OCEAN ACIDIFICATION

OVERVIEW

This hands-on activity supplements the 2014 Holiday Lectures: Biodiversity in the Age of Humans. Students will simulate the effects of decreasing pH caused by increasing atmospheric CO_2 levels. Students use straws to blow into beakers filled with artificial seawater and measure the change in pH. Using the graph provided, they determine the atmospheric CO_2 concentration that would produce the same pH change in the ocean. Finally, students determine how many years it would take to reach this atmospheric concentration at the current rate of CO_2 emissions. Additional analysis questions ask students to consider the effects of ocean acidification on marine ecosystems.

KEY CONCEPTS

- Human activity has resulted in increasing concentrations of CO_2 in the atmosphere.
- Carbon dioxide reacts with seawater to produce carbonic acid which, through a series of chemical reactions, results in decreased levels of carbonate ions.
- Carbonate ion availability impacts the ability of skeleton-building marine organisms such as corals and bivalves to build shells and exoskeletons. This ultimately impacts the ocean's food web.
- Human actions can have far-reaching unintended consequences.

LEARNING OBJECTIVES

Students will be able to:

- Explain the role of atmospheric CO_2 in ocean acidification
- Collect, analyze, and interpret data to draw a conclusion
- Use models of atmospheric CO_2 concentrations to make predications
- Predict the impacts of ocean acidification on marine ecosystems

CURRICULUM CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	MS-LS2, MS-EES3, HS-LS2, HS-ESS3
Common Core (2010)	
AP Environmental Science (2013)	
IB Environmental Systems and Societies (2010)	
AP Biology (2012-13)	2.D.1, 2.D.3, 4.A.5, 4.A.6, 4.B.4
IB Biology (2016)	

KEY TERMS

pH, acidification, alkaline, calcium carbonate, exoskeleton, food web, concentration, chemical reaction, soluble

TIME REQUIREMENTS

This hands-on activity can be conducted in one 50-minute period. This estimate does not include teacher preparation, postlab discussions, or any time required for watching portions of the Holiday Lectures.

SUGGESTED AUDIENCE

This activity is appropriate for middle-school life and earth science and high school biology (all levels including AP and IB) and earth/environmental science (all levels including AP).

PRIOR KNOWLEDGE

Students should know that gases can dissolve in water and that humans add large quantities of CO_2 into the atmosphere primarily through deforestation and the burning of fossil fuels. Students should also have a basic understanding of ecosystems and food webs.

MATERIALS

Each pair of students will need:

- Beaker or cup to hold 100 ml of "seawater"
- Straw
- Blue or red sticky dots (or colored pencils)
- Timer
- Student Handout
- Data-collection graphs (if not using poster)

Common station for whole class:

- Tank with circulating seawater
  - Instant Ocean Aquarium Sea Salt Mixture or other nonbuffer-enhanced salt. (Do not use enriched mixes such as Reef Crystals with added calcium or calcium carbonate)
  - Water pump to circulate water in tank
- pH meters or probes, or short-range pH paper. (Standard pH paper/strips are not precise enough to measure the pH change, but a combination of short-range papers, such as pH 6.0–8.0 and pH 4.5–8.5, would work.)
- Distilled or tap water for rinsing off pH meters
- Poster with data-collection graphs or 8.5 x 11" graphs

PROCEDURE

<u>Prior to the Activity</u>:

1. *Prepare seawater at least 24 hours in advance of the activity:*
   a. Follow package directions to make seawater; typically about 1 cup of salt per 2 gallons of water.
   b. Circulate water in the tank with a water pump to allow salts to completely dissolve and pH to stabilize at 8.2.
2. Prepare common station.

