The Power of pH: Changing Ocean Chemistry

Topics
Ocean Acidification, pH

Grades
9-12

Site
Indoors

Duration
Two 45-minute periods

Materials
See page 3

Vocabulary
carbon footprints, carbonate buffer system, climate change, ocean acidification, pH

Next Generation Science Standards

Practices
Analyzing and interpreting data

Core Ideas
PS1.B Chemical reactions
ESS3.D Global climate

Crosscutting Concepts
Cause and effect

Performance Expectations
See page 6

Focus Question

How does carbon dioxide released from the burning of fossil fuels affect the health of the ocean?

Overview

What is pH and how does carbon dioxide released from the burning of fossil fuels increase the acidity of the ocean? Students explore the answers to these questions in this two-part lab investigation. Students first investigate the power of pH by creating their own pH scale through a serial dilution of hydrochloric acid and sodium hydroxide. Students then compare the pH of fresh water and sea water and add carbon dioxide to observe how pH is affected. Finally, the effect of ocean acidification on marine life is observed through the use of calcium carbonate powder and hydrochloric acid.

Objectives

Students will be able to:

- Describe the logarithmic nature of the pH scale as it relates to the concentration of hydrogen ions within a solution and decreasing ocean pH.
- Explain the relationship between carbon dioxide and the pH of a solution.
- Recognize the reaction between an acidic solution and calcium carbonate, and infer possible implications for ocean organisms in a lower pH ocean.

Background

Since the mid-1700s and the advent of the Industrial Revolution, human activities (like the burning of fossil fuels, deforestation, industrialization, cement production, etc.) have increased the amount of carbon dioxide (CO_2) gas in the atmosphere. This human-released carbon dioxide and other greenhouse gases have contributed to **climate change**--a change in weather patterns and climate over the long term. The increase in CO_2 has also led to **ocean acidification**.

Ocean acidification refers to the chemical processes through which human-released CO_2 dissolves in seawater and thus lowers ocean pH. The dissolution of carbon dioxide in ocean water is a natural process and part of the ocean's role as a carbon sink. However, it is estimated that the ocean has taken up one-third, or 33%, of human-released CO_2. This increased uptake of CO_2 by the ocean has tipped the **carbonate buffer system** and resulted in a 0.1 unit drop in average surface ocean **pH** from approximately 8.2 in preindustrial times to approximately 8.1 today. (Note: the pH of the ocean varies with location and depth.) Due to the logarithmic nature of the pH scale, a 0.1 unit pH drop is nearly a 26% increase in the ocean hydrogen-ion concentration and acidity! Though ocean pH is still basic, this decrease in pH is described as "ocean acidification." See student reading "Ocean Acidification" for more specifics.

How Do We Know Ocean pH Has Decreased?

As ice sheets develop into glaciers, air bubbles become trapped in the freezing ice. The CO_2 content can be calculated from these air bubbles. This gives us a record of what atmospheric CO_2 levels were in the past. Since atmospheric CO_2 is roughly in equilibrium with ocean surface CO_2, we can use this ice core data to calculate what ocean pH was in the recent past. Ocean pH from tens of millions of years ago can also be calculated from the ratio of stable isotopes of boron in marine carbonates.

Effects on Marine Organisms

The effects of a lower pH ocean are still being studied. However, implications for marine life may include changes in respiration rates and reproductive capabilities. Of great concern is the impact ocean acidification may have on ocean calcifiers like molluscs, corals and some plankton. Calcifiers absorb calcium (Ca^{2+}) and carbonate ions (CO_3^{2-}) from surrounding waters in order to build their shells and skeletons. The excess hydrogen ions produced from the CO_2 dissolving in sea water react with the carbonate ions to form more bicarbonate. This makes the carbonate ions less available and may cause the shells and skeletons of ocean calcifiers to become weaker. The reaction of carbon dioxide with water to dissolve calcium carbonate is written as: $CaCO_3 + CO_2 + H_2O \longrightarrow Ca^{2+} + 2HCO_3^-$. If ocean waters become too acidic calcium carbonate structures may even begin to dissolve. This has implications for plankton, corals, molluscs and other organisms important in the marine food web and ocean ecosystem.

