Coral Reefs in Danger: Ocean Acidification Lesson

by Bill Andrake

In this webisode, Jonathan narrates a comprehensive lesson about the biology of corals and the coral reef ecosystem in our tropical oceans. Once established, these primitive animals create one of the most important and diverse ecosystems on the planet. The reef provides a home to thousands of fish and invertebrates, which attract many larger species including sharks and turtles. Almost all marine life in shallow tropical seas is dependent upon the health of the coral reef. However, like many other ecosystems on our planet, coral reefs are threatened by human activities. The chemistry of our oceans is being altered by changes to our atmosphere, which put corals and the habitat they create in serious jeopardy.

Science Lesson: Coral Reefs in Danger: Ocean Acidification - Based on Webisode 41
Grade Level: 6-8
Time: Four (45-55 min) class periods (Introduction, Activity & Follow-up).

Introduction

Increases in carbon dioxide to the atmosphere from the burning of fossil fuels and deforestation threaten to change the chemistry of the seas. Evidence suggests that this increase in atmospheric carbon dioxide is lowering the pH of the oceans in a process called *ocean acidification*. When carbon dioxide is dissolved in water it lowers the pH as carbonic acid is formed. Ocean acificiation appears to be a very real threat to the delicate balance of the oceans' pH. If acidification continues at current rates, many marine species and ecosystems may not be able to tolerate the change. This lesson looks at the process, the factors involved in, and the effects of ocean acidification on marine organisms; namely those such as corals and other species who build and rely on carbonate exoskeletons for their existence.

Science Standards

National Science Education Standards
Physical Science:
- Properties and Changes of Properties in Matter
- Chemical Reactions

Ocean Literacy Principles
Principle #6: The Ocean and Humans are Inextricably Connected

Objectives

- To demonstrate how pH in water is lowered with the addition of CO_2.
- Demonstrate the effects of a lower pH on the calcium carbonate exoskeletons or shells of marine animals.
- To bring relevance to a study of acid/base chemistry.
- To bring an awareness and understanding of ocean acidification, its cause and potential impact on life in our oceans.

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Background: Acids, Bases, and what is pH?

Acids and *bases* are two groups of chemicals that when present in water can have an impact on aquatic life the life in it. Like many other compounds, when acids and bases are dissolved in water, their molecules are broken up into + or - charged particles known as ions.

A common example of this happens when table salt or sodium chloride (NaCl) is dissolved in water. Its molecules are broken down into positively charged sodium ions Na^+ and negatively charged chlorine ions Cl^-. Without water molecules forcing them apart the positive sodium ion attracts the negative chlorine ion. The ions bond together forming a neutral sodium chloride molecule as opposite charges attract.

Acids are compounds that when dissolved in water release positively charged hydrogen ions H + when dissolved in water. For example, this is what happens when hydrochloric acid (HCl) is in water.

HCl in water H^+ + Cl^- ions + H_2O molecules

Other Common Acids: Sulfuric Acid (H_2SO_4) Nitric Acid (HNO_3)
Carbonic Acid (H_2CO_3) Acetic Acid (CH_3COOH)

From their chemical formulas what do these acids have in common? ____

____

Acids are corrosive. They break down metals, minerals, and damage organic molecules. They have a sour taste in fact, the word acid comes from the latin word "acidus" which means "sour." Examples: vinegar and citric acid in citrus fruits.

It's these reactive H+ ions that give acids these properties and define acids.

Bases are compounds that release negatively charged hydroxide ions (OH -) when dissolved in water. For example, this shows what happens when sodium hydroxide (NaOH) is in water:

NaOH in water ------------------> Na^+ + OH^- ions + H_2O molecules

Other Common Bases: Potassium Hydroxide (KOH)
Calcium Hydroxide Ca $(OH)_2$
Magnesium Hydroxide $Mg(OH)_2$

Background (continued)

From their chemical formula... what do these bases have in common?

____

Bases are caustic... they destroy organic molecules. They have a bitter taste... and slippery feel... soaps and detergents are basic (also called *alkaline*).

Too many of these hydroxide particles (OH^-) (from bases) or hydrogen (H^+) particles (from acids) in water harm aquatic life .

