ehp

LESSON:

The Buffer Zone

Acid–Base Chemistry in the World's Oceans

Summary Students review introductory acid–base chemistry, conduct an experiment simulating ocean acidification resulting from excess atmospheric carbon dioxide (CO_2), and discuss potential human implications of increased ocean temperatures and acidification.

Lesson Type **Experiment**—students collect, manipulate, and/or summarize data from an experiment or activity they conduct.

Focus Lesson—this lesson develops students' skills and topical understanding by having them read and interpret information from an in-depth *EHP* news article.

***EHP* Article** In Hot Water: Global Warming Takes a Toll on Coral Reefs
Environ Health Perspect 116:A292–A299 (2008)
http://www.ehponline.org/members/2008/116-7/focus.html

Objectives By the end of this lesson, students should be able to

- define *acid*, *base*, *neutral*, *salt*, and *buffer*
- measure the pH of solutions
- describe how excess CO_2 contributes to the acidification of the world's oceans
- describe the potential human impacts of pH and temperature changes in oceans

Class Time 60–90 minutes

Grade Level 9–12

Subjects Addressed Biology, Chemistry, Environmental Science, General Science

Aligning with Standards

SKILLS USED OR DEVELOPED

- Classification
- Communication (note-taking, oral, written—including summarization)
- Comprehension (listening, reading)
- Critical thinking and response
- Experimentation (conducting, data analysis, design)
- Manipulation
- Observation
- Research

SPECIFIC CONTENT ADDRESSED

- Climate change/global warming
- pH
- Ocean chemistry

NATIONAL SCIENCE EDUCATION STANDARDS MET

Science Content Standards

Unifying Concepts and Processes Standard

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Evolution and equilibrium

Science as Inquiry Standard

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

National Institute of Environmental Health Sciences

Physical Science Standard
- Chemical reactions

Life Science Standard
- Interdependence of organisms

Earth and Space Science Standard
- Geochemical cycles

Science in Personal and Social Perspectives Standard
- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

History and Nature of Science Standard
- Nature of scientific knowledge

Prepping the Lesson (30–45 minutes)

INSTRUCTIONS

1. Download the article "In Hot Water: Global Warming Takes a Toll on Coral Reefs" at http://www.ehponline.org/members/2008/116-7/focus.html.
2. Review Background Information, Implementing the Lesson, Assessing the Lesson, and Student Instructions for this lesson.
3. Make copies of the Student Instructions.
4. Gather supplies for experiments.

MATERIALS

per student
- 1 copy of "In Hot Water: Global Warming Takes a Toll on Coral Reefs," preferably in color
- 1 copy of the Student Instructions

per group of 3–5 students
- pH test (4 colorimetric test strips or a pH meter)
- alkalinity test (colorimetric test liquid or strips)
- 20 g sea salt (sea salt should be used because the buffering minerals make it the best replicate for seawater; it is available at pet stores that sell saltwater aquariums)
- 600 mL carbonated water (soda water with no added sugar or flavorings)
- 600 mL distilled water
- 4 500-mL containers
- 3 500-mL beakers
- scale
- labels
- stirring rod or spoon

VOCABULARY
- acid
- acidic
- alkaline
- alkalinity
- base
- basic
- buffer
- carbon dioxide (CO_2)
- conjugate acid/base
- conjugation
- coral bleaching
- neutral
- pH
- salts
- solution
- symbiotic

BACKGROUND INFORMATION

Most of the necessary background information is provided in the Student Instructions and the accompanying article. However, it may be helpful to discuss alkalinity with students, especially as it applies to oceans and the context of the experiment for which the students conduct this activity. Alkalinity refers to the buffering capacity of a solution. In the oceans, bicarbonates are the primary buffer, but carbonates and other minerals (such as borate) can contribute to alkalinity/buffering. Alkalinity can be thought of as how much acid it takes to convert bicarbonate to carbonic acid. In the lesson, students test alkalinity and are introduced to buffers and basic salts but may wonder how alkalinity (and their test for alkalinity) relates to what they are learning. Some questions students may ask include:

- **How are alkalinity and buffering related or different?** Alkalinity is a measure of the buffering capacity of water, the capacity of bases to neutralize acids, or the ability of water to resist change in pH. Buffers are the chemicals (like bicarbonate salt) present in the water that help neutralize acid.

