Does increased atmospheric carbon dioxide change the pH of water? Ocean Acidification in the Polar Regions

Overview

There is a plausible explanation for how carbon dioxide molecules could interact with water molecules thereby forming a solution where the carbon dioxide is the solute and water is the solvent (as it usually is). The weak inter-molecular attractive forces rely on the polarity of the water molecule and the high density of electrons at either end of the carbon dioxide molecule. The next piece of this is the formation of the carbonate ion a very stable polyatomic ion composed of 3 oxygen atoms, 1 carbon atom, and having a charge of –2 symbolized: CO32-. The reaction for this goes like this: CO2 + H20 –-> H2CO3 . It is the CO3 part of this that is the carbonate ion. The H2CO3 is known as carbonic acid (as in "the acid of carbonate"). Carbonic acid has a tendency to break up or "disassociate" into hydrogen ions (H+) and carbonate ions (CO32-). The equation for this is: H2CO3 –-> 2H+ + CO32-. In this equation there are two hydrogen ions formed for every one carbonate ion formed. The next reaction that takes place involves the H+ ions from the previous reaction and water molecules, abundant because all of this is taking place in a solution mostly made up of water. The reaction goes like this: H+ + H2O –-> H3O+. The H3O+ can be a rare species and it is called the hydronium ion. The amount of hydronium ions present in a solution will then dictate how acidic or basic a solution is.

The concentration of hydronium ions present in a solution dictates how acidic or basic a solution is. This is where the infamous pH scale comes in. It seems that chemists came up with the pH scale in order to confuse everyone as

Details

Lesson
ArcticAntarctic
Less than a week
Download, Share, and Remix
High school and Up

Materials

One Vernier (or other) CO2 Gas Sensors
One Vernier (or other) pH Sensor
Data collection computer to interface the above probes
A 12 oz can of soda water
0ne 400 ml beaker
One ring stand and 2 clamps
Molecular models (ball and stick) or drawn models of the carbon dioxide molecule and the water molecule. This will be used to explore the chemical reactions between the carbon dioxide and water molecules.

much as possible. Actually the intent was to simplify the whole acid base thing but one could argue it made it much harder to learn.

Chemists count molecules in a quantity called a "mole". For solutions we talk about moles of a particular molecule per 1 liter of a solution, so moles/liters or abbreviated mol/L. We can have 1 mole of H3O+ in 1 liter of solution which is considered to be very acidic. You would expect the pH number to be large to reflect the fact that it is very acidic. However, 1 mole of H3O+ in 1 liter of solution actually has a pH number of 0. Here is how it works: 1 mole of H3O+ in 1 liter of solution can also be written as 10^0 mol H3O+/L. A .1 mole of H3O+ in 1 liter of solution can be written as 10^-1 mol H3O+/L and has a pH of 1. A .001 mole of H3O+ in 1 liter of solution can be written as 10^-2 mol H+/L and has a pH of 2. The number in the exponent is the pH number with the negative sign removed. And that is why then the more acidic a solution, the lower the pH number and the higher the concentration (mol/L) of the H3O+ ions.

Since the pH scale is based on powers of ten each move from one pH number to the next represents a ten-fold change in the concentration of H3O+. BUT, the twist is that a 1 unit decrease in pH is a 10 fold increase in H3O+. So pH 0 is 10^0 or 1 mol/L H3O+ concentration. A pH 1 solution is 10^-1 or .1 mol/L which is 1/10 the concentration of the pH 0 solution. When we keep going with this, a pH 2 solution has a H3O+ concentration of 10^-2 mol/L or .01 mol/L and is 1/100 the concentration of the pH 0. So this keeps going. A pH 7 solution (sometimes called the neutral pH) has a H3O+ concentration of 10^-7 mol/L or .0000001 mol/L and is 1/10000000 the concentration of a pH 0 solution. Finally if we go to a pH 14 solution, the numbers just keep getting smaller. The H3O+ of a pH 14 solution is 10^-14 mol/L or .00000000000001 mol/L, really small. So to simplify all this and get rid of all those 0's we chemists use the 0, 1, 2....to represent those various concentration levels. The rule is as the numbers go up, the concentration of H3O+ goes down each by a factor of ten.

There is a relationship then between carbon dioxide and pH. Carbon dioxide can dissolve in water and then reacts with water to form carbonic acid. Since the acid then dissociates into carbonate ions and hydrogen ions and eventually forms H30+ ions, it follows that an increase in CO2 will cause a decrease in pH because the solution is getting more acidic. Since CO2 is a gas the only way to increase the concentration of CO2 dissolved in water is to first increase the concentration of CO2 in the air that is in contact with the solution. In chemistry speak we refer to

Standards

Next Generation Science Standards (NGSS)

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

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.

it as increasing the partial pressure of CO2 (pCO2) which is the pressure that the CO2 exerts if you were to separate it from all the other gasses in the air. This is the basics behind what is known as Ocean Acidification.

