidic solution. Explain that the stirring stick represents ocean currents and that even though CO_2 enters seawater from the surface, the resulting hydrogen ions are distributed throughout our oceans by the movement of water in the form of currents.

Why is it so important that we understand how the chemistry of our oceans is changing?

- We need to be able to predict how organisms and ecosystems in our oceans are going to react to this changing chemistry and what we can do to mitigate the effects of ocean acidification. The very first step is to understand the process itself—how and why the exchange of CO_2 is occurring at the surface of our oceans.

TEACHER BACKGROUND:

Carbon dioxide is the main greenhouse gas emitted by human activities. It is naturally present in the atmosphere as part of Earth's carbon cycle. However, human activities are altering the carbon cycle, both by adding CO_2 to the atmosphere and by removing natural sinks that absorb CO_2, such as forests. Human-related emissions have greatly increased atmospheric CO_2 since the Industrial Revolution, mostly through the combustion of fossil fuels (coal, natural gas, and oil) for energy.

Sources of Carbon Emissions

The main sources of CO_2 emissions in the United States are electricity, transportation, and industry. The combustion of fossil fuels to produce electricity is the largest single source of CO_2 emissions in the nation, accounting for about 38 percent of total U.S. emissions. Transportation includes highway vehicles, air travel, marine transportation, and trains, and accounts for about 32 percent of total U.S. emissions. Between the years of 1990 and 2012, CO_2 emissions in the United States increased by about 5 percent. CO_2 emissions are influenced by many factors, including population growth, economic growth, changing energy prices, new technology, changing behavior, and seasonal temperatures.

Ocean acidification equation: $CO_{2\,(aq)} + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3^- + H^+ \Leftrightarrow CO_3^{2-} + 2\,H^+$

Carbon dioxide (CO_2) reacts with water (H_2O) to form carbonic acid (H_2CO_3), which then dissociates to form bicarbonate (HCO_3^-) and hydrogen ions (H^+). Seawater is naturally saturated with carbonate ions (CO_3^{2-}), a base that acts like an antacid to neutralize the H^+, forming more bicarbonate.

The net reaction for this equation: $CO_{2\,(aq)} + H_2O + CO_3^{2-} \Leftrightarrow 2HCO_3^-$

where H^+ increases proportionally to the ratio between the concentrations of HCO_3^- and of CO_3^{2-}. The increase in H^+ concentration is what causes ocean acidification, where the decrease in concentration of naturally occurring CO_3^{2-} is the main threat to calcifying marine organisms (see Lesson 3).

Reducing Emissions

The best way to reduce CO_2 emissions is to curb our consumption of fossil fuels. Individuals, homes, businesses, industries, and transportation can all reduce carbon emissions by adhering to a number of strategies. Some of these include using energy-efficient appliances, driving fuel-efficient vehicles, conserving energy by turning off lights and electronics when they aren't in use, producing energy from renewable resources like wind and solar, recycling materials, and consuming local food products that aren't transported long distances.

Dry Ice

Dry ice is the solid form of CO_2. It is most often used as a cooling agent to preserve frozen foods. Dry ice sublimates at -109.3°F, turning from a solid directly to a gas. It can burn human skin, so it must be handled with care.

How to Make Red Cabbage pH Indicator

Place two cups of chopped red cabbage in a large beaker or other glass container. Add boiling water to cover the cabbage. Allow at least ten minutes for the color to leach out of the cabbage. Filter out the cabbage to leave a red-purple-bluish-colored liquid. The pH of this liquid is about 7.

GLOSSARY:

Bromothymol Blue: A pH indicator for acids and bases

Cabbage Juice pH Indicator: Natural pH indicator that changes colors according to the acidity of the solution

Carbon Footprint: Total amount of greenhouse gases produced to directly and indirectly support human activities; usually expressed in equivalent tons of CO_2; the sum of all emissions of CO_2 produced by the activities of an individual or group of individuals in a given time frame

Dry Ice: Solid form of CO_2; used most often as a cooling agent

Fossil Fuels: General term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals, that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the earth's crust over hundreds of millions of years

Le Chatelier's Principle: When a system at equilibrium is subjected to change in concentration, temperature, volume, or pressure, then the equilibrium readjusts itself to counteract the effect of the applied change and a new equilibrium is established; also known as "The Equilibrium Law."

pH Indicator: Indicates where a solution lies on the pH scale using a predetermined color

Sublimation: Process by which a solid changes directly into a gas, skipping the liquid phase

RESOURCES:

- U.S. EPA, Calculations and References
http://www.epa.gov/cleanenergy/energy-resources/refs.html