- **What does alkalinity have to do with this experiment?** We are measuring the ability of sea salt to buffer the acid and comparing it with the buffering ability of the salt-free water.

- **What does the experiment tell us about the oceans?** The oceans have the ability to "absorb" or buffer the additional acids entering the water as a result of increased CO_2 in the atmosphere; however, if there is too much acid, the buffering systems become overwhelmed and the pH in the oceans begin to drop.

RESOURCES

Environmental Health Perspectives, Environews by Topic page, http://ehp.niehs.nih.gov/. Choose Climate Change/Global Warming, Marine Science

Casiday R, Frey R. Blood, sweat, and buffers: pH regulation during exercise. Acid–base equilibria experiment. St. Louis, MO: Department of Chemistry, Washington University. http://www.chemistry.wustl.edu/~edudev/LabTutorials/Buffer/Buffer.html

Holmes-Farley R. 2002. Calcium and alkalinity. *Reef Keeping* 1(3). http://reefkeeping.com/issues/2002-04/rhf/feature/index.php

The Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. London, UK: The Royal Society. http://royalsociety.org/displaypagedoc.asp?id=13539

Implementing the Lesson

INSTRUCTIONS

1. Have students individually complete Step 1 or read the information in Step 1 together as a class. Discuss pH, acids, bases, and buffers as needed to clarify concepts. Students do not need know the details of how pH is calculated in order to complete this lesson.

2. Divide the class into groups of 3–5 students each. Have the students gather the supplies and conduct the experiment in Step 2.

3. Have students complete Steps 3 and 4 individually and submit their written responses for credit/grading.

4. Discuss the questions in Step 5 as a class or within groups. The goal of this discussion is to have the students reflect on the scientific process and observe how it is being used to better understand the potential impact of climate change on coral reefs (you may want to note that this research is in its early stages).

5. Review the scientific process with the students:
   - Observe and collect descriptive information about a phenomenon.
   - Develop a hypothesis or an "educated" explanation for the phenomenon.
   - Make a prediction that can be proven false by the experiment.
   - Perform an experiment to test the prediction.
     - The experiment can manipulate physical phenomena (variables) or simply acquire additional facts (observations).
     - Repeat for verification.
   - Use the experimental results to assess the validity of the hypothesis.
   - Incorporate the knowledge into the larger framework of science.

Notes & Helpful Hints

- A complementary *EHP* Science Education lesson, "Coral Reef Web," can be downloaded at http://www.ehponline.org/science-ed/2005/coralweb.pdf. In "Coral Reef Web," students design a diagram (or "web") to show the interdependence of plants, animals, and microorganisms in the coral reefs of the world. The diagram also includes common stressors placed on that environment and ways in which the health of the reef ecosystem can affect the health of people.

Assessing the Lesson (steps not requiring teacher feedback are not listed below; see Student Instructions for complete step-by-step instructions)

Step 2 **Now you will conduct the buffering experiment.**

Ensure that students have completed their data table and that the data are reasonable (e.g., neutral pH for distilled water) and appropriate for the type of equipment used to measure the pH or alkalinity (e.g., a specific number if using a meter, or a range or approximation if using a colorimetric test).

