The NOAA Ship *Okeanos Explorer*

www.oceanexplorer.noaa.gov

NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Off Base

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Ocean Health within the "Why Do We Explore?" theme.

Focus

pH, buffers, and ocean acidification

Grade Level

9-12 (Biology/Chemistry/Earth Science)

Focus Question

What factors tend to resist changes in pH of the ocean, and why is the ocean becoming more acidic?

Learning Objectives

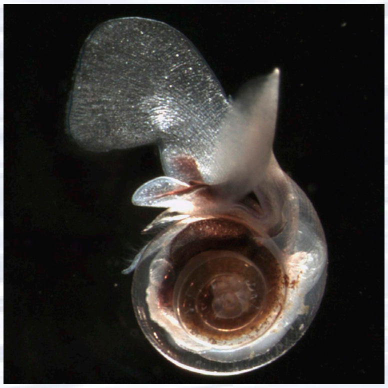
- Students will be able to define pH.
- Students will be able to define a buffer, and explain in general terms the carbonate buffer system of seawater.
- Students will be able to explain Le Chatelier's Principle, and will be able to predict how the carbonate buffer system of seawater will respond to a change in concentration of hydrogen ions.
- Students will be able to identify how an increase in atmospheric carbon dioxide might affect the pH of the ocean, and will be able to discuss how this alteration in pH might affect biological organisms.

Materials

- Copies of *Ocean Acidification Inquiry Guide*; one copy for each student group
- Protective goggles and gloves; one set for each student and one for the teacher
- 100 ml glass beaker; one for each student group
- 100 ml graduated cylinder; one cylinder may be shared by several student groups, but have separate cylinders for distilled water and seawater
- 500 ml glass beaker
- 2 - 1 liter beakers or Erlenmeyer flasks for mixing solutions
- Glass stirring rod; one for each student group
- Sodium hydroxide pellets, approximately 50 grams (see Learning Procedure Step 1)
- Solid citric acid (to neutralize sodium hydroxide spills); approximate 450 grams
- Distilled water; approximately 150 ml for each student group, plus 1.5 liters for making solutions (see Learning Procedure Step 1)
- Artificial seawater; approximately 150 ml for each student group, plus approximately 250 ml for demonstration
- pH test paper, wide range; one roll for each student group
- Dilute acetic acid solution in dropper bottles; one bottle containing approximately 50 ml for each student group (see Learning Procedure Step 1)
- 0.1 M sodium hydroxide solution in dropper bottles; one bottle containing approximately 50 ml for each student group (see Learning Procedure Step 1)

Audiovisual Materials

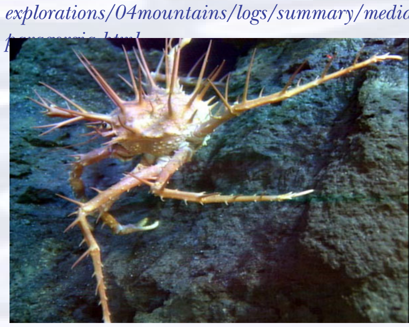
- Marker board, blackboard, or overhead projector with transparencies, or digital equivalent



Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO_2 in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO_2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.
http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg

According to the Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers), surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Large *Paragorgia* colonies on basalt substrate. From the Mountains in the Sea 2004. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04mountains/logs/summary/media/



Unusual spiny crab spotted on NW Rota 1 volcano. Crabs are opportunistic predators at vent sites. The body of this crab is ~2 in. (~5 cm) across. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/march30/media/spinycrab.html

Teaching Time

Two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

32

Key Words and Concepts

Buffer
pH
Calcium carbonate
Ocean acidification

Background Information

Carbon dioxide (CO_2) concentrations in Earth's atmosphere have increased by 36% since the Industrial Revolution (from approximately 280 parts per million (ppm) in pre-industrial times to 382 ppm in 2006; NOAA Earth Systems Research Laboratory, http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html#global). According to the Intergovernmental Panel on Climate Change, present CO_2 concentrations are higher than any time in at least the last 650,000 years, and almost all of this increase is due to human activities (Intergovernmental Panel on Climate Change (IPCC), 2007).

While there has been much discussion about the impacts of increased atmospheric CO_2 on global climate, these changes have also caused another change: ocean acidification. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others.