- U.S. EPA, Carbon Dioxide Emissions
http://www.epa.gov/climatechange/ghgemissions/gases/co2.html

HIGH SCHOOL STANDARDS:

California Common Core Standards

ELA/Literacy

- WHST.9-12.2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

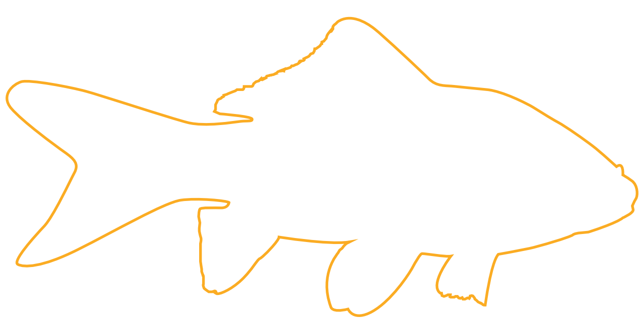
California Science Content Standards

Chemistry

- 9.a. Students know how to use Le Chatelier's principle to predict the effect of changes in concentration, temperature, and pressure.

California Next Generation Science Standards

- HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
  - Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collision of molecules and the rearrangement 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.



Name: ______________________

Date: ______________________

OCEANS ABSORBING OUR CARBON

Carbon Footprint Calculation

What is the carbon footprint for your household?

What household activities contributed to this number? Why?

According to the EPA, what are the biggest sources of CO2 emissions?

Why have carbon emissions in the United States increased over the last couple of decades? Are they projected to increase or decrease over the next decade? By how much?

What are some ways that we can reduce carbon emissions?

Why is it important that we reduce emissions?

Name: ________________________

Date: ________________________

OCEANS ABSORBING OUR CARBON

Dry Ice Experiment

What is the natural pH of our oceans?

What is Le Chatelier's principle? How does it apply to this experiment?

Write the balanced chemical equation for ocean acidification and label each element.

What is dry ice?

What is the name for the process of a solid turning directly into a gas?

How does this experiment with dry ice represent what is actually happening in our atmosphere and oceans?

LESSON 4

CALCIFICATION IN A CHANGING OCEAN

Enduring Understanding: Even very small changes in the pH of seawater can have a detrimental effect on the survival of calcareous marine organisms. The influx of CO2 in our oceans offsets calcification, the biochemical process by which animals grow their shells and skeletons.

Materials

- "Calcification in a Changing Ocean" datasheet
- Petri dishes
- 3 to 6 household solutions varying in pH (You may use just one acid, one base, and water as a control, or you can choose to add more solutions.)
- Beakers (to measure solutions)
- Cleaned eggshells (chalk or calcium carbonate antacid is an alternative if eggshells are not available)
- pH test strips
- Seashell from clam, mussel, or oyster (optional)
- Glass container (large enough for seashell)
- Vinegar
- Whiteboard or blackboard
- Writing materials

SETUP:

1. Obtain and clean eggshells.
2. Make copies of "Calcification in a Changing Ocean" datasheet.
3. Write the chemical equation for calcification on the board.
4. Divide the materials in accordance with student groups of four to six individuals.

PROGRAM OUTLINE:

Ocean acidification and shells

- What is calcification? (Teacher-led classroom discussion.)
  - Explain that calcareous organisms in the ocean build their shells and skeletons by taking up carbonate and affixing it with calcium to form calcium carbonate (simplified equation):

$$CO_3^{2-} + Ca^{+2} ==> CaCO_3$$

- How might ocean acidification harm animals with calcareous shells or skeletons?
  - Have your students guess which marine species have calcareous shells or skeletons. Be sure to discuss local species as well as those found in tropical ecosystems. Have your students predict what might occur to these animals as seawater becomes more acidic.
- Use household solutions to demonstrate how increasing acidity dissolves shells.
  - Split your class into groups. Give each group one petri dish for each solution they will be testing, a small amount of eggshells, and three to six household solutions with

measurement beakers.

- o Assign as homework: Have your students design a four-day experiment that would test the effects of each solution on the eggshells using the scientific method and the tools you've given them. Encourage them to use online resources and scientific papers (such as those that can be found on Google Scholar) to investigate similar experiments and the chemical properties of each solution. You may choose to require that they show you their resources.