Conservation and Action

To slow the rate of climate change and ocean acidification, measures need to be taken to reduce the amount of carbon dioxide released by human activities. Individuals can take action to reduce **carbon footprints** by driving less, turning off lights, unplugging electronic devices and appliances when not in use and buying local produce. Support of large-scale policies requiring more energy efficiency and reduction of emissions is another way to reduce carbon footprints. Many countries are now looking into ways to reduce emissions by utilizing more renewable energy sources such as solar panels and wind turbines. Many countries are also looking into ways to strengthen and protect other natural carbon sinks, including forests and wetland areas.

VOCABULARY

Carbonate buffer system: a system regulating the pH of the ocean in which carbonate ions bond with excess hydrogen ions in the presence of an acid and which dissociate from hydrogen ions in the presence of a base

Carbon footprint: a quantitative measure of greenhouse gas emissions based on calculations of carbon emitting behaviors

Climate change: any change in global temperature, precipitation or other long-term weather patterns term due to natural variability and human activity, primarily the rapid increase in greenhouse gas emissions in the atmosphere

Ocean acidification: the process of lowering the oceans' pH by dissolving additional atmospheric carbon dioxide in seawater

pH: a measurement of the concentration of hydrogen ions (H^+) within a solution; the more hydrogen ions the lower the pH and the more acidic a solution

Materials

For each student:

- Investigation 1 and Investigation 2 student sheets
- Safety glasses
- Gloves
- Rinse bucket or tub

Investigation 1
Per group:

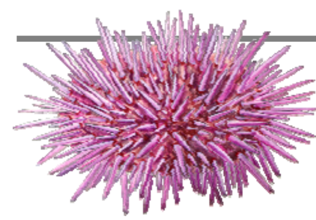
- Thirteen 10mL flat-bottomed, screw-top vials and caps
- Sharpie marker to label vials
- One 10mL graduated cylinder
- Pipet
- 0.1M Hydrochloric acid (HCl)
- 0.1M Sodium hydroxide (NaOH)
- 130 mL of distilled water for serial dilutions
- Distilled water for rinsing
- Universal Indicator solution (with color key)
- White index card
- Colored pencils

Investigation 2
Per group:

- Three 10mL flat-bottomed, screw-top vials and caps
- Sharpie marker to label vials
- One 10mL graduated cylinder
- 0.1M Hydrochloric acid (HCl)
- 10 mL distilled water
- 10 mL sea water or prepared "Instant Ocean"
- Universal Indicator
- Plastic pipet
- Scissors
- Balloon
- Stopwatch
- Twist tie
- Crushed shells or other calcium carbonate

A TON OF CARBON EMISSIONS IS RELEASED BY TRAVELING 5,000 MILES IN AN AIRPLANE, DRIVING 2,500 MILES IN A MEDIUM-SIZED CAR OR CUTTING DOWN AND BURNING A TREE ABOUT A FOOT IN DIAMETER AND 40-FEET TALL.

Nature Conservancy website



Teacher Preparation

1. Build any necessary background beforehand on the carbon cycle, climate change, logarithm scales or pH.

2. Gather materials for the investigations and make copies of the student pages. If you do not have sea water available, purchase "Instant Ocean" from an aquarium supply store or make your own sea water using recipes available online.

3. Try the investigations before giving to students. This will help you better gauge how much time it will take your students. Keep the pH scale you created as an example or comparison for students during the two investigations. Depending on your available time, you may or may not choose to have the students complete the "Before Lab" questions.

