pH, CO_2 and the Fate of Shelled Organisms

What is the relationship between pH, CO_2 and shelled organisms?

A Partnership between California Current Ecosystem Long Term Ecological Research (CCE LTER) and Ocean Institute (OI)
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Introduction:

What does CO_2 have to do with pH?

The ocean and the atmosphere exchange massive amounts of carbon dioxide (CO_2). While animal respiration adds some CO_2 to seawater, the increase is mostly due to anthropogenic inputs that have exceeded the natural limit. This accumulation of CO_2 in the atmosphere has changed the amount that is absorbed in the surface waters of the oceans.

When CO_2 is dissolved in seawater it becomes a weak acid which generates a number of changes in seawater chemistry. A buffering reaction takes place where hydrogen ions and bicarbonate ions are produced (($CO_2 + H_2O \leftrightarrow H_2CO_3$(carbonic acid)$\leftrightarrow H^+ + HCO_3^-$(bicarbonate)).

As more CO_2 is dissolved in seawater, the water becomes less efficient at buffering the chemical change, resulting in the release of more hydrogen ions (H^+). These H^+ ions decrease the pH and the seawater becomes more acidic. Over extended periods of time, typically a decade or longer, this change in ocean chemistry is called ocean acidification. On average the ocean is considered slightly basic with a pH of 8.2 to 8.1. However, it may reach 7.8 in 2100 (Gattuso and Lavigne 2009).

How might a decrease in pH affect calcification processes of shelled organisms?

Changes in the chemistry of seawater can have a wide range of effects on several biological processes and the regulation of pH. Calcium carbonate ($CaCO_3$) is one of the most common building blocks in the formation of skeletons, shells and other protective structures of many organisms ranging from plankton to cephalopods. Examples may include such organisms as pteropods, coccolithophores , and foraminifera. Other living organisms such as snails, clams, nautilus, and corals also produce calcium carbonate shells. As more CO_2 is added to seawater, t H^+ ions increase and the more difficult it becomes to make the shells because $CaCO_3$ in the shells dissolves too quickly, weakening the shells. The question remains, if rates of calcification slow down in these organisms, will they be able to compensate for the additional energy demands required to calcify under these conditions, even if sufficient energy resources in terms of food, nutrients and light may still be available?

Target students: Grade 9-12 Biology, Marine Science, or Environmental Science

CA standards addressed:

Chemistry Standards: students should know

5b Acids are hydrogen-ion donating and bases are hydrogen-ion accepting substances

5d How to use the pH scale to characterize acid and base solutions

Ecology

6b How to analyze change in an ecosystem resulting from changes in climate, human activity

Investigation and Experimentation

1a Scientific progress is made by asking meaningful questions, selecting appropriate tools

1b Identifying and communicating sources of unavoidable experimental error

1c Identify possible reasons for unavoidable error

1d Formulating explanations

1k Recognize the cumulative nature of scientific evidence

1m Investigate a science-based societal issue

National Science Standards:

NS.9-12.1 SCIENCE AS INQUIRY - Abilities necessary to do scientific inquiry, understandings about scientific inquiry

NS.9-12.6 PERSONAL AND SOCIAL PERSPECTIVES - Environmental quality, natural and human-induced hazards

NS.9-12.7 HISTORY AND NATURE OF SCIENCE - Nature of scientific knowledge

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Time Frame:
Initial set-up and data collection - 1 lab period(60 min)
Final data collection and conclusion - 1 lab period (60 min)

Purpose: Measure the effects of decreasing pH (as a result of increased CO_2 dissolution in the ocean) on the mass of marine shelled organisms.

Hypothesis: As the pH of a solvent decreases, the mass of a shell will be affected.

