U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Marine Fisheries Service

Lesson 3: Ocean Acidification

Overview

Lesson 3 describes the ocean as a carbon sink that absorbs atmospheric carbon. Students read evidence that increasing carbon dioxide (CO_2) levels in the ocean are correlated with decreasing ocean pH. In the activity, students develop and test a hypothesis about how acidic solutions affect calcium carbonate, which forms shells. Students explain the connection between ocean acidification and shell-building organisms including corals.

Lesson Objectives

Students will:

1. Describe human activities that increase carbon in the atmosphere
2. Describe the relationship between dissolved carbon dioxide and ocean pH
3. Explain how ocean acidification affects marine life

Lesson Contents

1. Teaching Lesson 3
   a. Introduction
   b. Lecture Notes
   c. Additional Resources
2. Teacher's Edition: Ocean Acidification
3. Student Activity: Ocean Acidification
4. Student Handout
5. Mock Bowl Quiz

Standards Addressed

National Science Education Standards, Grades 9-12
Unifying concepts and processes
Science as inquiry
Physical science
Earth and space science
Science in personal and social perspectives

Ocean Literacy Principles
The ocean and humans are inextricably interconnected

DCPS, High School
Chemistry
C.2.6. Write equations that describe chemical changes and reactions
C.3.2. Define pH as the negative of the logarithm of the hydrogen (hydronium) ion concentration, and calculate pH from concentration data.

Environmental Science
E.1.12. Analyze situations and solve problems that require combining concepts from more than one topic area of science and applying these concepts.
E.2.1. Understand and explain that human beings are part of Earth's ecosystems, and that human activities can deliberately or inadvertently alter ecosystems.

Lesson Outline[1]

I. Introduction

Introduce the material by asking your students to guess which elements from the periodic table are found in the ocean and to give a few examples. They may be surprised to know that the ocean contains almost all of the elements.

The major components (from greatest to smallest component) of seawater are[2]:

- Hydrogen
- Oxygen
- Chlorine
- Sodium
- Magnesium
- Sulfate
- Calcium
- Potassium

Other minor components are:

- Bromine
- Boron
- Carbon
- Nitrogen
- Strontium
- Silicon

Some trace elements (found at less than 0.95ppm) include:

- Phosphorus
- Argon
- Zinc
- Rubidium

II. Lecture Notes

Use the PowerPoint for Lesson 3 (File: Lesson 3 – Ocean Acidification.ppt) to present the following information. Save the "wrap-up" slides for after the activity is complete. Distribute the Student Handout before you begin for students to take notes on key information.

The ocean is a carbon sink (slide 3)

1. A **carbon sink** is a natural or manmade reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period.

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[1] Unless otherwise indicated, all websites provided and referenced in this guide were last accessed in November 2010.

[2]Turekian, K. *Oceans*. 1988. Prentice-Hall, New Jersey. 149pp.

2. The ocean is the largest natural carbon sink on Earth.

How does the ocean sequester carbon? (slide 3)

1. **Carbon sequestration** refers to the storage of carbon for indefinite time.

2. Carbon dioxide is dissolved into the ocean surface from the atmosphere and then moved to the deep ocean through physical processes and biological processes.

Carbon dioxide in the ocean (slide 5)

1. Some marine organisms use carbon dioxide to live. Carbon dioxide is taken up by marine plants and algae during photosynthesis.

2. When carbon dioxide dissolves in seawater, most of it becomes bicarbonate ions and hydrogen ions. This increase in hydrogen ions is what decreases the pH. In addition, some of the hydrogen combines with carbonate to form more bicarbonate, decreasing the concentration of carbonate in seawater. Many marine organisms use carbonate, combined with calcium, to form their exoskeletons, shells or other structures (e.g. corals).

Humans affect the amount of carbon dioxide in the ocean (slide 7)

1. Carbon dioxide in the atmosphere has been increasing since industrial times because of use of energy in homes, burning of fossil fuels for industry, emissions from transportation, cement manufacturing and deforestation.

2. Evidence indicates that pH in the oceans has decreased over the same time period.

Wrap-up: How can ocean acidification affect marine life? (slides 10-12)

1. Breaking down exoskeletons and shells. Evidence shows that some shelled organisms build shells more slowly, and some shells weaken and dissolve in acidic environments.