Procedure

1. INTRODUCE THE ISSUE OF OCEAN ACIDIFICATION.
   Use a brief video about ocean acidification like the Natural Resources Defense Council's at http://www.nrdc.org/oceans/acidification/aboutthefilm.asp to pique student interest about an acidifying ocean and its effects on marine organisms. Make sure students understand that climate change and ocean acidification are two different phenomena that share the same cause – rapid increase of carbon dioxide in the atmosphere due to human-induced combustion of fossil fuel. Since about 1750 and the advent of the Industrial Revolution, the ocean has absorbed approximately 33% of human-produced carbon dioxide, causing a 0.1 decrease in average surface ocean pH.

2. INTRODUCE THE FOCUS QUESTION TO THE CLASS.
Share the question: *How does carbon dioxide released from the burning of fossil fuels affect the health of the ocean?* You may write it up on the whiteboard or have students add it to their science notebook. Give students time to write their initial thoughts down or discuss with a partner. At this point, if they've watched the video in step one , they will likely know carbon dioxide affects acidity but not how or the breadth of the issue.

TEACHER TIP

For student understanding, focus on the concentration of each pH solution rather than the color.

Why? Each pH vial may not exhibit an individual color. Universal Indicator is effective in exhibiting pH color ranges. For example:

pH 1.0-3.0 red
pH 3.0-6.0 orange/yellow
pH 7.0 green
pH 8.0-11.0 blue
pH 12.0-14.0 purple

There may be variations within each range however.

Investigation 1: Create Your Own pH Scale

3. GIVE THE CLASS INSTRUCTIONS FOR INVESTIGATION 1: CREATE YOUR OWN PH SCALE.
Tell the class they are going to find out why a 0.1 decrease in pH is so drastic by investigating the logarithmic nature of pH. Demo the first step of the dilution for the class. Point out the materials, stress the importance of safety equipment (glasses and gloves) when working with hazardous chemicals and ensure there is no food or drink in the lab. Be sure students understand the importance of rinsing their graduated cylinders and pipets with distilled water between steps. Even slight variations in one step of the procedure can cause the rest of their pH scale to be inaccurate. (This may be a good time to talk about science process and the importance of following procedures exactly.)

4. IN SMALL GROUPS, STUDENTS COMPLETE INVESTIGATION 1 AND CREATE THEIR OWN PH SCALE.
Pass out **Investigation 1: Create Your Own pH Scale** to student pairs. You may choose to have each group do only part of the pH scale (Part One: pH 1-7 or Part Two: pH 8-13) and then work with another pair to create a complete scale depending on available time and materials. Ensure that everyone is wearing gloves and safety glasses. Students should complete **Create Your Own pH Scale Data Sheet** when they finish. Make sure students keep the pH scale they created. They will need it for Investigation 2.

5. AS A CLASS, DISCUSS STUDENTS' RESULTS AND THE POWER OF THE PH SCALE.
You may assess students' comprehension with questions like: Does an increase in hydrogen ions mean a solution is getting more acidic or more basic? What about an increase in pH? Discuss the logarithmic nature of pH and what a slight change can mean. How significant is a 1 unit change in pH? How about a 0.1 unit change in pH? Due to the nature of the pH scale, a 0.1 unit decrease in pH is nearly a 26% increase in acidity.

Investigation 2: Ocean Acidification

6. GIVE THE CLASS INSTRUCTIONS FOR INVESTIGATION 2: OCEAN ACIDIFICATION.
Discuss the ocean as a carbon sink and what that means for ocean chemistry. Do students think seawater is an acid or a base? Is seawater more acidic or basic than fresh water? Why? Is the pH of the ocean constant? (No, it changes based on depth, water temperature, salinity, other minerals in the water, etc.) If carbon dioxide is added, is the pH going to go up or down? Why do they think so?

7. IN SMALL GROUPS, STUDENTS COMPLETE INVESTIGATION 2 AND INVESTIGATE OCEAN ACIDIFICATION.
Pass out **Investigation 2: Ocean Acidification** to student pairs. You will probably need to model for students how to use the balloon and cutoff pipet to add CO_2 to the vials of seawater and distilled water in Part Two: Effects of CO_2 on the Ocean for students.

