



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>

## Section 6: Key Topic – Ocean Health

### Off Base

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

#### Materials

- Copies of *Ocean Acidification Investigation Guide*; one 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

### 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

*NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.*

Carbon dioxide (CO<sub>2</sub>) 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 391 ppm in December of 2011; 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<sub>2</sub> concentrations are higher than any time in at least the last 800,000 years, and almost all of this increase is due to human activities (Lüthi *et al.*, 2008; Tans, 2008).

While there has been much discussion about the impacts of increased atmospheric CO<sub>2</sub> on global climate, these changes have also caused another change: ocean acidification. Each year, the ocean absorbs approximately 25% of the CO<sub>2</sub> added to the atmosphere by human activities. When CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> concentrations will affect the acidification problem.



Dry ice, a pH indicator, and water can be used in the classroom to demonstrate the acidifying effects of carbon dioxide in ocean water. For a similar demonstration using human respiration instead of dry ice, see page 41. Image credit: NOAA/CRCP



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/birez/mussel\\_mound\\_birez.jpg](http://oceanexplorer.noaa.gov/explorations/04fire/logs/birez/mussel_mound_birez.jpg)



*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  $\text{CO}_2$  in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved  $\text{CO}_2$  on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.

<http://www.noaaneews.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/hirez/paragorgia\\_hirez.jpg](http://oceanexplorer.noaa.gov/explorations/04mountains/logs/hirez/paragorgia_hirez.jpg)



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/hirez/spinycrab\\_hirez.jpg](http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/spinycrab_hirez.jpg)

Research is just beginning on the impacts of ocean acidification on marine organisms 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 investigation 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:

- 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 lesson, *To Boldly Go...*
- 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 Investigation 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 Investigation Guide* and the materials listed in Part 2 of the worksheet.

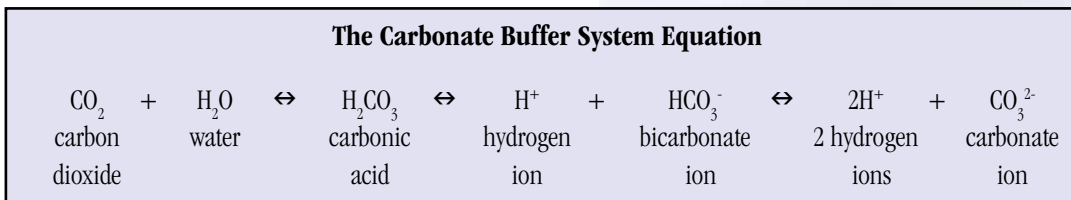
4. When students have completed the procedures described in the *Investigation Guide*, lead a discussion of their results.

**Answers for Background Research & Analysis Questions**

1. About 25% of the CO<sub>2</sub> added to the atmosphere from human activities is absorbed by the ocean each year.
2. When CO<sub>2</sub> 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 acidic 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<sub>2</sub> 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<sub>2</sub> emissions, not climate change.
10. The only measures that will reduce ocean acidification are those that reduce atmospheric CO<sub>2</sub>.
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 that are sufficiently acidic to damage coral skeletons.
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<sub>2</sub>, which will make it more difficult to stabilize atmospheric CO<sub>2</sub> concentrations.
14. Atmospheric CO<sub>2</sub> concentrations can be stabilized with technology that is presently available or will soon be available. The cost of stabilizing atmospheric CO<sub>2</sub> 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 Activity**

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:



This 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. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater,



## Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: [http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe\\_ngss.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf).

## Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

[oceaneducation@noaa.gov](mailto:oceaneducation@noaa.gov)

## For More Information

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## Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC for NOAA. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov>

although not in the same concentrations (about 87% of inorganic carbon is bicarbonate, about 12% is carbonate, and carbonic acid and carbon dioxide combined are about 1%). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

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/](http://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 *Investigation 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](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

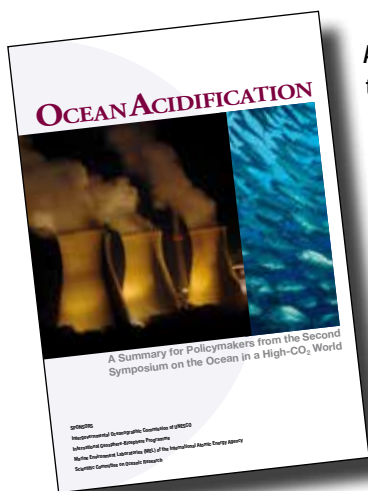
<http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html> Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

## Other Resources

See page 217 for Other Resources.



## Ocean Acidification Investigation 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<sub>2</sub> World* (<http://ocean-acidification.net/OAdocs/SPM-lorezv2.pdf>), and find answers to the following questions:

1. About how much of the CO<sub>2</sub> added to the atmosphere from human activities is absorbed by the ocean each year?  
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2. When CO<sub>2</sub> dissolves in seawater, what compound is formed?  
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3. How may ocean acidification affect marine organisms and ecosystems?  
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\_\_\_\_\_  
\_\_\_\_\_
4. Which regions of Earth's ocean will be first to become acidic enough to dissolve some shells?  
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\_\_\_\_\_  
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5. How much has ocean acidity increased since the Industrial Revolution?  
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6. In geologic history, has ocean acidification ever been linked to mass extinctions of marine organisms, and if so, when and how?  
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\_\_\_\_\_  
\_\_\_\_\_
7. Ocean pH is known to fluctuate. How is the present increase in acidity different from past fluctuations?  
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\_\_\_\_\_  
\_\_\_\_\_

8. In the 1990's the Intergovernmental Panel on Climate Change (IPCC) developed a "worst case scenario" for projected CO<sub>2</sub> emissions. How do current CO<sub>2</sub> emissions compare with the "worst case scenario?"

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

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

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

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

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

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

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## Part 2. Hands-On Activity

### 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 activity!**

**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!**





### Data Chart for Buffer Properties of Seawater

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

### Analysis

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

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

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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?

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