Step 3 a. **Refer to the pH data you recorded above. Write whether each experimental parameter below is acidic, basic, or neutral.**

Distilled water: neutral

Distilled water with sea salt: basic

Carbonated water: acidic

Carbonated water with sea salt: acidic (but less acidic than carbonated water alone)

b. **What gas is used to make carbonated water? (Read the bottle label or search online for the information.)**

Carbon dioxide (CO_2)

c. **Based on what you have learned about CO_2, acids, bases, salts, and buffers, generate a hypothesis about what you think could happen to the pH of the oceans if CO_2 continues to be released into the atmosphere at current levels. Incorporate the following concepts into your hypothesis: pH, acid, basic, salt, buffer, and CO_2.**

Students should write clear hypotheses that incorporate the terms *pH*, *acid*, *base*, *salt*, *buffer*, and *CO_2*. Students should demonstrate a clear understanding of those terms in their hypotheses. Based upon the experiment, students' hypotheses should in some way describe a reduction in ocean pH (acidification) as a result of increased CO_2 overloading the buffering capacity of the oceans.

Step 4 a. **Describe the symbiotic relationship between coral and zooxanthellae, including what happens to coral if zooxanthellae die.**

Zooxanthellae are a type of algae. They provide corals with nutrients, such as carbon, that are produced during algal photosynthesis. In return, corals provide zooxanthellae shelter and access to sunlight. If zooxanthellae die, corals will starve.

b. **How do coral reefs benefit humans?**

- They provide habitat for important food sources (e.g., fish).
- They protect shorelines from storms and erosion.
- They are a source of medicines.

c. **List two ways excessive CO_2 can contribute to an ocean's decline.**

- It can increase ocean temperature as a result of an overall increase in the Earth's temperature.
- It can lower the pH of the ocean.

d. How does the experiment you conducted simulate the relationship between CO_2 and the ocean?

By adding the appropriate amount of sea salt to the distilled water, a "typical" ocean environment was simulated. Adding the sea salt to the carbonated water simulated an ocean environment that has excess CO_2. The CO_2, which is converted to carbonic acid, results in an acidic environment that exceeds the buffering ability of the sea salt/minerals.

e. Based on the information you read in the article, is your hypothesis supported or not supported? Explain.

Student responses will vary depending on their hypotheses. Make sure students restate their hypotheses and provide clear, logical examples showing why their hypotheses were supported or not supported based on the information in the article.

Step 5

a. How did the scientific process help scientists untangle the variables of temperature, coral bleaching, disease, and coral death?

- Scientists conducted routine annual surveys on reef sites. This is part of a data collection process to identify, understand, and monitor the reef ecosystem. The goal of this research is to identify characteristics of a normal reef ecosystem.
- Some corals began to bleach when sea temperatures rose to over 30°C (86°F). This was a sign of an anomaly in the system (a change from normal). Scientists quadrupled monitoring efforts to reduce the chance of missing important information related to the event.
- The scientists had their own hypotheses (which are not explicitly shared in the article) about what might happen to the coral reefs with the temperature increase, but as described in the article, "the bleaching outbreak mushroomed far beyond their expectations."
- The increased monitoring revealed that although corals were beginning to recover, they were ultimately killed by disease. The scientists counted more than 6,000 disease patches, or lesions, on the corals they observed. Counting the number of lesions is an example of quantitative data collection. Qualitative data collection involved the scientists identifying and describing the types of diseases on the corals.
- The detailed data collection helped scientists make several connections that could have been lost had this data collection not been occurring. They observed that an increase in ocean temperatures was associated with coral bleaching (death of the symbiotic algae zooxanthellae). When the temperatures dropped, the corals began to recover but were ultimately killed by disease.

b. The scientific process involves many people testing different hypotheses in an attempt to explain a single event or process. What are some hypotheses explaining the relationship between rising ocean temperature and coral bleaching?

- Warming may trigger the release of zooxanthellae-killing toxins by *Vibrio* bacteria.
- Heat-stressed corals may give off acidic free radicals that drive the algae away.
- Some combination of both scenarios might be occurring.
- Warming may trigger coral illness by stressing the animals, leaving them open to infection (their immunity is worn down from exhaustion).
- Heat stress may change normally harmless bacteria into opportunistic killers.

c. What are some of the variables mentioned in the article that may affect coral health?