2. Increased acidity can lead to coral reef decline.

3. Some scientists are concerned that increased acidity might interfere with marine mammal communication. Evidence indicates that sound can travel further in the increasingly acidic ocean, resulting in a louder environment that could confuse marine mammals[3].

III. Additional Web Resources

1. Background information
   http://www.pmel.noaa.gov/co2/OA/

[3] Hester, KC et al. 2008. Unanticipated consequences of ocean acidification: A noisier ocean at lower pH. *Geophysical Research Letters* 35: L19601.

Ocean Acidification

The original source of the activity for this lesson is the SMILE Program at Oregon State University. This lesson, titled "Dissolving Issues: Ocean Acidification," was adapted with permission by SMILE.

The original lesson can be found at the link below:
http://people.oregonstate.edu/~doverl/SMILE/STW08/Activity%204%20Dissolving%20Issues/

Overview:
Part I walks students through an exercise explaining why increasing atmospheric CO_2 affects ocean pH. Part II is an optional hands-on activity or demonstration for students to test the effect of increased acidity on calcium carbonate.

Answer Key Part I: Use of CO_2 in the oceans
As you know, CO_2 from the atmosphere dissolves into seawater. Let's look at this process in more detail:

First, CO_2 reacts with water to form carbonic acid ($H_2CO_3^-$):

(1) $CO_2 + H_2O \rightarrow H_2CO_3^-$

Carbonic acid can then dissociate into bicarbonate (HCO_3^-):

(2) $H_2CO_3^- \rightarrow H^+ + HCO_3^-$

Bicarbonate can then dissociate into carbonate ions (CO_3^{2-})

(3) $HCO_3^- \rightarrow H^+ + CO_3^{2-}$

There are **two** very important biological and chemical processes that are dependent upon the above compounds.

First, some marine organisms use carbonate to form calcium carbonate ($CaCO_3$). Can you list two examples of vital uses of calcium carbonate to marine life?

Possible answers: Shell formation, exoskeleton formation, coral reef formation

Second, carbonate ions regulate the pH of seawater. If an acid is added to seawater, the carbonate ion reacts with excess hydrogen ions to produce bicarbonate (see equation 2). If a base is added to seawater, this bicarbonate will donate hydrogen ions to neutralize the base.

(4) $2CO_3^{2-} + H_2SO_4$ (an example of an acid) $\rightarrow 2HCO_3^-$ (bicarbonate) $+ SO_4^{2-}$

Questions for Part I

1. The above reactions are all *reversible*, meaning that a chemical change can cause them to occur in the opposite direction.
    a. Write the reverse reaction of equation (3).

    $CO_3^{2-} + H^+ \rightarrow HCO_3^-$

    b. Thinking about your answer from question (a), if excess CO_2 results in an excess of hydrogen ions in seawater what will happen to carbonate?

    Some of the excess Hydrogen ions will combine with carbonate to form bicarbonate therefore reducing the availability of carbonate to marine organisms.

    c. What effects do you think this could have on the formation of skeletal structures for marine life?

    Shells, corals and exoskeletons may break down or corrode.

Teacher Notes: Common misconceptions

First recall the initial equations presented above representing the chemical reactions that follow when CO_2 dissolves in seawater.

(1) $CO_2 + H_2O \rightarrow H_2CO_3^-$

(2) $H_2CO_3^- \rightarrow H^+ + HCO_3^-$

(3) $HCO_3^- \rightarrow H^+ + CO_3^{2-}$

When first viewing these equations it may *appear* that both hydrogen ions and *carbonate ions increase in solutions as a result of CO_2dissolving in seawater.* **This is not the case!** This would be true if the reactions above only occurred in a single direction but chemical equations can actually go in either direction. A more correct representation of this would be:

(4) $CO_2 + H_2O \leftarrow \rightarrow H_2CO_3^-$

(5) $H_2CO_3^- \leftarrow \rightarrow H^+ + HCO_3^-$

(6) $HCO_3^- \leftarrow \rightarrow H^+ + CO_3^{2-}$

It is ultimately the rates of occurrence and net direction of the above reactions that determine seawater pH and carbonate availability. First when CO_2 dissolves in seawater the primary reactions that occur are (1) and (2) going in the direction as listed.