8. AS A CLASS, DISCUSS THE STUDENTS' RESULTS AND THE EFFECTS OF CO_2 ON THE OCEAN'S PH.

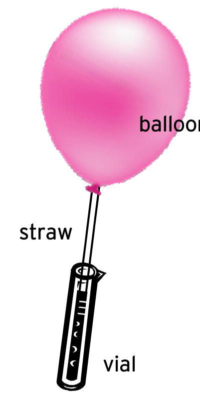
Review how CO_2 affects ocean pH. What happened to the calcium carbonate in the HCl solution? Why? (Make sure students understand this is a dramatic example and the ocean is not predicted to become that acidic.) What other implications might a lower pH ocean have for marine animals? *(affects shell and skeleton formation of plankton, corals, molluscs and other organisms which may lead to decreased biodiversity, changing ocean communities, food web impacts, species growth, respiration and reproduction implications)* Ask students if they think marine or fresh water organisms are more tolerant of a changing pH and why. You may choose to walk students through the chemical process of CO_2 absorption by the oceans on a whiteboard or overhead.

9. BRAINSTORM WAYS TO REDUCE EXCESS CARBON DIOXIDE IN THE ATMOSPHERE.

Estimates are that average surface ocean pH will decrease by an additional 0.4 units of pH by 2100 if humans continue with business as usual. As a class discuss some of these sources of human-released CO_2. Are there ways to reduce the CO_2? What are large-scale, policy actions and regulations that can reduce CO_2 emissions? What are some actions communities could take? What are individual actions students can take?

10. RETURN TO THE FOCUS QUESTION.

Now that students have created a pH scale and added CO_2 to water, have them revisit the question: *How does carbon dioxide released from the burning of fossil fuels affect the health of the ocean?* Students may think on their own or discuss with a partner and add to their original entry. They should include details about the exponential nature of the pH scale and much more depth than their original entry.



Model how to add CO_2 to the vials in Part Two: Effects of CO_2 on the Ocean.

Extensions

virtualurchin.stanford.edu/AcidOcean.htm

Students can explore the effects an increasingly acidic ocean may have on marine life by doing a virtual lab experiment with sea urchins.

www.keystonecurriculum.org/highschool/2009_lesson_intros/EXT_LA_GreatDebate_HS09.html

Students participate in a debate in this activity examining the reasoning behind the controversy of climate change.

Resources

Websites

Alliance for Climate Education www.acespace.org

Learn what other students and schools are doing to fight the climate crisis and sign up for services, like school assembly presentations.

CLEAN: Climate Literacy & Energy Awareness Network www.cleannet.org

The CLEAN project, a part of the National Science Digital Library, provides a reviewed collection of resources coupled with the tools to enable an online community to share and discuss teaching about climate and energy science.

By making small changes on our own and big changes together, we can help accomplish the goals we all share: healthy oceans, clean air and water, and our well-being.

Monterey Bay Aquarium website

European Project on Ocean Acidification www.epoca-project.eu/index.php/FAQ.html
Learn more about ocean acidification from a collaboration of experts from around the world.

Monterey Bay Aquarium Research Institute www.mbari.org/highCO_2
Learn more about the cutting-edge science and research being done to investigate a high CO_2/low pH ocean.

NASA's Eyes on the Earth climate.nasa.gov/
Read about the latest in climate science and monitor the impacts of global climate change on the planet.

Pew Center on Global Climate Change
pewclimate.org/science-impacts/realities-vs-misconceptions
Separate fact from fiction and ensure misconceptions are addressed by reading about the science behind climate change.

References

Articles

"Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms." *Nature* 437: 681-686.

"Ocean acidification: the other CO_2 problem." *The Annual Review of Marine Science* 1:169-192.

Standards

Next Generation Science Standards www.nextgenscience.org

Performance Expectations

Relates to HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Relates to HS-ESS3-6: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

Common Core State Standards www.corestandards.org

Science and Technical Subjects

RST.9-10.7, Reading Science and Technical Subjects: Translate quantitative or technical information expressed in words in a text into visual form and translate information expressed verbally or mathematically into words.