Materials:

- ✓ pH tester (probe, wide range paper, or wide range indicator solution)
- ✓ 8 - 100 mL beakers
- ✓ Balance (electronic is best but triple beam should work)
- ✓ Forceps, or spoon
- ✓ Eight shells (small clam shells - about an inch across - these can be purchased at any craft store)
- ✓ 50 mL of each of the following solutions:

•Lemon juice	•White vinegar	•Distilled water	•Salt water solution
•Egg white	•Black coffee	•Ammonia	•Milk

Procedure:

1. Obtain eight 100 mL beakers, labeling each with one with the above solution names.
2. Using a graduated cylinder, fill each of the eight beakers with 50 mL of the solutions.
3. Record the pH of each of the solutions and record the values on the data table.
4. Obtain eight shells of roughly equal size. Find the initial mass of each of the shells and record on the data table (be sure to keep track of which shells will be placed in each substance)
5. Once the initial masses have been recorded, use forceps to place each shell into the appropriate substance and set them aside for 24 hrs.
6. After 24 hours, carefully remove the shells from each substance, pat them dry and find the final mass. If there is not enough shell to remove by hand, carefully pour the substance through a paper towel or cheese cloth, allow it to dry and find the mass of the remaining pieces.
7. Properly dispose of all remaining substances.

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Data Table

Sample #	Substance pH	Initial Shell Mass (g)	Final Shell Mass (g)	Change in Mass (g) (initial - final)
Lemon juice				
Vinegar				
Distilled water				
Egg white				
Coffee				
Ammonia				
Salt Water				
Milk				

Analysis:

1. Graph the above data showing change in the mass of each shell as a function of pH (negative values should be used).
2. In what pH solution did the shells lose the most mass? Why do you think this happened?
3. In what pH did the shell mass not change much at all? Why do you think this is so?
4. What is the relationship between change in shell mass and pH?
5. If the CO_2 concentration in the ocean increases, what happens to the pH?
6. What are the possible consequences for shelled animals - specifically small planktonic organisms if CO_2 levels continue to increase in both our atmosphere and our ocean?

Conclusion:

- Restate your initial hypothesis.
- Was the initial hypothesis correct or incorrect?
- Restate data explaining what each substance did to the shell mass.
- Explain any error sources which may have altered your results.
- Why might it be a problem if we see a decrease in photosynthetic marine phytoplankton?

Reference:

Gattuso, Jean-Pierre & Jansson, Linda (2011) Ocean Acidification, Oxford University press, New York, pgs. 1 - 326.

Additional Resources:

1. Global Warming and CO_2 – Evidence from past earth warming episodes from UC Santa Cruz Currents Online: http://currents.ucsc.edu/04-05/06-13/ocean.asp.

2. Science Bridge Labs, U.C. San Diego, Ocean Acidification Lab (teacher guides, power points, and other classroom materials).

3. Windows to the Universe, Changing Planet: Ocean Acidification (video and lesson).

4. Ocean acidification activity and virtual lab: http://i2i.stanford.edu/acid_act.htm

5. American Museum of Natural History Acid Oceans Quicktime movie (6:38 min.)

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Possible Student Answers
Analysis:

1. As the pH of the substance decreases, there should be a greater decrease in shell mass. As the pH of the substance nears 7.8-8.0 and above, there should be very little observable change in mass.

2. The substances with the lowest pH are lemon juice and vinegar which should have had the greatest effect on the shells by decreasing the mass. The lower pH means the substance is more acidic or has more free hydrogen ions to react with the calcium carbonate ($CaCO_3$) shells, softening the shell and decreasing its mass.

3. Shell mass did not change in the substances whose pH most closely mirrored ocean pH (7.8 and up). As substances become more basic, they have less free hydrogen ions to react with the calcium carbonate of the shell.

4. As pH decreases, shell mass decreases.

5. As CO_2 values in the ocean increase, this causes the pH to decrease due to a chemical reaction between water and CO_2 which creates a weak acid.

6. If CO_2 levels continue to increase, we will see pH levels decrease and the ocean seawater becoming more acidic. If this happens, it may cause small marine organisms with $CaCO_3$ shells to weaken and dissolve. The question remains, if rates of calcification slow down in these organisms, will organisms be able to compensate for the additional energy demands required to calcify under these conditions, even if sufficient energy resources in-terms-of food, nutrients and light may still be available? Ocean acidification will undoubtedly expose many of these organisms to increased predation, refuge for some intertidal organisms to avoid desiccation during low tide, and decline in skeletal support. Some organisms may be able to regulate their metabolism and continue with calcification to compensate for increased acidity of seawater. Nonetheless, it comes at a substantial energetic cost that could have been spent on other essential processes for growth. While less CO_2 may accumulate in the atmosphere as a result of ocean absorption of CO_2, this absorption can have negative effects on many shell-bearing organisms in the ocean. Scientists still need a better understanding of the variations in the effects of ocean acidification on shelled organisms.

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