- Students should use the scientific method: (1) generate the question, (2) form a hypothesis, (3) test the hypothesis, and (4) analyze results. Their investigation should include testing the pH of each solution and how the various solutions affect their eggshells over a given time period (with a maximum of four days). They need to create a table or scientific investigation sheet on which they can record their observations.
- At the end of the fourth day your students should wrap up their experiments and write down their final observations. Have each group share its results with the rest of the class. Offer them additional solutions of specified pH values and have them predict how they might affect the shells.
- Have your students write out the steps of their investigation, including data, observations, and analysis.

• What is the chemical process that occurred with the eggshells in the acid? (Teacher-led classroom discussion.)
  - The calcium carbonate ($CaCO_3$) in the eggshells reacts with the hydrogen ions (H^+) in the acid and dissolves to produce carbon dioxide (CO_2), water (H_2O), and calcium ions (Ca^{+2}). The bubbles that form are the CO_2. This is the chemical equation for this process:

$$CaCO_3 + 2H^+ <=> Ca^{+2} + H_2O + CO_2$$

• Dissolving seashells (optional demonstration)
  - Place a seashell in a large glass container and add enough vinegar to it to cover the top of the shell. Over the next few minutes, the shell will begin to noticeably bubble. What is happening?
    - o The high acidity of the vinegar breaks down the calcium carbonate of the shell and turns it into carbon dioxide, which bubbles off as a gas.
  - Explain that the ocean is not going to turn to vinegar overnight; rather, this experiment demonstrates the most extreme effects of an acidic solution on calcareous shells. The immediate concern for calcareous animals is the lack of carbonate ions that they can use to create their calcium carbonate shells.

Ocean acidification and calcification

• Ocean acidification affects the ability of organisms to build their calcium carbonate ($CaCO_3$) shells and/or skeletons.
• As extra CO_2 enters the oceans, it increases the concentration of bicarbonate and carbonic acid. This also increases the concentration of hydrogen ions. Have your students predict what may happen if the increase in hydrogen ions (H^+) is greater than the increase in bicarbonate (HCO_3^-) in the following equation:

$$HCO_3^- <=> CO_3^{2-} + H^+$$

  - Answer: The increase in H^+ ions would create an imbalance in the reaction. To maintain equilibrium

PROGRAM OUTLINE CONTINUED:

(Le Chatelier's principle), some naturally occurring carbonate ions (CO_3^{2-}) combine with H^+ ions to make more bicarbonate (see Lesson 3). This decreases the ocean's concentration of carbonate ions.

- Have your students examine the simplified equation that represents calcification (where $CaCO_3$ is the formed calcareous structure):

$$CO_3^{2-} + Ca^{+2} \Longrightarrow CaCO^3$$

  - With less available CO_3^{2-}, the rate of this reaction slows significantly and less $CaCO_3$ is formed.
- Discuss what impacts this dissolution could have on marine organisms.
  - Their shells and skeletons become thinner and weaker, making them more vulnerable to predation, competition, and harsh elements.
  - They use more metabolic energy to try and build shells, so they have less energy available for basic survival needs, such as finding food and shelter.
- What are some solutions to the ocean acidification problem?
  - Reducing human carbon emissions
  - Conducting scientific studies so that we better understand how marine organisms will be impacted
  - Making informed decisions regarding ocean policy management and how to conduct future scientific studies

TEACHER BACKGROUND:

Calcium Carbonate

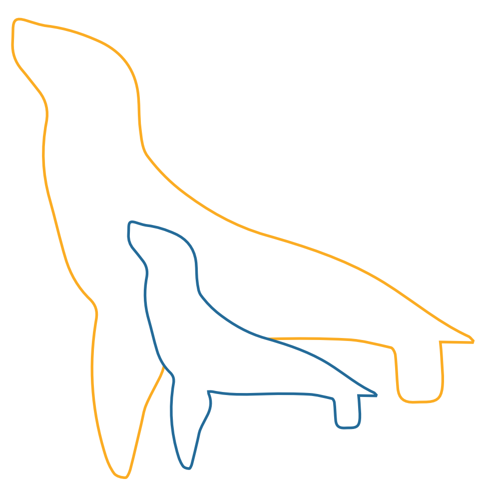
Eggshells are made of calcium carbonate, the same material produced by shelled marine organisms. This makes eggshells an excellent model for seashells. Chalk is also made of calcium carbonate and makes a good substitute for this experiment. Depending on their pH, the solutions in this experiment will affect the eggshells to varying degrees. Neutral water and basic solutions will cause no noticeable change, while acidic solutions will cause the eggshells to bubble as they break down calcium carbonate to form carbon dioxide and water. The more acidic the solution, the more the eggshells will bubble. After 72 hours, they will have lost enough calcium carbonate that they will be soft to the touch. This is only an example of extreme exposure to a very concentrated acid. The eggshells in the water and the base should be unaffected, since the calcium carbonate does not react with pure water or a basic solution.