Equation (2) shows that formation of carbonic acid results in an increase in the hydrogen ion concentration (and thus a decrease in pH). This leaves equation (3) as a key player in determining carbonate availability in seawater. Chemical reactions in seawater can send any of the above equations in either direction as the system tries to maintain equilibrium. As more CO_2 dissolves and H^+ ions increase in solution, equation (3) will shift in the opposite direction (to the left) to produce bicarbonate. Thus in the system's attempt to reduce the hydrogen ion concentration, it binds hydrogen and carbonate ions together thereby reducing carbonate availability to marine organisms.

Part II: Testing the effect of increased acidity on calcium carbonate (Optional)

Part II of the handout is optional. This example is for illustrative purposes only, as vinegar is extremely acidic compared to ocean water. In fact, even the tap water is much more acidic that ocean water. If you wish to complete this activity, you will need pieces of plain white chalk, cups (plastic, paper or Styrofoam), and a bottle of vinegar. The vinegar simulates seawater that is slightly acidic. The chalk simulates marine bicarbonate skeletal material like shells or corals.

1. Give each group two cups, one filled with tap water and the other with vinegar.
2. Give each group two pieces of chalk.
3. Indicate that the chalk is made of calcium carbonate and will serve as our representation of shells and corals and that the vinegar is a weak acid similar to carbonic acid.
4. Ask students what they think will happen to the chalk if it is left in the mildly acidic vinegar. Also ask if they would expect the same outcome for the chalk placed into the water?
5. As specified in Part II of the handout, each group should formulate hypotheses and test them by placing their pieces of chalk into the cups. The students should record their observations and notice that the chalk in the vinegar starts to dissolve right away.

NOTE: **To save time and resources, you can demonstrate this exercise for the class rather than having them complete the task in groups.**

Answer Key Synthesis Questions

1. Based on the outcome of the chalk experiment, what do you think will happen to shells and corals in a slightly more acidic ocean over time?
   They might dissolve or corrode.

2. What specific organisms and marine ecosystems do you think might be affected by the human activities you saw in the PowerPoint?
   Organisms with shells (e.g., mollusks) and exoskeletons (e.g., phytoplankton). Ecosystems dependent upon these skeletal structures (e.g., coral reefs).

Ocean Acidification

You just learned about the importance of carbon in the oceans. Now let's think about how human activities can change ocean chemistry, and what this means for marine organisms.

Part I: Use of CO_2 in the oceans

As you know, CO_2 from the atmosphere dissolves into seawater. Let's look at this process in more detail:

First, CO_2 reacts with water to form carbonic acid ($H_2CO_3^-$):

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(2) $H_2CO_3^- \rightarrow H^+ + HCO_3^-$

Bicarbonate can then dissociate into carbonate ions (CO_3^{2-})

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There are **two** very important biological and chemical processes that are dependent upon the above compounds.

First, some marine organisms use carbonate to form calcium carbonate ($CaCO_3$). Can you list two examples of vital uses of calcium carbonate to marine life?

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Second, carbonate ions regulate the pH of seawater. If an acid is added to seawater, the carbonate ion reacts with excess hydrogen ions to produce bicarbonate (see equation 2). If a base is added to seawater, this bicarbonate will donate hydrogen ions to neutralize the base.

(4) $2CO_3^{2-} + H_2SO_4$ (an example of an acid) $\rightarrow 2HCO_3^-$ (bicarbonate) + SO_4^{2-}

Questions for Part I

1. The above reactions are all *reversible*, meaning that a chemical change can cause them to occur in the opposite direction.
   a. Write the reverse reaction of equation (3).

   b. Thinking about your answer from question (a), if excess CO_2 results in an excess of hydrogen ions in seawater what will happen to carbonate?

   c. What effects do you think this could have on the formation of skeletal structures for marine life?

Part II: Testing the effect of increased acidity on calcium carbonate (Optional)

Your teacher has provided you with two pieces of chalk and two cups, one filled with water and the other with vinegar. The chalk is made of calcium carbonate and will serve as our representation of shells and corals. The vinegar is a weak acid similar to carbonic acid. What do you think will happen to the chalk if it is left in the mildly acidic vinegar? Do you expect the same outcome as the chalk placed into the water?