But

When the (H^+) particles in water is equal to the hydroxide particles (OH^-) you simply will have water... a "neutral" situation... not acidic and not basic.

Acids "neutralize" bases and vice versa.

H^+ + OH^- -----------> H_2O

What is pH? ... Potential of Hydrogen

- pH measures how acidic or basic the water is.
- pH measures the concentration of (H^+) ions in a solution.
- The higher the concentration of (H^+) ions, the *lower* the pH.
- The higher the amount of (OH^-) ions... the lower the (H^+) particles, so the *higher* the pH.

H^+	H^+	H^+	H^+	H^+
H^+	H^+	H^+	H^+	H^+
OH^-	H^+	H^+	H^+	H^+
H^+	H^+	H^+	H^+	OH^-

Low pH: *acidic*

H^+	H^+	H^+	H^+	H^+
OH^-	OH^-	OH^-	OH^-	OH^-
H^+	H^+	H^+	H^+	H^+
OH^-	OH^-	OH^-	OH^-	OH^-

Neutral pH: *water*

OH^-	OH^-	OH^-	OH^-	OH^-
OH^-	OH^-	OH^-	OH^-	OH^-
H^+	OH^-	OH^-	OH^-	OH^-
OH^-	OH^-	OH^-	OH^-	H^+

High pH: *alkaline* (basic)

Background (continued)

pH is measured on a scale from 0-14. **Pure water** has a **pH of 7** and is considered to have a **neutral pH**. A **pH** of less than 7 is acidic and higher than 7 is basic or *alkaline*.

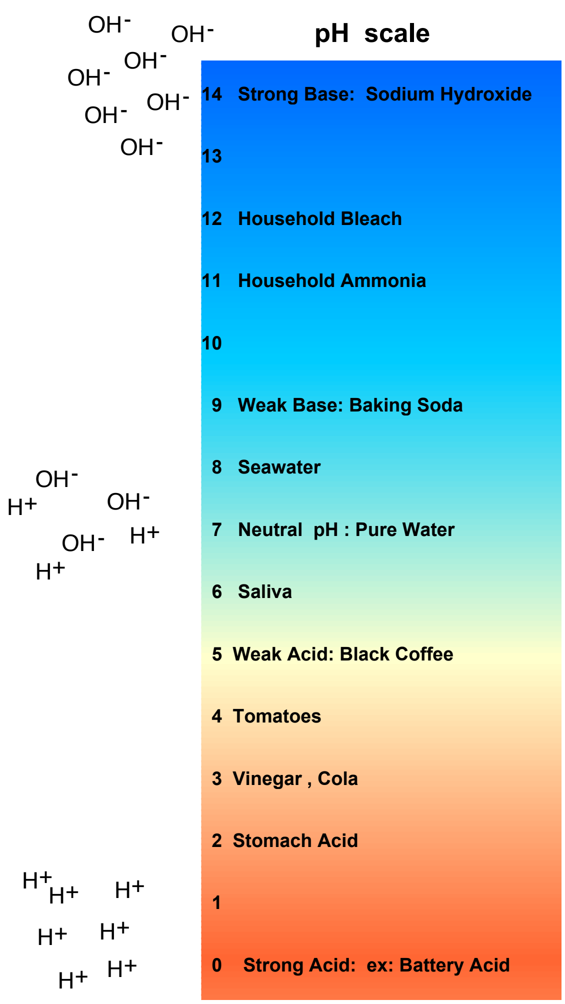
The lower the pH the stronger the acid. The higher the pH the more alkaline the solution is.

The pH scale is *logarithmic* so each whole number step on the pH scale differs by a factor of ten. A pH of 2 is *ten times* more acidic than a 3. A pH of 3 is ten times more acidic than a 4 and so on.

This means that a solution with a pH of 2 is 100 times more acidic than a solution with pH of 4 and 10,000 times more acidic than a solution with a pH of 6.

Freshwater organisms generally live in a pH range of 7.0 to 7.5. Seawater has a higher pH than freshwater due to its salts and mineral content, thus most marine creatures live in an environment with a pH range of 8.0 to 8.4.

A pH scale with some common acids and bases:



Vocabulary:

Acids: Compounds that when dissolved in water release positively charged hydrogen ions H^+ when dissolved in water.