The chemical equation for the reaction of calcium carbonate shells exposed to acid:

$$CaCO_3 + 2H^+ \Leftrightarrow Ca^{+2} + H_2O + CO_2$$

Calcium carbonate ($CaCO_3$) reacts with hydrogen ions (H^+) to dissolve and produce calcium ions (Ca^{+2}), water (H_2O), and carbon dioxide (CO_2).

The more immediate concern with ocean acidification is the availability of carbonate. Numerous marine species rely on naturally occurring carbonate to build their calcareous structures. Ocean acidification decreases the availability of carbonate, making it harder for these organisms to produce a calcareous structure. Their shells and skeletons become thinner and weaker, making them more vulnerable to predation, competition, and harsh elements. They use more metabolic energy to try and build shells, so they have less energy available for basic survival needs, such as finding food and shelter. Many scientists fear that ocean acidification could eventually decrease marine biodiversity on a large scale.



GLOSSARY:

Acid: Chemical substance with pH less than 7; produces H^+ ions in aqueous solutions and neutralizes alkalis; typically corrosive; changes litmus from blue to red; common examples: citric acid (from fruits or vegetables), ascorbic acid (vitamin C), vinegar, carbonic acid (carbonation in soft drinks), lactic acid (in buttermilk)

Base: Chemical substance with pH greater than 7; produces OH^- ions and accepts protons; typically turns red (acidified) litmus blue; common examples: detergents, soap, lye, ammonia

Calcareous: Adjective meaning mostly or partly composed of calcium carbonate

Calcification: Process by which marine organisms sequester carbonate and calcium to form calcium carbonate shells and skeletons

Calcium Carbonate: White, insoluble solid occurring naturally as chalk, limestone, marble, and calcite; forms mollusk shells and stony corals

Control: Test subject that is not altered or changed to act as a comparison model to indicate or measure the effect of the variables

Chemical Equilibrium: In a chemical reaction, the state in which both reactants and products are present in concentrations that have no further tendency to change with time

Dissolution: Process of dissolving a solid substance into a solvent to make a solution

Precipitation: Forming a solid when a substance separates out from a solution

Sequester: The act of forming a chelate or other stable compound with an ion, atom, or molecule so that it is no longer available for reactions

HIGH SCHOOL STANDARDS:

California Common Core Standards

ELA/Literacy

- WHST.9-12.7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

California Science Content Standards

Chemistry

- 8.a. Students know the rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time.

California Next Generation Science Standards

- HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.
  - In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the number of all types of molecules present.

PROGRAM MATERIALS:

- "Calcification in a Changing Ocean" datasheet

Name: ______________________

Date: ______________________

CALCIFICATION IN A CHANGING OCEAN

From our discussion in class, explain the process of calcification.

How might ocean acidification harm calcareous animals?

Test the pH of each of your solutions. Write out a hypothesis for how each will affect your calcium carbonate eggshells. In the space below, design a table that includes space for your hypothesis for each solution and observations.

Name: ______________________

Date: ______________________

CALCIFICATION IN A CHANGING OCEAN CONTINUED

What is the chemical process that occurs when the eggshells are exposed to an acid?

Does the concentration of the acid matter in this experiment? Why do you think this?

What did you observe happening to the eggshells in the water? In the base? Use evidence from your investigation to support your idea.

HS CHEMISTRY

RESOURCES

Websites

• Channel Island's National Marine Sanctuary, "Understanding Ocean Acidification"
http://www.cisanctuary.org/ocean-acidification/index.html

• NOAA, "Ocean Acidification Educational Resources for the High School Classroom"
http://coralreef.noaa.gov/education/oa/curricula-activities.html

• NOAA, PMEL Carbon Program, "What Is Ocean Acidification?"
http://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F

• NRDC, Ocean Acidification Location Map and The Acid Test video
http://www.nrdc.org/oceans/acidification/

• Ocean Ark Alliance, "Ocean Acidification: The Other CO2 Challenge"
http://oceanacidification.net

• OER Commons, Open Educational Resources on Ocean Acidification
https://www.oercommons.org/search?batch_start=20&f.search=our+changing+ocean+estuaries&sort_by=title

• U.S. EPA, "Calculations and References"
http://www.epa.gov/cleanenergy/energy-resources/refs.html

• U.S. EPA, "Overview of Greenhouse Gases"
http://www.epa.gov/climatechange/ghgemissions/gases/co2.html