One of the driving forces behind all chemical systems is this idea of equilibrium or balance. Anytime there is a change in a chemical system, the system will shift to reestablish the equilibrium. The earth's oceans and atmosphere can be thought of as a huge chemical system that is in equilibrium. It has been well established that the oceans pH has been locked in at 8.1 which remember is a H3O+ concentration of 10^-8.1 mol/L or.0000000079 mol/L. We also know that historically (think Pre-Industrial Age) the earth's atmosphere has had a CO2 concentration hovering right around 280 parts per million (ppm). Beginning in the late 1950's consistent records of the concentration of CO2 have been kept and there has been a steady consistent increase observed. Today we are at 400 ppm. That increase in CO2 in the atmosphere has caused a shift in the equilibrium state and resulted in a change in the ocean's pH. That change ranges from .1 to .2 pH units all in the downward direction so that today most oceans pH range from 8.0 to 7.9. The explanation for this goes something like this: the increase in CO2 causes more CO2 to be dissolved in the oceans water which causes more carbonic acid to form which results in an increase in the amount of H3O+ which causes a change in pH in the downward direction. And the result: Ocean Acidification. So when you open a bottle of club soda what do you think happens to the pH as the club soda goes flat??

Objectives

At the conclusion of this lesson students should be able to incorporate the following understandings into their thinking about carbon dioxide and its relationship to ocean acidification:

1) As the atmospheric concentration of carbon dioxide above water increases, the acidity of the water will increase causing the pH to decrease.

2) Although carbon dioxide is nonpolar and water is polar, CO2 readily dissolves in water because it will react with water to form carbonic acid: a. CO2 + H20 ––> H2CO3

3) Carbonic acid will dissociate into hydrogen ions (H+) and carbonate ions (CO32-). The equation for this is: H2CO3 ––> 2H+ + CO32-

4) H+ ions from the previous reaction and water molecules, (abundant because all of this is taking place in a solution mostly made up of water) react to form the hydronium ion (H3O+): a. H+ + H2O ––> H3O+

5) The cold waters of the Arctic and Antarctic could see rapid increases in acidity because: a. CO2 is more soluble in cold water than warm water b. Loss of polar ice exposes more ocean surface to CO2.

Lesson Preparation

- Consider doing or reviewing the lesson entitled "How Does Polar Ice Coverage Effect the Carbon Dioxide Concentration of Polar Water Bodies?" as a precursor.
- Gather the materials listed for this experiment.

Procedure

- Set up the ring stand so that the sensors are positioned pointing downward and clamped (not too tightly) in the clamps.
- Position the 400 ml beaker under the sensors.
- Set up the computer so the sensor is interfaced according to manufacture directions and collecting data continuously. The experiment will run for at least 24 hours.
- Fill the beaker ¾ full with room temperature soda water.
- Position the CO2 sensors' tip even with the top edge of the beaker so it is suspended and centered over the beaker.
- Position the pH sensor by lowering it into the soda water.
- Begin collecting data with the computer.

After a 24 hour (or more) data collection period, students should process the data with the following questions being used as a guide:

1) What were the independent, dependent, and control variables in this experiment?

2) Did the concentration of carbon dioxide over the airspace of the soda water beaker change over time? If so describe the change.

3) Based on your observation of the carbon dioxide concentration over the soda water beaker, what could be inferred about the concentration of the carbon dioxide dissolved in the soda water?

4) Did the pH the soda water change over time? If so describe the change.

5) Based on your observation of the carbon dioxide concentration of the airspace over the soda water beaker, what could be inferred about the concentration of the carbon dioxide dissolved in the water?

6) If you were to plot the pH of the soda water versus the concentration of dissolved carbon dioxide in the soda water, what would the graph look like?

7) What relationship exists between the concentration of the dissolved carbon dioxide and pH?

8) What relationship exists between the concentration of dissolved carbon dioxide and the concentration of hydrogen ions in the solution?

9) Consider the reaction between carbon dioxide and water. Write a balanced chemical reaction that would show the synthesis product of this reaction. Name the product.

10) Starting with the product from item 8 above write the possible dissociation reactions that could take place. Would the products change the hydrogen ion concentration? If so in which direction?

11) If there were a 10% increase in dissolved carbon dioxide in a solution that is at pH 7, what would the percent change in hydrogen ion concentration be if we assume all of the CO2 reacts with water? What would the new pH be?

12) The worlds' oceans have experienced a decrease in pH from 8.1 to 8.0 in recent years. What percent change in hydrogen ion concentration does this represent? What could be the cause of this change?