- Different diseases (e.g., the white plague bacterium *Aurantimonas coralicida*, which may be linked to the bacterium *Serratia marcescens*).
- Different pollutants (e.g., chemicals, sewage contamination, and sediments from unpaved roads and land development).
- Different types of corals.

d. What are some suggestions to reduce coral bleaching and coral death?

- Reduce the input of CO_2 into the atmosphere.
- Properly install and use silt curtains (temporary flexible sediment barriers) to catch silt.
- Reduce ocean dumping of waste such as sewage sludge, industrial waste, and infectious medical waste.
- Reduce runoff and non–point source pollution (pollution running into a water body from numerous diffuse sources).
- Treat coral diseases.
- Prevent overfishing.

Authors and Reviewers

Author: Stefani Hines, College of Pharmacy, University of New Mexico

Reviewers: Jennifer K. Campbell and Laura Hemminger, Center for School and Community Health Education, School of Public Health, University of Medicine & Dentistry of New Jersey; Paul Lioy, University of Medicine & Dentistry of New Jersey; Susan M. Booker, Martha M. Dimes, Erin Dooley, and Dorothy L. Ritter, *Environmental Health Perspectives*; Philip M. Iannaccone, Northwestern University

Give us your feedback! Send comments about this lesson to ehpscienceed@niehs.nih.gov.

ehp

STUDENT INSTRUCTIONS:

The Buffer Zone

Acid–Base Chemistry in the World's Oceans

Step 1 Consider the following information in preparation for the rest of this lesson:

What is pH? What do *alkalinity* and *buffering* mean? How do these concepts relate to each other and to global climate change? Why do we care?

In this lesson you will learn about the concepts of pH, acid, base, alkalinity, and buffering by completing a simple experiment and reading an article about scientists' discoveries related to global climate change and our oceans. You will also discuss with your classmates the effects that changes in the ocean may have on humans.

Acids, Bases, and pH

You may already be familiar with the concepts of acids, bases, and pH. There are many examples of acids and bases in our daily lives. For example, vinegar, an acid, is composed of about 5% acetic acid in about 95% water. Baking soda, a base, is a white crystalline solid composed of sodium bicarbonate.

So what makes vinegar an acid and baking soda a base? The difference is how they behave in water once they dissolve. Vinegar and other acids release positive hydrogen ions (H^+) in water; the plus sign refers to a net positive charge. Baking soda and other bases release negative hydroxide ions ($OH^–$) in water.

Just as distance can be measured in meters and mass in grams, pH is a measure of whether a chemical behaves like an acid (H^+) or a base ($OH^–$), or whether it is neutral ($H^+ = OH^–$). Instruments such as meters and special chemical test strips measure pH.

pH is reported as a range from 0 to 14. One way to think about the pH scale is to start in the middle, at 7. If you place a pH instrument in a solution (a mixture of water and other chemicals) and obtain a value of 7, that means the ratio of H^+ to $OH^–$ is equal, and the pH is neutral. If the pH is less than 7, there is more H^+ than $OH^–$ in the water, and the pH is acidic (acid = pH < 7). Conversely, when there is more $OH^–$ in the water, the pH is basic, or alkaline (basic = pH > 7).

Salts

When learning about acids and bases, it is important to know about salts. You may be familiar with table salt— sodium chloride (NaCl)—but there are many different forms of salt, such as calcium chloride (CaCl), magnesium sulfate ($MgSO_4$, commonly called Epsom salts), and sodium bicarbonate ($NaHCO_3$).

Salts are formed when an acid and a base are combined. For example, when a strong acid, such as hydrochloric acid (HCl), is mixed with a strong base, such as sodium hydroxide (NaOH), salt and water are produced, resulting in a net neutral charge. This chemical reaction can be shown as

$HCl + NaOH \rightarrow NaCl + H_2O$.

The $\rightarrow$ indicates a 1-way reaction, meaning once the reaction occurs, it is done; new products are formed, and the reaction is irreversible.