<u>During the Activity</u>:

1. Each student team obtains:
   a. 1 beaker with 100 ml seawater
   b. Straw
2. Students measure the initial pH of the seawater in their beaker. Alternatively, students can record the pH of the seawater in the tank from a sensor left in the tank.
3. Assign half of your student teams to Blue and the other half to Red. The Blue teams blow into the beaker for 10 seconds and the Red teams for 20 seconds.
4. One student serves as the timer while the second student uses the straw to blow gently, but consistently, into the beaker for the designated amount of time.
5. At the end of the time period, record the final pH of the seawater in the beaker.

6. Using dots of the appropriate color (blue for 10 seconds, red for 20 seconds), place one dot on Graph A—pH of Seawater as a Function of Atmospheric CO_2 Concentration. Students should use their final pH value to determine the concentration of atmospheric CO_2 which would produce the same pH.
7. Using the atmospheric CO_2 concentration determined in Graph A, place a second dot (of the same color) on Graph B: Projected Dates of Atmospheric CO_2 to show when that concentration of atmospheric CO_2 would be reached at the current rate of increase.

Tips:

- Beakers can be filled with 100 ml of seawater just prior to the lesson to save time.
- If reusing student beakers or cups, have students rinse used beakers in a bucket of seawater.
- Encourage students to blow into their beakers gently but consistently. Blowing into the beakers too vigorously can result in splashing seawater from the cups and produce CO_2 concentrations beyond the scale of the graphs.

TEACHING NOTES

Seawater:

- For this activity, it is important to make sure the salt does not contain calcium or calcium carbonate, as they act as buffers to prevent pH change. Some seawater-salt mixes have enhanced levels of calcium to promote coral reef health.
- Circulate the water in the tank for at least 24 hours to allow the salts to fully dissolve and the pH to stabilize before beginning the activity. This is particularly important when making large volumes of seawater.
- If using water from a salt-water aquarium, check to make sure the salt water doesn't contain an elevated level of calcium or calcium carbonate.

Measuring pH:

- Standard paper pH strips are not precise enough to measure the small changes in pH produced by this activity.
- pH meters or probes should be used. If pH probes are limited, a single probe can be placed in the tank and its reading can serve as the initial reading for all student teams.
- A separate rinse station can be set up for pH probes to minimize congestion near the seawater tank.
- Alternatively, you can obtain special short-range pH papers that cover a much smaller range of pH at a greater resolution. Ranges such as pH 6.0–8.0 and pH 4.5–8.5 are available.

Logistics:

- Laminate the poster and graphs to allow easy removal of colored dot stickers.
- As an alternative to printing a large poster, individual graphs can be printed for each student team, and colored pencils can be substituted for colored dots.

Hydrogen Ion:

In this activity, the term "hydrogen ion" is used and denoted by H^+. This is a simplification. In reality, free hydrogen ions are very reactive and not stable in aqueous solution. Instead, they react with water to form H_3O^+, hydronium or hydroxonium ions:

$$H^+ + H_2O \rightarrow H_3O^+$$

Generally, when discussing acidic aqueous solution, scientists use H^+ instead of H_3O^+ as a convenient shorthand.

Comparison to Real Seawater:

Natural seawater is buffered, so it takes a large amount of dissolved carbon dioxide to change the pH of the ocean. In this activity, we are deliberately using a seawater-salt mix with limited buffering capacity so that you can see a pH change with reasonably little effort.

Organisms Vulnerable to pH Change:

Many invertebrate species use calcium carbonate as an integral part of the skeleton and are vulnerable to pH change. They include mollusks (snails, oysters, clams, and relatives), echinoderms (sea urchins and sea stars), reef-building corals, and plankton with calcium-based skeleton such as foraminifera. Other animals such as crustaceans (crabs, lobsters) also use calcium carbonate as part of their skeleton, but their skeletons also contain biogenic molecules so they are not quite as severely affected.

Answer Key

1. Why was it important to record the pH of the seawater sample before blowing into it?

The initial pH reading serves as a baseline from which the change caused by blowing into the water can be measured.