13) Since the solubility of carbon dioxide increases as the temperature of the water it is dissolved in decreases, could this lead to greater or lesser ocean acidification in the waters of the Arctic and Antarctic?

Extension

How does the temperature affect the solubility of carbon dioxide and thereby the pH of a solution?

A similar experiment can be run by bubbling generated carbon dioxide gas through a water sample and measuring the rate of pH change. A chemical indicator such as universal indicator or a pH sensor can be used and a cold, room temperature and warm water sample can be investigated.

Resources

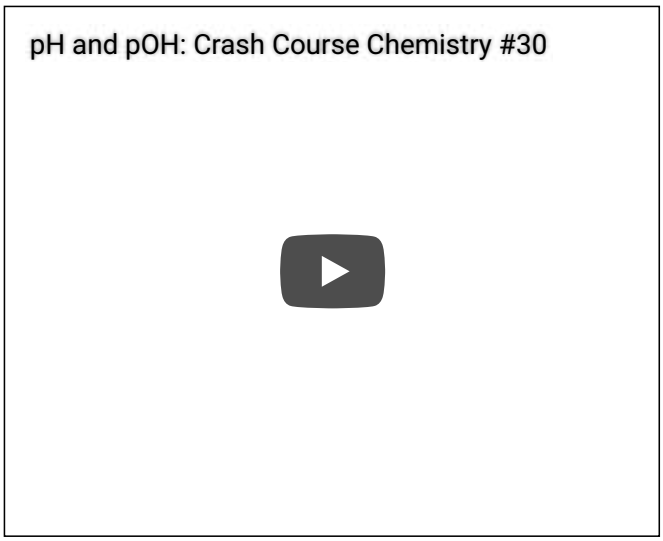
1) Vernier sensors available at: Vernier CO2 Gas Sensor and pH Sensor available at https://www.vernier.com/products/

2) PASCO CO2 Gas Sensor and pH Sensor available at https://www.pasco.com/products/probeware/sensors/index.cfm

3) Instructional videos:

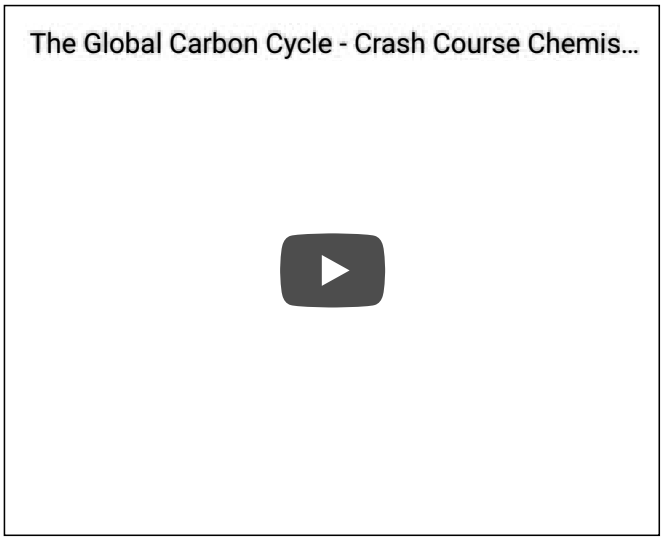
Acid Base reactions

Acid Base Scale: pH and pOH



Buffers

Global Carbon Cycle



4) Related Lesson Plan: "The Buffer Zone-Acid Base Chemistry in the World's Oceans" https://aamboceanservice.blob.core.windows.net/oceanservice-prod/educati...

Assessment

The following questions can be used to assess student learning:

1) Sketch a graph of the concentration of dissolved carbon dioxide in a solution and the pH of the solution.

2) CO_2 readily dissolves in water because: a. CO_2 is polar and water is nonpolar b. CO_2 is nonpolar and water is polar c. CO_2 reacts with water to form carbonic acid d. Carbonic acid decomposes to form CO_2 and water

3) As the concentration of CO_2 in a solution increases, the pH: a. Increases b. Decreases c. Does not change d. Can not be measured

4) In an aqueous solution, the dissociation of carbonic acid into hydrogen ions and carbonate ions: H_2CO_3 ––> $2H^+ + CO_3^{2-}$ will cause the pH of a solution to: a. Increase b. Decrease c. Stay the same

5) The change in the worlds oceans from a pH of 8.1 to a pH of 8.0 has resulted in a. Ocean Acidification b. Ocean Basification c. Ocean Stratification d. Ocean Renumeration

6) The recent change in the Earth's CO_2 concentration from 280 ppm to approximately 400 ppm is most closely linked to: a. An increase in UV radiation at the poles b. An increase in the world's oceans pH from 8.0 to 8.1 c. A decrease in the world's oceans pH from 8.1 to 8.0 d. No change in the pH of the world's oceans

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