Forming your hypothesis:

1. Write your hypothesis about what you think will happen to chalk placed in the vinegar compared to the chalk placed in the water.

Testing your hypothesis:

2. Place one piece of chalk into the cup of water, and the other into the cup of vinegar. Let them sit for 10 minutes. Observe and record any changes as you are waiting.

3. If you have computer access while you are waiting, research some marine organisms that build shells and exoskeletons from calcium carbonate. This might help you answer the questions.

4. After ten minutes, remove both pieces of chalk from your cups. Write down your observations about what happened to the chalk in both the treatment and control solutions and answer the questions below.

Synthesis questions

1. Based on the outcome of the chalk experiment, what do you think will happen to shells and corals in a slightly more acidic ocean over time?

2. What specific organisms and marine ecosystems do you think might be affected by the human activities you saw in the PowerPoint?

Tips for the Bowl – Ocean Acidification

The information on this handout is based on previous NOSB questions and topics. Look over these concepts to bring your best to the competition!

Definitions
Write definitions and key concepts for these terms during your teacher's presentation.

Carbon sink:

Carbon sequestration:

Bicarbonate:

Carbonate ion:

pH:

Make the connections!
Make sure you understand the following relationships from this section.

1. As the amount of hydrogen ions *increases* in a solution, the pH level *decreases*
2. As temperature OR salinity *increases*, the amount of gas the ocean can absorb *decreases*

Why does it matter?
The concepts you learn are almost always related to human interaction with the oceans. Here are just a few of the human-ocean interactions from this lesson. Can you think of others?

- When shelled organisms are affected by ocean acidification, larger species that need them for food may decline in number. This may affect the availability of some human food sources like fish and shellfish.
- Coral reef ecosystems may decline because of increasing ocean acidity. If coral reef quality is poor, fewer people will want to visit the reefs. As a result, money from tourism may decline in coral reef areas.

Check out this ocean acidification learning tool online:
http://www.whoi.edu/oceanus/viewFlash.do?fileid=55243&id=38052&aid=52990

Ocean Acidification

1. Short answer: This term refers to the capture and storage of carbon:
   Answer: Carbon sequestration

2. When carbon dioxide combines with ocean water, what is the primary end product produced?
   w. Calcium carbonate
   x. **Bicarbonate**
   y. Carbonic acid
   z. Carbonate

3. Compared to the 1700s, average sea-surface pH levels have...
   w. Risen uniformly across the oceans
   x. Risen variably across the oceans
   y. Fallen uniformly across the oceans
   z. **Fallen variably across the oceans**

4. Which of the following regulate(s) the pH of seawater?
   w. **Carbonate ions**
   x. Calcium carbonate
   y. Bicarbonate
   z. Carbonate

5. The amount of gases that can dissolve in seawater depends on temperature and:
   w. Nutrients
   x. Depth
   y. Currents
   z. **Salinity**

6. When the temperature or salinity of seawater **decreases**, the amount of CO_2 that can be absorbed:
   w. Remains the same
   x. **Increases**
   y. Decreases
   z. Can either increase or decrease

7. What is the approximate pH of typical ocean water?
   w. Around 6
   x. Around 9
   y. **Around 8**
   z. Around 10

8. Short answer: What term is used to refer to substances with **very low** pH values?
   Answer: Acid (or Acidic)

9. Shells and corals may dissolve in an acidic environment. This is due to the breakdown of:
   w. Bicarbonate
   x. Carbon dioxide
   y. The carbon sink
   z. **Calcium carbonate**

10. Team Challenge Question

Match the following terms with the correct definition or formula by writing the corresponding letter next to the term. (5pt)

Carbon sink	a. capture and storage of carbon
Carbon sequestration	b. $-\log[H^+]$
Bicarbonate	c. system that stores carbon
Carbonate ion	d. HCO_3^-
pH	e. CO_3^{2-}

ANSWER

Carbon sink **c**	a. capture and storage of carbon
Carbon sequestration **a**	b. $-\log[H^+]$
Bicarbonate **d**	c. system that stores carbon
Carbonate ion **e**	d. HCO_3^-
pH **b**	e. CO_3^{2-}