2. What chemical molecule did you measure with the pH probe? Where did this molecule come from?

Hydrogen ions (H^+) were measured with the pH probe. pH is a logarithmic measurement of hydrogen ion concentration. The hydrogen ions came from the dissociation of carbonic acid which was formed when carbon dioxide reacted with water.

(Technically, hydrogen in water mainly exists as hydronium ion, but when the hydronium ion reacts with the pH probe, it releases the water molecule; thus you could actually say you are measuring hydrogen ions.)

3. How does atmospheric carbon dioxide influence pH levels in the ocean?

Increasing carbon dioxide lowers the pH of the ocean by producing more hydrogen ions in surface waters. When carbon dioxide reacts with water, it forms carbonic acid, which then dissociates into bicarbonate and hydrogen ions. The more carbon dioxide that reacts with water, the more hydrogen ions are produced.

4. What are two ways bicarbonate ions can be formed in the ocean?

Bicarbonate ions are produced when carbonic acid dissociates into bicarbonate and hydrogen ions. Bicarbonate ions are also formed when hydrogen ions react with carbonate ions.

5. How does lower pH decrease available carbonate ions in the ocean?

Lower pH increases the concentration of hydrogen ions which combine with carbonate ions to form bicarbonate, thus reducing the number of carbonate ions in the ocean.

6. Some groups blew into their beakers for 10 seconds; others blew into their beakers for 20 seconds, twice as long. Describe the patterns or trends you observed as you compare the data from the different lengths of time.

Answers will vary. However, the longer time should produce a lower pH and greater concentration of carbon dioxide. The time to reach the atmospheric carbon dioxide concentration should also be longer.

7. The mineral aragonite is a particularly soluble form of calcium carbonate used in the formation of tropical coral reefs and cold-water pteropods. Pteropods, commonly called "sea butterflies," are free-swimming mollusks about the size of a small pea and are the primary food source for krill, whales, salmon, and other important fish such as cod and pollock. Since carbon dioxide, like most gases, is more soluble in cold water than warm water, which organism (corals or pteropods) will be the first to be affected by ocean acidification? Justify your answer.

Since carbon dioxide is more soluble in cold water, more will dissolve resulting in a greater decrease in pH. Thus cold-water pteropods (and the organisms that eat them) will be affected by ocean acidification sooner than tropical corals. This does not imply, however, that tropical corals will not be affected by ocean acidification.

8. Coral reefs are composed of thousands of individual coral animals whose exoskeletons are joined together. Experiments have shown that, in controlled conditions, individual coral animals are able to survive and even reproduce without their calcium carbonate exoskeleton in acidified conditions. Further, they are able to resume building their exoskeletons when reintroduced to normal marine conditions.

    a. Even though individual coral animals can survive and reproduce without their exoskeletons, what are the negative effects on both coral animals and those that depend on coral reef structures?

Individual coral animals without their exoskeletons may be more easily eaten by organisms that consume them. However, individual coral animals are likely to be more dispersed than they were in a colony. Organisms that used the structure of the coral reef for protection and food sources will struggle when the reef structure is damaged or absent.

    b. How do these experiments suggest how humans could help corals survive as ocean acidification increases?

We could reduce the amount of carbon dioxide we emit into the atmosphere. We could provide physical refuges for coral animals by creating ocean environments with the proper pH for them to rebuild their exoskeletons or consider plans to increase the pH of the ocean.

REFERENCES

Caldeira, Ken, and Wickett, Michael E. 2003. "Oceanography: Anthropogenic Carbon and Ocean pH." *Nature* 425: 365. Print.

Fine, Maoz, and Tchernov, Dan. 2007. "Scleractinian Coral Species Survive and Recover from Decalcification." *Science* 315: 1811. Print.

Student Handout Figure 1: Historical changes in annual mean sea surface pH between 1700s and 1990s. ©2009 Plumbago (https://commons.wikimedia.org/wiki/File:WOA05_GLODAP_del_pH_AYool.png)

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