ENVIRONMENTAL HEALTH PERSPECTIVES

THE BUFFER ZONE
ACID-BASE CHEMISTRY IN THE WORLD'S OCEANS

After reading the *EHP* news article **In Hot Water: Global Warming Takes a Toll on Coral Reef**s, students conduct experiments that simulate ocean acidification resulting from excess atmospheric carbon dioxide and discuss potential human implications of increases in ocean temperatures and acidification due to climate change.

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Overview

Grade Level: **9–12**

Subjects Addressed: Biology, Chemistry, Environmental Science, General Science

Class Time: **60-90 minutes**.

Each student should begin by reading **In Hot Water: Global Warming Takes a Toll on Coral Reefs** http://ehponline.org/article/info:doi/10.1289/ehp.116-a292

OBJECTIVE

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; and **describe** the potential human impacts of pH and temperature changes in oceans.

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

MATERIALS (per group of 3–5 students)

» pH test (4 colorimetric test strips or a pH meter; results may vary depending upon the manufacturer of the pH strips; pH measurements can also be made using a pH indicator)
» 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; prepare solutions and test the pH strips with the different solutions for accurate pH readings)
» 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

Aligning with Standards

NATIONAL SCIENCE EDUCATION STANDARDS

Specific Content Standards

Unifying Concepts and Processes Standard
» Systems, order, and organization
» Change, constancy, and measurement
» Evidence, models, and explanation
» Evolution and equilibrium

Physical Science Standards
» Chemical reactions

Life Science Standards
» Interdependence of organisms

Earth and Space Science Standards
» Geochemical cycles

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

History and Nature of Science Standard
» Nature of scientific knowledge

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

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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.

Prepping the Lesson

1. Download the article **In Hot Water: Global Warming Takes a Toll on Coral Reefs** at **http://ehponline.org/article/info:doi/10.1289/ehp.116-a292**

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. Perform experiment before class time to ensure all reagents and supplies work as per instructions.

VOCABULARY WORDS

Acid, Conjugate acid/base, Acidic, Conjugation, Alkaline, Coral bleaching, Alkalinity, Neutral, Base, pH, Basic, Salts, Buffer, Solution, Carbon dioxide (CO_2), Symbiotic

NOTES AND 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.

Implementing the Lesson

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.

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.

RESOURCES:

Environmental Health Perspectives, News by Topic page, **http://ehp03.niehs.nih.gov/article/browsenews.action**
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**

National Resources Defense Council. Ocean Acidification: The Other CO_2 Problem. **http://www.nrdc.org/oceans/acidification/default.asp**

State of the Science FACT SHEET: Ocean acidification, **nrc.noaa.gov/plans_docs/2008/Ocean_AcidificationFINAL.pdf**