Alkaline: Meaning "basic"--the opposite of *acidic*.

Bases: Compounds that when dissolved in water release negatively charged hydroxide ions OH^- when dissolved in water.

Compounds: Pure substances formed from the chemical combination of two or more different elements.

Exoskeleton: External shell of an animal.

Ions: Positive or negative charged atoms or molecules

Molecules: Particles formed from two or more atoms chemically combined in a specific way.

Ocean Acidification: The lowering of the pH in the oceans due to the increased absorption of carbon dioxide from the atmosphere.

Organic Molecules: Carbon-based molecules associated with living things: include carbohydrates, proteins, fats, oils, and nucleic acids such as DNA.

pH: A measure of a solution's acidity. It measures the concentration of H^+ ions in a solution. A higher pH (pH 8- 14) is *alkaline* (basic) and a lower pH (0-6) is *acidic*.

Ocean Acidification Part 1: How can acids affect marine life?

Activity: **Egg in acetic acid (a.k.a. vinegar) Demonstration**

This demonstration shows the effects of an acid on a shelled organism.

Materials: Glass or clear plastic jar with lid (*large enough to hold an egg),* an egg, and household distilled white vinegar (acetic acid).

Procedure: Gently place an egg in the jar that is two-thirds to three quarters full with vinegar.

Observe what happens when an egg is placed in a jar of vinegar and record your observations below.

____

____

Close the jar and leave it overnight.

Next day : Remove the egg from the acid and place it in a dish or on paper towels.

What happened to the **calcium carbonate** shell of the egg in acid?

____

An egg contains all of the chemicals (proteins and other materials) to make a chicken. What happened to these materials the day after the egg was placed in vinegar?

____

In what way is an egg like many marine creatures? ____

____

List as many sea creatures as you can think of that have **calcium carbonate** (limestone) shells or exoskeletons?

____

____

____

What could happen to those shells (exoskeletons) if the pH of the ocean continues to be lowered and acidity increases? __________

____

____

Ocean Acidification Part 1: How can acids affect marine life? (continued)

What could a lower pH do to the proteins and other organic molecules that make the soft tissue of a marine organism. ____________
____

Follow-up explanations and chemistry behind the observations:

Acids are **corrosive**, they breakdown metals and many minerals including the **calcium carbonate** ($CaCO_3$) shell of a chicken egg as seen in this activity. Calcium carbonate or "limestone" is used to build the exoskeletons of many marine creatures, including the shells of mollusks, corals, and echinoderms. This mineral is also important in the formation of cell walls of phytoplankton species such as coccolithophores and coralline algae.

The following is the chemical reaction that occurred when vinegar (acetic acid) broke down shell of the chicken egg.

$$2\ CH_3COOH \quad + \quad CaCO_3 \quad \text{---------->} \quad Ca(CH_3COO)_2 \quad + \quad CO_2 \quad + \quad H_2O$$

2 molecules of acetic acid	1 molecule of calcium carbonate	1 molecule of calcium acetate	1 molecule of carbon dioxide	1 molecule of water

In the reaction, the hydrogen ions from the two acetic acid molecules (H) pull one of the oxygen atoms from $CaCO_3$ and forms water. Now the carbonate ion (CO_3^{-2}) in calcium carbonate becomes CO_2 (carbon dioxide gas)… the bubbles coming off of the egg shell when it was placed in the vinegar. The calcium bonds with the acetate ions from the acetic acid (CH_3COO^-) to form calcium acetate which remains dissolved in the solution.

In addition acids **denature** or alter important organic **molecules** found in living things, especially proteins that build tissue and control chemical reactions in organisms. Proteins are long chains of amino acids, placed in a specific sequence and are twisted and folded into three dimensional structures. The unique function of a particular protein is determined by its specific shape which can be altered by heat (i.e. cooking) or by chemicals such as acids. When this happens, proteins are **denatured,** becoming useless and living tissue is damaged.

In this activity, as the shell disappeared, the clear egg proteins reacted to the vinegar, and were **denatured** becoming sort of rubbery and "cooked".

In a way the chicken egg served as a model for what a marine organism with a calcium carbonate exoskeleton may face with continued ocean acidification.