In this example, when you mix the same ratio of a strong acid and a strong base, a net neutral charge occurs ($H^+ = OH^–$, so the pH = 7). However, not all acids and bases are strong; some are weak. "Strong" and "weak" refer to how completely the H^+ or $OH^–$ disassociates from its parent chemical and doesn't necessarily reflect where the acid or base falls on the pH scale. Strong acids and bases have complete disassociation of H^+ or $OH^–$, whereas weak acids and bases have varying degrees of disassociation. Mixing strong acids and weak bases (or strong bases and weak acids) still produces salt, but those salts are not neutral; they behave like a weak acid or a weak base when mixed with water. Sodium bicarbonate is an example of a salt that behaves like a weak base in water.

The pH of Life

So why are acids, bases, and salts important? The bottom line: Life depends on them!

Most living things can live only in or near a neutral pH of 7. For example, the human body is constantly regulating its pH to make sure blood stays at a pH of around 7.4. If the pH of our blood changes to below 6.8 or above 7.8, we could die. When we exercise, our body produces lactic acid, which is what makes our muscles sore. Our body uses weak basic salts such as sodium bicarbonate to help neutralize (or "buffer") the acid. Keeping proper salt levels in our body during heavy exercise (when acids can build up quickly) is one reason why various salts are added to sports drinks.

The acid–base buffering is a constant back-and-forth process called conjugation. Here, the acid becomes its conjugate base when the acid loses its H^+ ion (it then has basic properties), and the base becomes its conjugate acid when the base accepts the H^+ ion. If there are equal amounts of acid and base, that equilibrium results in a neutral pH. If a weak acid is added to the system, a buffer can absorb a certain amount of the acid again, bringing the pH closer to neutral again. But if too much acid is added, the buffer is "used up," and the pH starts to drop.

An important buffering system that occurs both in our blood and in the ocean is between bicarbonates (HCO_3^-) and carbonic acid (H_2CO_3). Bicarbonates and carbonic acid come from minerals and carbon dioxide (CO_2), respectively. The bicarbonate–carbonic acid buffering equation in water is

$$H_3O^+ + HCO_3^- \leftrightarrow H_2CO_3 + H_2O.$$

The $\leftrightarrow$ indicates a back-and-forth, reversible, 2-way reaction.

Now that you have a general conceptual understanding of acids and bases and how they support life, you are going to conduct a simple acid–base experiment. What you learn from the experiment will later be applied to the real-world situation of global warming from excess CO_2 in the environment and its impact on the oceans. You will then write a hypothesis about what you think could happen to the pH of the oceans if CO_2 continues to be released into the atmosphere at current levels.

Step 2 Now you will conduct the buffering experiment. You will need the following materials for each group of students:

- pH test (4 colorimetric test strips or pH meter)
- alkalinity test (colorimetric test liquid or strips)
- 20 g sea salt
- 600 mL carbonated water
- 600 mL distilled water
- 4 500-mL containers
- 3 500-mL beakers
- scale
- labels
- stirring rod or spoon

a. Obtain the materials for your group.

b. Label your four containers and (if using them) your pH test strips:

   #1 distilled water

   #2 distilled water with sea salt

   #3 carbonated water

   #4 carbonated water with sea salt

c. Measure two quantities of 300 mL of distilled water and add to container #1 and to container #2.

d. Measure two quantities of 300 mL of carbonated water and add to container #3 and to container #4.

e. Measure 10 g of sea salt and add to container #2 ("distilled water with sea salt"). Stir until dissolved. (NOTE: This ratio of sea salt to water is similar to that in the ocean.)

f. Measure 10 g of sea salt and add to container #4 ("carbonated water with sea salt"). Stir until dissolved.

g. Measure the pH of the solutions in the four containers by following the instructions on the pH test kit or meter. Record the pH of each in the table below.

h. Measure the alkalinity of the solutions in the four containers by following the instructions on the alkalinity test kit. Record the alkalinity or alkalinity range of each in the table below.