Ocean acidification is a result of increased CO_2 emissions, and is not directly related to climate change. There are many uncertainties about the causes, extent, and impacts of global climate change; but these do not apply to ocean acidification which can be observed happening right now and is highly predictable into the future. Measures to reduce global temperatures or the concentration of other greenhouse gases will have no effect on ocean acidification. Only a reduction in atmospheric CO_2 concentrations will affect the acidification problem.

At NW Eifuku volcano, mussels are so dense in some places that they obscure the bottom. The mussels are ~18 cm (7 in) long. The white galatheid crabs are ~6 cm (2.5 in) long. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/april11/media/mussel_mound.html*

Research is just beginning on the impacts of ocean acidification on marine organims and ecosystems (more than 60% of the research papers on this subject have been published since 2004). Impacts have been observed in many species, however, and range from interference with calcification processes to reduced resistance to other environmental stresses such as increasing temperatures and pollution.

This lesson guides a student inquiry into some properties of the ocean's carbonate buffer system, and how changes in atmospheric carbon dioxide levels may affect ocean pH and biological organisms that depend upon calcification.

Learning Procedure

1. To prepare for this lesson:
   - If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, *To Boldly Go…* (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   - Review the introductory essay *Exploring the "C's": Climate Change and Cold-Water Corals* for the *Lophelia* II 2009 Expedition (http://oceanexplorer.noaa.gov/explorations/09lophelia/background/climatechange/climatechange.html)
   - Review procedures and questions on the *Ocean Acidification Inquiry Guide*; and
   - Prepare solutions for student inquiries:

   (a) 4 M sodium hydroxide solution: Dissolve 40 g NaOH in 100 ml water, then dilute to 250 ml.

   (b) 0.1 M sodium hydroxide solution: Dilute 25 ml of 4 M sodium hydroxide solution to a volume of 1 liter. Transfer the solution to dropper bottles, one bottle for each student group.

   [NOTE: Be careful! Concentrated sodium hydroxide is dangerous. Use goggles and protective rubber gloves when working with solid chemicals and solutions, and be sure the surfaces of gloves and bottles are dry to avoid accidental slippage when bottles are handled. Any chemical that contacts the skin should be immediately washed off with copious quantities of water. Then apply dilute vinegar solution to neutralize traces of the alkali. Spills of alkalis should be diluted as above before mopping up. For large spills, solid citric acid should be used as a neutralizer.]

(c) Dilute acetic acid solution: Transfer white vinegar to dropper bottles, one bottle for each student group.
(d) Artificial seawater: Follow directions on package to prepare required quantity (see Materials; typically, 1 liter will require about two tablespoons of the dry powder).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons why ocean exploration is important, which should include understanding and maintaining ocean health.

3. Review the concept of acids, bases, pH, and Le Chatelier's Principle (If a system that is in equilibrium is changed, the system will react in such a way as to undo the effect of the change). Ask students what might cause significant pH changes in the ocean. If students do not identify increased atmospheric carbon dioxide as a potential cause, do not prompt them on this point right now.

   Tell students that their assignment is to investigate some of the aspects of pH in seawater, and impacts of reduced pH caused by increased concentrations of atmospheric carbon dioxide. Provide each student group with a copy of the *Ocean Acidification Inquiry Guide* and the materials listed in Part 2 of the worksheet.

4. When students have completed the procedures described in the *Inquiry Guide*, lead a discussion of their results.

Answers for Background Research & Analysis Questions

1. About 25% of the CO_2 added to the atmosphere from human activities is absorbed by the ocean each year.
2. When CO_2 dissolves in seawater, carbonic acid is formed.
3. Ocean acidification may affect shell and skeleton formation, physiology, and/or reproduction in marine organisms.
4. Polar regions of Earth's ocean are expected to be first to become corrosive enough to dissolve some shells.
5. Ocean acidity has increased 30% since the Industrial Revolution.
6. An episode of ocean acidification 65 million years ago is linked to mass extinctions of marine organisms.
7. The present increase in ocean acidification is happening 100 times faster than any other acidification event in at least 20 million years.