Ocean Acidification Part 2: How Do The Oceans Become Acidic?

Activity: Carbon Dioxide and pH in Water

Materials:
- water
- an aquarium pH test kit (the liquid drops not the strips)
- beaker or clear plastic cup
- crushed coral or seashells
- drinking straw

Procedure:
Fill a clear plastic cup or small beaker half - way with water.

Next, add a few drops of pH indicator solution (from an aquarium pH test kit) to the water and mix it with a straw.

Record the color and pH of the solution. color:______________ from the pH color chart in the test kit determine the pH of this solution _____

Slowly!!! exhale through the straw into the water with pH indicator solution until you notice a color change?

Describe the color change of the solution: ____

What is the new pH of the solution ___________

What gas are you adding to the solution as you exhale? _____________

What does the addition of carbon dioxide gas do to the pH of water? ________________

This is "acidification."

When CO_2 is added to water it forms **carbonic acid** (H_2CO_3).

$$CO_2 + H_2O \text{ --------------> } H_2CO_3$$

Like all acids, carbonic acid when dissolved in water releases hydrogen ions (H^+).

$$\underset{\text{Carbonic Acid}}{H_2CO_3} + \underset{\text{Water}}{H_2O} \text{ ----------------> } \underset{\text{Hydrogen ion}}{2\,H^+} + \underset{\text{Carbonate ion}}{CO_3^{-2}}$$

<u>It's the hydrogen ions</u> that define acids and give them their chemical properties.

The greater the concentration of hydrogen ions in water the lower the pH.

Add a teaspoon or two of crushed coral or seashells to this solution and swirl it around slowly for <u>several minutes</u>. (Eventually you will notice a color change) .

Ocean Acidification Part 2: How Do The Oceans Become Acidic?

What is happening to the pH of the solution as the coral or seashells are added?

____

What material make up these exoskeletons ? ______________________________

Although you can't see it, the carbonate exoskeletons were broken down somewhat by the carbonic acid as it was **neutralized.**

You can see this process in the chemical reaction:

H_2CO_3	+	$Ca\ CO_3$	------------>	Ca^{+2}	+	$2\ HCO_3^{-1}$
Carbonic Acid		*Calcium Carbonate*		*Calcium Ion*		*2 Bicarbonate Ions*

The carbonic acid reacts with the calcium carbonate resulting in calcium ions and bicarbonate ions which neutralizes the acid, but the calcium carbonate is broken down in the process.

Carbonate to Bicarbonate… a major concern with ocean acidification.

The "building blocks" for marine creatures to build calcium carbonate exoskeletons are calcium ions (Ca^{+2}) and carbonate ions (CO_3^{-2}) dissolved in the seawater.

With acidification hydrogen ions (H^+) from the carbonic acid bond to dissolved carbonate ions (CO_3^{-2}) in the water forming bicarbonate ions (HCO_3^{-1}).

Bicarbonate ions are useless for shell building. As acidification increases, more carbonate ions become bicarbonate ions, making carbonate ions few and far between in the sea. This would make it more difficult for creatures such as corals to build calcium carbonate exoskeletons and the health of the coral reef ecosystem will decline.

A good animation that shows this process can be viewed at "The Center for Ocean Solutions" website on Ocean Acidification at:

http://centerforoceansolutions.org/climate/impacts/ocean-acidification/

Ocean Acidification Part 3: Follow-up Questions and Activities

What is ocean acidification?

What are the reasons for the increasing level of CO_2 in the atmosphere?

Describe how the addition of carbon dioxide can lower the pH of seawater:

Describe one way that a drop in pH can harm marine life. (Be complete)