RST 11-12.3, Reading Science and Technical Subjects: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text

Acknowledgements

Thanks to Mike Guardino, chemistry and physics teacher at Carmel High School, and his AP Chemistry and Honors Chemistry students for the adaptation and piloting of this lab.

Investigation 1
Create Your Own pH Scale!

The pH of the surface ocean is lower and more acidic now than it was before the Industrial Revolution. Scientists attribute this to rising levels of CO_2 in our atmosphere.

How does CO_2 alter the chemistry of our ocean? In this two-part investigation, you are going to explore the changing pH of the ocean to find out.

Before the Lab

1. Read "pH: The Power of Hydrogen."

2. Read "Part One: pH 1-7." Complete the following tasks and questions on a separate sheet of paper.
   - Create a materials list based on the lab procedure.
   - Why is it important to rinse the pipet and graduated cylinder between each step?
   - Why is it important to mix the contents of the vial in each step?
   - Which pH solution is the most concentrated acid?

3. Read "Part Two: pH 8-13." Answer the following questions on a separate sheet of paper.
   - Why do the pH numbers decrease with each step?
   - Which pH solution is the most concentrated base?
   - What do you think is going to happen to the vials when you add universal indicator?

During the Lab

Part One: pH 1-7

Wear eye protection and gloves throughout this experiment! Wash your hands thoroughly when you are finished. Do not eat, drink, or chew anything while you are in the laboratory!

1. Use a pencil or indelible marker to label a screw top vial "pH 1." Measure 10 mL of 0.1M HCl in a graduated cylinder and pour it into the vial. *Don't screw the cap on yet.*

2. Measure 9 mL of distilled water in a graduated cylinder.

3. Use a pipet to add 1 mL of the "pH 1" solution (0.1M HCl) to the water, diluting the acid to 0.01M.

4. Pour this solution into another screw top vial and label it "pH 2." Screw the top tightly on the vial and gently shake to mix the contents. Unscrew top after mixing.

5. Rinse the graduated cylinder and pipet with distilled water.

6. Repeat steps 2-5, adding 1 mL of the previous pH solution to 9 mL of distilled water, pouring into a vial, labeling "pH 3," screwing on top, shaking gently to mix contents and unscrewing the top.

Vial (pH)	Contents
1	10 mL of 0.1M HCl
2	9 mL of distilled water + 1 mL from vial 1
3	9 mL of distilled water + 1 mL from vial 2
4	9 mL of distilled water + 1 mL from vial 3
5	9 mL of distilled water + 1 mL from vial 4
6	9 mL of distilled water + 1 mL from vial 5
7	10 mL of distilled water

7. Continue this process, diluting the solution in each vial by taking 1 mL of the previous solution (and the highest pH), adding to 9 mL of distilled water, pouring into a vial and labeling sequentially. Stop once you have six vials. (The last vial should be labeled "pH 6.")

   Remember to gently shake each vial to mix the contents before you take out 1 mL!
   Be sure to rinse out the graduated cylinder and pipet with distilled water after each measurement!

8. Now measure 10 mL of distilled water in the graduated cylinder and add to a vial. Label it "pH 7."

9. Use a clean pipet to add 10 drops of universal indicator to each vial. Gently shake to mix contents.

10. Now fill out the **Create Your Own pH Scale** data sheet.

Part Two: pH 8-13

Wear eye protection and gloves throughout this experiment! Wash your hands thoroughly when you are finished. Do not eat, drink, or chew anything while you are in the laboratory!

1. Use the pencil or indelible marker to label a screw top vial "pH 13." Measure 10 mL of 0.1M NaOH in a graduated cylinder and pour it into the vial. *Don't screw the cap on yet.*

2. Measure 9 mL of distilled water in a graduated cylinder.

3. Use a pipet to add 1 mL of the "pH 13" solution (0.1M NaOH) to the water, diluting the solution to .01M.

4. Pour this solution into another screw top vial and label it "pH 12." Screw the top on the vial and gently shake to mix the contents.