	1 **Distilled Water**	**2** **Distilled Water with Sea Salt**	**3** **Carbonated Water**	**4** **Carbonated Water with Sea Salt**
pH				
Alkalinity				

NOTE: You may be using colorimetric tests to test for alkalinity and pH. Colorimetric tests use chemical reactions that result in color changes to loosely measure the amount of the substance you are testing. The term "loosely" is used for two reasons. First, these tests are not precise in their measurements; instead, you must use your judgment to match the color against a scale (so two people looking at the same pH test strip may interpret different shades of color). Second, some tests, such as the alkalinity test, provide a range rather than a single quantity. For example, the comparison chart for your alkalinity test may show a gradation of color from blue to yellow. If your sample turns blue, the alkalinity of the water you are testing is in the "high" range of 2.9–3.6 milliequivalents/liter (meq/L). If your sample is bluish-yellow, the alkalinity is somewhere in the range of 1.7–2.8 meq/L (which is considered normal for a saltwater aquarium environment). Although these colorimetric tests are not precise, they still provide useful information.

Metered instruments can provide precise quantitative measurements rather than a range. In the case of a pH meter, the tip of the meter's probe (what you stick in the water) is actually measuring the activity of the H^+ ions (the meter measures the change in free energy as ions diffuse across a membrane).

Step 3 Answer the following questions:

a. Refer to the pH data you recorded above. Write whether each experimental parameter below is acidic, basic, or neutral.

Distilled water:

Distilled water with sea salt:

Carbonated water:

Carbonated water with sea salt:

b. What gas is used to make carbonated water? (Read the bottle label or search online for information.)

c. CO_2 is the gas that is released during combustion, or burning, of carbon-based chemicals such as wood, gasoline, coal, and propane (the gas used in some barbecues). As more humans use more fossil fuel–based energy, more CO_2 is released into the atmosphere. The oceans naturally absorb CO_2.

Based on what you have learned about CO_2, acids, bases, salts, and buffers, generate a hypothesis about what you think could happen to the pH of the oceans if CO_2 continues to be released into the atmosphere at current levels. Be sure to incorporate the following concepts into your hypothesis: pH, acid, basic, salt, buffer, and CO_2. Write your hypothesis below.

Step 4 Read "In Hot Water: Global Warming Takes a Toll on Coral Reefs" and answer the following questions:

a. Describe the symbiotic relationship between coral and zooxanthellae, including what happens to coral if zooxanthellae die.

b. How do coral reefs benefit humans?

c. List two ways excessive CO_2 can contribute to an ocean's decline.

d. How does the experiment you conducted simulate the relationship between CO_2 and the oceans?

e. Based on the information you read in the article, is your hypothesis supported or not supported? Explain.

Step 5 Answer the following questions, then discuss your answers as a class or within your group.

a. How did the scientific process help scientists untangle the variables of temperature, coral bleaching, disease, and coral death?

b. The scientific process involves many people testing different hypotheses in an attempt to explain a single event or process. What are some hypotheses explaining the relationship between rising ocean temperature and coral bleaching?

c. Observing and describing the natural environment can be particularly challenging because there are many unidentifiable and uncontrollable variables. The article states that "links between warming and disease have only recently gained traction among scientists, although that picture too is complicated; diseases don't always follow bleaching, and sometimes they occur in the absence of warmer water."

The environment is very complex, and similar types of habitats may vary widely depending on their geographic location. For example, a coral reef near Florida has variables different from those of a coral reef near Australia. The Florida reef may receive more wastewater runoff, whereas the Australian reef may be more protected from runoff. Or the Florida reef has different types or amounts of fish compared with the reef in Australia. However, large-scale events such as rising ocean temperatures may produce similar overall effects. This is called *variability*. What are some of the variables mentioned in the article that may affect coral health?

d. What are some ways to reduce coral bleaching and death?