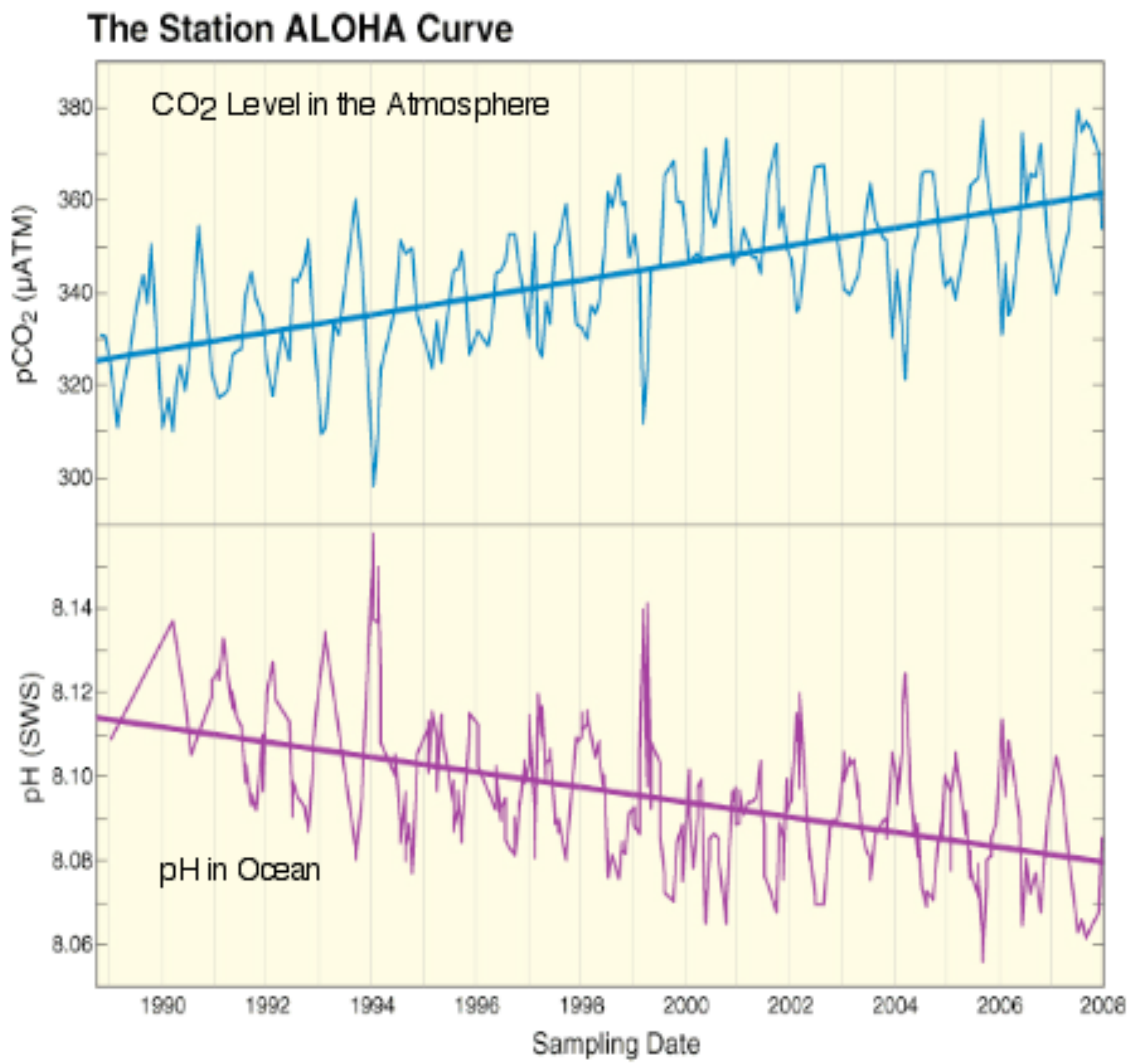
Understanding the Carbon Cycle.

A good resource for helping students to understand the "Carbon Problem" is "The Carbon Bathtub." Published in National Geographic Magazine, December 2009.

The article can be accessed at:

http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

Ocean Acidification Data Analysis Activity



This graph summarizes data collected at Station ALOHA, the site of the U.S. Joint Global Ocean Flux Study. Hawaii Ocean Time series program.

After studying this graph, answer the following questions:

1) What is the relationship between the CO_2 levels in the atmosphere and the pH levels in the ocean?

___

___

Questions from the Station ALOHA graph continued.

2) Describe the chemistry (chemical reaction) that explains the data in this graph. (Be complete)

3) Although the average level of carbon dioxide is rising, the CO_2 level has an increase followed by a decrease **within** each year.