5. Rinse the graduated cylinder and pipet with distilled water.

6. Repeat step 2, adding 1 mL of the previous pH solution to 9 mL of distilled water, pouring into a vial, labeling "pH 11" and shaking gently to mix contents. Unscrew top after mixing.

7. Continue this process, diluting the solution in each vial by taking 1 mL of the previous solution (and the lowest pH number), adding to 9 mL of distilled water and pouring into a vial. **Note that the pH numbers decrease with each step.** Stop once you have six vials. (The last vial should be labeled "pH 8.")

   Remember to gently shake each vial to mix the contents before you take out 1 mL!

   Be sure to rinse out the graduated cylinder and pipet with distilled water after each measurement!

Vial (pH)	Contents
13	10 mL of 0.1M NaOH
12	9 mL of distilled water + 1 mL from vial 13
11	9 mL of distilled water + 1 mL from vial 12
10	9 mL of distilled water + 1 mL from vial 11
9	9 mL of distilled water + 1 mL from vial 10
8	9 mL of distilled water + 1 mL from vial 9

8. Use a clean pipet to add 10 drops of universal indicator to each vial. Gently shake to mix contents.

9. Now fill out the **Create Your Own pH Scale** data sheet.

Keep the pH scale you just created. You will need it for Investigation 2.

pH: The Power of Hydrogen

What do stomach enzymes, Coca-cola® and lemon juice have in common? All are acids. An acid is a corrosive solution that increases hydrogen-ion activity when dissolved in water and can be measured on a pH scale.

Did you know?

A mole is a unit of measurement used to count atoms.

For example, a dozen is a unit of measurement that equals 12 objects.

A mole is a unit of measurement that equals 6.022×10^{23} objects.

What does pH mean?

It's an abbreviation for "power of the hydrogen ion." The pH scale measures the concentration of hydrogen ions [H^+] within a solution in moles (mol) per liter.

The pH scale ranges from 0-14. The more hydrogen [H^+] ions and fewer hydroxide [OH^-] ions, the lower the pH number and the more acidic the solution (e.g., Coca-cola® with a pH of 2.5). The fewer hydrogen [H^+] ions and more hydroxide [OH^-] ions, the higher the pH number and the more basic it is (e.g., bleach with a pH of 13.0). A neutral substance of pH 7.0 (e.g., distilled water) has equal concentrations of hydrogen [H^+] and hydroxide [OH^-] ions.

What do earthquakes have to do with pH?

The pH scale and the Richter scale are logarithmic. An earthquake measuring 6.0 on the Richter scale is 10 times stronger than one measuring 5.0 on the scale. In chemistry, a solution with a pH of 5.0 is 10 times more acidic than a solution with a pH of 6.0. Why?

A standard logarithmic scale means that two adjacent values increase or decrease by a power of 10. The pH scale is a negative logarithmic scale, so a decrease in pH of 1 unit is actually a ten-fold increase in the amount of hydrogen ions. A solution with a pH of 5.0 is 100 times more acidic than a neutral substance of pH 7.0 and 1,000,000 times more acidic than pH 11.0!

	pH	[H^+]	[OH^-]
↑	14	1×10^{-14} M H^+	1×10^{0} M OH^-
	13	1×10^{-13} M H^+	1×10^{-1} M OH^-
	12	1×10^{-12} M H^+	1×10^{-2} M OH^-
increased	11	1×10^{-11} M H^+	1×10^{-3} M OH^-
basicity	10	1×10^{-10} M H^+	1×10^{-4} M OH^-
	9	1×10^{-9} M H^+	1×10^{-5} M OH^-
	8	1×10^{-8} M H^+	1×10^{-6} M OH^-
neutral	7	1×10^{-7} M H^+	1×10^{-7} M OH^-
	6	1×10^{-6} M H^+	1×10^{-8} M OH^-
	5	1×10^{-5} M H^+	1×10^{-9} M OH^-
increased	4	1×10^{-4} M H^+	1×10^{-10} M OH^-
acidity	3	1×10^{-3} M H^+	1×10^{-11} M OH^-
	2	1×10^{-2} M H^+	1×10^{-12} M OH^-
	1	1×10^{-1} M H^+	1×10^{-13} M OH^-
↓	0	1×10^{0} M H^+	1×10^{-14} M OH^-

What does pH mean for life?