8. Current CO_2 emissions are higher than the "worst case scenario" developed by the Intergovernmental Panel on Climate Change in the 1990's.
9. Ocean acidification is a result of CO_2 emissions, not climate change.
10. The only measures that will reduce ocean acidification are those that reduce atmospheric CO_2.
11. As a result of ocean acidification, by the middle of this century, coral calcification rates will decline by one-third and erosion of corals will exceed new growth. By 2100, 70% of cold-water corals will be exposed to corrosive waters.
12. Economic impacts expected from ocean acidification include impacts on marine food webs that include commercially fished species, which threaten the food security of millions of people. In addition, impacts on coral reefs will affect shoreline protection and tourism.
13. Ocean acidification has a "feedback" effect on climate change, because decreasing pH reduces the ocean's capacity to absorb CO_2, which will make it more difficult to stabilize atmospheric CO_2 concentrations.
14. Atmospheric CO_2 concentrations can be stabilized with technology that is presently available or will soon be available. The cost of stabilizing atmospheric CO_2 at a level that will avoid most of the negative impacts of ocean acidification is less than the cost of doing nothing.

Discussion of Results of Hands-on Inquiry

Students should have found that seawater is much more resistant to changes in pH than distilled water, and consequently is a good buffer. Write the following equation on a marker board or overhead transparency so that it is visible to all students:

The Carbonate Buffer System Equation

$$CO_2 + H_2O <> H_2CO_3 <> H^+ + HCO_3^- <> H^+ + CO_3^{2-}$$

CO_2	+	H_2O	<>	H_2CO_3	<>	H^+	+	HCO_3^-	<>	H^+	+	CO_3^{2-}
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion		hydrogen ion		carbonate ion

Tell students that this equation describes the carbonate buffer system of seawater. The equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Be sure students understand that carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (bicarbonate and carbonate concentrations are much high than carbon dioxide and carbonic acid). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic).

Considering Le Chatelier's Principle, students should realize that if hydrogen ions are added to normal seawater the system will react in a way that tends to remove hydrogen ions from solution, so the reactions will proceed to the left. Similarly, if a very basic solution is added to normal seawater students should predict that the system will react in a way that tends to add more hydrogen ions, and so the reactions will proceed to the right.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Chemistry," or "Atmosphere" for links to resources about ocean chemistry or climate change.

The "Me" Connection

Have students write a brief essay describing how buffer systems are of personal benefit, and how a change in ocean pH might have personal impacts.

Connections to Other Subjects

English/Language Arts, Social Sciences, Mathematics

Assessment

Students' responses to Inquiry Guide questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html.

2. Have student groups prepare scientific posters about the ocean acidification issue. See http://oceanexplorer.noaa.gov/explorations/09bioluminescence/background/edu/media/ds_09_livinglight.pdf for information about scientific posters, and "Other Resources" for additional sources of information about ocean acidification.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration Program

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focussing on the exploration, understanding, and protection of Earth as a whole system

Hood, M., W. Broadgate, E. Urban, and O. Gaffney, eds. 2009. Ocean Acidification. A Summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World; available online at http://ioc3.unesco.org/oanet/OAdocs/SPM-lorezv2.pdf

SCOR/IOC Symposium Planning Committee. 2004. The Ocean in a High-CO_2 World. *Oceanography* 17(3):72-78; available online at http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/17_3/17.3_scor_ioc.pdf

Solomon, S., D. Qin, M. Manning (eds.) 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

Feely, R. A., C. L. Sabine, and V. J. Fabry. 2006. Carbon Dioxide and Our Ocean Legacy. Ocean Science Brief available online at http://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

http://www.ucar.edu/communications/Final_acidification.pdf – "Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research;" report from a workshop sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey

Havenhand, J. N., F.-R. Buttler, M. C. Thorndyke, J. E. Williamson. 2008. Near-future levels of ocean acidification reduce fertilization success in a sea urchin. *Current Biology*, 18:R651-R652

http://www.terrain.org/articles/21/burns.htm – Article on ocean acidification

http://www.oceana.org/climate/impacts/acid-oceans/ – Article on ocean acidification

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard B: Physical Science

- Properties and changes of properties in matter

Content Standard D: Earth and Space Science

- Structure of the Earth system

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments
- Science and technology in society
- Natural and human-induced hazards

Content Standard G: History and Nature of Science

- Nature of science

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education setting.
Please send your comments to: oceanexeducation@noaa.gov

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Ocean Acidification Inquiry Guide

A buffer is a solution that tends to resist changes in pH. Your assignment is to investigate some of the pH buffering capabilities of seawater.