During what season is there a peak in CO_2 ? ______________________

Explain this answer. ____

____

____

4) During what season is there the lowest level in CO_2 within each year on the graph? ________________

Explain this answer. ____

____

____

____

Answer key to follow up questions

What is ocean acidification?

Ocean acidification is lowering of the pH or "acidification" of the world's oceans due to the increase in carbon dioxide added to the oceans as a result of increasing atmospheric CO_2.

Why are atmospheric CO_2 levels increasing?

Carbon dioxide levels are rising as a result of increased burning of "fossil fuels" to create energy.

Describe how the addition of carbon dioxide can lower the pH of sea water.

Carbon dioxide (CO_2) *when added to water* (H_2O) *forms carbonic acid* (H_2CO_3). *Carbonic acid releases* H^+ *ions to the water, increasing the* H^+ *ion concentration and lowering the pH of the water.*

Describe one way that a drop in pH can harm marine life in the oceans. (Be complete)

Acids can break down the calcium carbonate exoskeleton of many marine creatures such as shelled mollusks and corals as well as diminish their ability to create shells and skeletons.

Answer key to ALOHA graph analysis activity

1) What is the relationship between the CO_2 levels in the atmosphere and the pH levels in the ocean?

The pH of the ocean decreases (becomes more acidic) as the carbon dioxide in the atmosphere increases.

2) Describe the chemistry (chemical reaction) that explains the data in this graph. (Be complete)

When CO_2 *is added to water it forms carbonic acid* (H_2CO_3).

$$CO_2 + H_2O \text{ -------------->} \quad H_2CO_3$$

Carbonic Acid

Like all acids, carbonic acid when dissolved in water releases hydrogen ions (H^+)*, lowering pH.*

$$H_2CO_3 + H_2O \text{ -------------->} \quad 2\,H^+ + CO_3^{-2}$$

3) Although the average level of carbon dioxide is rising, the CO_2 level has an increase followed by a decrease ***within*** each year. During what season is there a peak in CO_2?

A: Winter.

The Hawaii data represents the global trend with the global mixing of CO_2 in the atmosphere. The Northern Hemisphere and Southern Hemisphere in opposite seasons don't cancel each other out as one might expect. The Northern Hemisphere has a bigger role in the seasons globally because of more land mass (especially temperate landmass) and a much larger population (90% of the world is in the northern hemisphere). As a result, global CO_2 production is increased during the northern hemisphere's winter, when fossil fuel use increases for heating. At the same time, and more importantly, there is greatly reduced photosynthetic activity in the northern hemisphere (in both the ocean and on land) due to winter (trees lose leaves and phytoplankton dies off). At the same time, water temperatures are cooler, allowing for more absorption of CO_2 into the ocean. (Cold water dissolves more gas than warm water). The result is a noticeable change in pH in the water seasonally.

4) During what season is there the lowest level in CO_2 within each year on the graph?

A: Summer.

During summer for the northern hemisphere, there is more photosynthesis globally, removing CO_2 from the atmosphere. Sunlight is plentiful and plants (both land and sea) are at their peak. There is also less burning of fossil fuels, so less CO_2 is being generated.

Resources for Ocean Acidification and Related Topics

For overviews of ocean acidification with links to other resources and educational tools:

- NOAA Pacific Marine Environmental Laboratory Carbon Program: "Ocean Acidification"
  http://www.pmel.noaa.gov/co2/story/Ocean+Acidification
- "The Center for Ocean Solutions" website on Ocean Acidification at:
  http://centerforoceansolutions.org/climate/impacts/ocean-acidification/
- Ocean Acidification. Woods Hole Oceanographic Institution. http://www.whoi.edu/page.do?pid=30935

Resource for understanding the Carbon Cycle:

A good resource for helping students to understand the "Carbon Problem" is "The Carbon Bathtub." Published in National Geographic Magazine, December 2009.

The article can be accessed at: http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

Videos:

Natural Resources Defense Council Production: Acid Test: The Global Challenge of Ocean Acidification
http://www.youtube.com/watch?v=5cqCvcX7buo

ABC News Report: Ocean Acidification http://www.youtube.com/watch?v=W9cS0rl_NyI