Many biological systems are controlled by delicate pH systems. Human blood must stay between pH 7.35 and 7.45 in order for oxygen to be efficiently transferred from our lungs to our cells. A 0.4 pH unit change in our blood can result in death! Small changes in pH within organisms or their environments may result in large changes in the health of organisms and ecosystems.

Name:

Create Your Own pH Scale! Data Sheet

1. Fill in the chart below. Describe the color or use colored pencils to indicate the color of each vial in the "Color" column. Hint: Hold a white index card behind the vials to better observe colors.

Color (after adding indicator)	pH	Acid, Base or Neutral?	More $[H^+]$ or $[OH^-]$ ions?	Hydrogen Ion $[H^+]$ Concentration $[H^+]$ [mol/L]
	13.0			
	12.0			
	11.0			
	10.0			
	9.0			
	8.0			1×10^{-8}M H^+
	7.0			
	6.0			
	5.0			
	4.0			
	3.0			
	2.0			1×10^{-2}M H^+
	1.0			

2. The pH scale you created uses two diluted solutions to represent the pH scale.

   a. Is pH 1.0 or pH 6.0 a more concentrated acidic solution? Explain.

   b. Is pH 8.0 or pH 13.0 a more concentrated basic solution? Explain.

3. Stomach Enzymes: pH 2.3   Human Saliva: pH 6.5

   Which of the above has a greater concentration of hydrogen ions? Why?

4. Describe the relationship between pH and hydrogen ions.

5. pH 2 .0 1×10^{-2}M H^+ pH 8.0 1×10^{-8}M H^+

   How many times more acidic is a substance with a pH of 2.0 than a substance with a pH of 8.0?

Investigation 2
Ocean Acidification

Name:

Before the Lab

1. Predict the numerical pH of the ocean (1-14). Do you think it is acidic or basic? Why?
2. How do you think CO_2 affects the pH of the ocean?
3. Read "Ocean Acidification."

During the Lab

Part One: What Is the pH of the Ocean?

1. Use a graduated cylinder to measure 10 mL of seawater. Pour it into a screw top vial. Don't forget to label it. Use a clean pipet to add 10 drops of Universal Indicator to the vial. Gently shake to mix contents. Compare it to the pH scale you just created.
   - What is the approximate pH of your sample?
   - What is the most common pH of surface seawater (refer to "Ocean Acidification")?
   - If the pH of your sample is different, what might be the reasons?
2. Now use a graduated cylinder to measure 10 mL of distilled water. Pour it into a screw top vial and label it. Use a clean pipet to add 10 drops of Universal Indicator and shake gently. Compare it to the pH scale you just created.
   - What is the approximate pH of your sample?
   - How does the pH of the two samples compare?

Part Two: Effects of CO_2 on the Ocean

1. Blow up a large balloon and secure the opening with a twist tie. (Hint: Twist balloon neck before securing opening.)
2. Cut the end off of the bulb of a plastic pipet. Insert into the balloon neck.
3. Place the tip of the pipet in the seawater sample. Undo the twist tie and slowly release pressure on the balloon's neck.
4. Use a stopwatch to start timing as soon as the pressure is released and the solution begins bubbling. Stop timing as soon as the color changes. Compare it to the pH scale you just created. Record your data below.