Part 1. Background Research & Analysis

Obtain a copy of ***Ocean Acidification: A Summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World*** (http://ioc3.unesco.org/oanet/OAdocs/SPM-lorezv2.pdf), and find answers to the following questions:

1. About how much of the CO_2 added to the atmosphere from human activities is absorbed by the ocean each year?

   ____

2. When CO_2 dissolves in seawater, what compound is formed?

   ____

3. How may ocean acidification affect marine organisms and ecosystems?

   ____
   ____
   ____

4. Which regions of Earth's ocean will be first to become corrosive enough to dissolve some shells?

   ____
   ____
   ____

5. How much has ocean acidity increased since the Industrial Revolution?

   ____
   ____

6. In geologic history, has ocean acidification ever been linked to mass extinctions of marine organisms, and if so, when and how?

   ____
   ____
   ____

7. Ocean pH is known to fluctuate. How is the present increase in acidity different from past fluctuations?

   ____
   ____
   ____

Ocean Acidification Inquiry Guide - Page 2

8. In the 1990's the Intergovernmental Panel on Climate Change (IPCC) developed a "worst case scenario" for projected CO_2 emissions. How do current CO_2 emissions compare with the "worst case scenario?"

9. Is ocean acidification another result of climate change? Why or why not?

10. Will initiatives to combat climate change also reduce ocean acidification? Why or why not?

11. What impacts is ocean acidification expected to have on reef-building corals?

12. What are some economic impacts expected from ocean acidification?

13. Does ocean acidification have any "feedback" effect on climate change? If so, describe.

14. Practically speaking, what needs to be done to avoid the negative impacts associated with decreasing ocean pH?

Ocean Acidification Inquiry Guide - Page 3

Part 2. Hands-On Inquiry

Materials

- Distilled water, approximately 150 ml
- Artificial seawater, approximately 150 ml
- pH test paper
- Dilute acetic acid solution in dropper bottle
- 0.1 M sodium hydroxide solution in dropper bottle
- 100 ml glass beaker
- 100 ml graduated cylinder
- Glass stirring rod

Procedure

Wear eye protection and gloves throughout this inquiry!
Wash your hands thoroughly when you are finished!
Do not eat, drink, or chew anything while you are in the laboratory!

1. Measure 50 ml of distilled water into a 100 ml glass beaker. Test the pH by dipping a strip of pH test paper into the water and comparing the color of the paper to the chart on the test paper container. Record the pH on the data chart on the following page.

2. Add one drop of dilute acetic acid to the beaker, stir with a glass stirring rod, test the pH, and record the result on the data chart.

3. Repeat Step 3 until 20 drops of dilute acetic acid have been added, testing and recording the pH after each drop.

4. Rinse the beaker, then repeat Steps 1 through 3 using seawater instead of distilled water. Be sure to use a separate graduate cylinder for measuring the seawater.

5. Rinse the beaker and repeat Steps 1 through 3 with distilled water and seawater (use a different graduated cylinder for each!), but use 0.1 M sodium hydroxide solution instead of dilute acetic acid.

6. **Wash your hands thoroughly!**

Ocean Acidification Inquiry Guide - Page 4

Data Chart for Buffer Properties of Seawater Inquiry

Drops Added	Test with Added Acetic Acid: Distilled Water pH	Test with Added Acetic Acid: Seawater pH	Test with Added Sodium Hydroxide: Distilled Water pH	Test with Added Sodium Hydroxide: Seawater pH
0	________	________	________	________
1	________	________	________	________
2	________	________	________	________
3	________	________	________	________
4	________	________	________	________
5	________	________	________	________
6	________	________	________	________
7	________	________	________	________
8	________	________	________	________
9	________	________	________	________
10	________	________	________	________
11	________	________	________	________
12	________	________	________	________
13	________	________	________	________
14	________	________	________	________
15	________	________	________	________
16	________	________	________	________
17	________	________	________	________
18	________	________	________	________
19	________	________	________	________
20	________	________	________	________

Ocean Acidification Inquiry Guide - Page 5

Analysis

1. What do your data suggest about the buffer system of seawater compared to distilled water?

2. Recall Le Chatelier's Principle. What do you think would happen if hydrogen ions were added to normal seawater?

3. What do you think would happen if a very basic solution (which tends to remove hydrogen ions from solution) were added to normal seawater?