   Time: Color: pH:

5. Repeat the procedure using the sample of distilled water. Record your data below.

Time: Color: pH:

6. Fill out the chart below.

Solution	Part One	Measured pH	Acid, base or neutral?	Part Two	pH (after adding CO_2)	Time (in seconds) for pH to change
Seawater						
Distilled water						

7. Compare the results of the distilled water and seawater. Why are they different? (Refer back to "Ocean Acidification.")

8. How does the balloon experiment model ocean absorption of CO_2?

Part Three: Effects of Changing pH on Marine Life

1. What do you think will happen to a calcium carbonate shell when added to acidic solution? Why?

2. Now try it! Measure 10mL of 0.1M HCl in a graduated cylinder. Pour it into a screw top vial. Add 10 drops of Universal Indicator. Add a stopper and gently shake to mix contents. Take the stopper off and add crushed shells ($CaCO_3$) to the vial.

   Do you think the pH will increase or decrease? Why?

   What happens to the calcium carbonate ($CaCO_3$)?

   How do you think this is similar to what is happening in the ocean? How is it different? Explain.

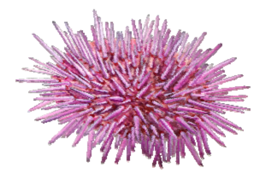
Ocean Acidification

Between 1751 and 1994, surface ocean pH is estimated to have decreased from approximately 8.2 to 8.1. That may not seem like much but it is a nearly 26% increase in acidity!

What is causing the ocean's pH to change?

The ocean is one of the world's largest carbon sinks. Each day it absorbs more than one million metric tons of carbon dioxide (CO_2) every hour! CO_2 is a naturally-occurring gas in our atmosphere that is integral in maintaining a healthy climate. However, additional CO_2 is released into the atmosphere from the burning of coal, oil and other fossil fuels. It is estimated that in the United States, approximately 15 million metric tons of CO_2 are emitted every day due to human activities. When CO_2 dissolves in the ocean, it increases the hydrogen-ion concentration.

A Massive Carbon Sink



The absorption of CO_2 by the ocean is a natural process. Chemically it looks like this:

Carbonate Buffering System: A System Out of Balance

Phase One

As the ocean absorbs carbon dioxide (CO_2) it bonds with water and forms carbonic acid (H_2CO_3).

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3}$$

Phase Two

Carbonic acid can dissociate into a hydrogen ion (H^+) and a bicarbonate ion (HCO_3^-).

$$\underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

Phase Three

The bicarbonate ion can further dissociate into a hydrogen ion (H^+) and a carbonate ion (CO_3^{2-}).

$$\underset{\text{bicarbonate ion}}{HCO_3^-} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{carbonate ion}}{CO_3^{2-}}$$

Seawater is more resistant to changes in pH than fresh water. This is because of a carbonate buffer system. Carbonate ions (CO_3^{2-}) tie up excess hydrogen ions when an acid is added and result in carbonic acid (H_2CO_3). The carbonic acid (H_2CO_3) donates hydrogen (H^+) ions when a base is added. This system regulates the pH of seawater. Depending on the addition of hydrogen ions, the reactions will reduce or increase carbonate ions to remain in equilibrium.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-} \rightleftharpoons \underset{\text{hydrogen ion}}{H^+} + \underset{\text{carbonate ion}}{CO_3^{2-}}$$

However, an excessive amount of hydrogen ions released into ocean waters (as with the absorption of excess atmospheric CO_2) causes the ocean to become more acidic and tips the delicate buffering system of the ocean.

The Effects on Marine Organisms

Carbonate ions (CO_3^{2-}) can bond with calcium ions (Ca^{2+}) to form the compound calcium carbonate ($CaCO_3$) which is utilized by marine organisms to build shells and skeletons. However, if there are excess hydrogen (H^+) ions, those ions will usually reunite with the carbonate ions to form more bicarbonate. This makes the carbonate (CO_3^{2-}) ions less available for shell– and skeleton-building animals. If ocean waters become too acidic, calcium carbonate structures may even begin to dissolve!