NAME: ___________________________________

LABORATORY EXERCISE

Ocean Acidification: The Role of CO_2

In this lab we are going to examine the effects of temperature on oceanic carbon dioxide uptake from the atmosphere. **Show all calculations.**

PART 1 » DEMONSTRATION

Your instructor will demonstrate the movement of CO_2 from the atmosphere to the ocean using a bottle of water and a dye. This particular dye is yellow when the water is neutral or basic, and changes to red when the water becomes acidic. The demo will be run using freshwater and seawater. Watch the demonstration closely and answer the following questions:

QUESTION 1 » What color is the water initially, before CO_2 is added to the bottle?

QUESTION 2 » What happens to the freshwater when CO_2 is added? What about the seawater?

QUESTION 3 » What physical process controls the movement of CO_2 from the atmosphere to the water in the bottle?

QUESTION 4 » Is it possible to return the water in the bottle to the yellow color? How would you accomplish this?

PART 2 » ATMOSPHERIC CO_2

QUESTION 5 » Use Figure 1 below, which shows the atmospheric CO_2 concentration measured on Mauna Loa, to answer the following questions.

a » What is the current level of CO_2 in the atmosphere?

b » There are two lines on the graph. What process causes the red line to oscillate (move up and down)?

c » Describe the trend shown by the blue line. What anthropogenic activities are causing this trend?

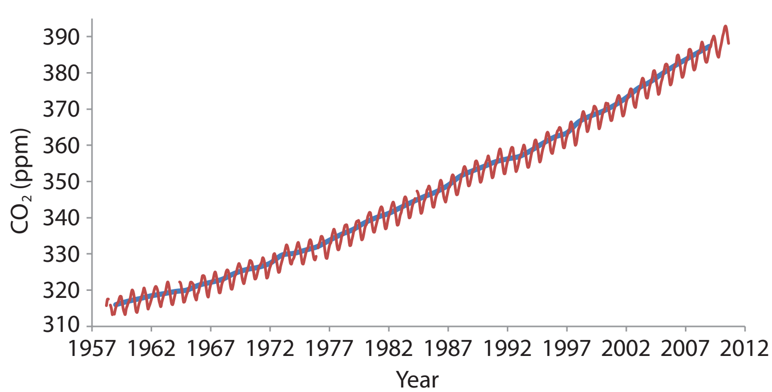

Figure 1. Atmospheric CO_2 record from Mauna Loa, Hawai'i. The blue line shows the annual average atmospheric CO_2 concentration in ppm. The red line indicates the monthly values showing the seasonal oscillation in atmospheric CO_2 concentration in ppm. *From http://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html*

PART 3 » THE DISSOLUTION OF CO_2 IN WATER

QUESTION 6 » Write out the chemical reaction that occurs when CO_2 dissolves into water. Draw a box around the species showing the most abundant form of CO_2 in seawater.

QUESTION 7 » How does the dissolution of CO_2 into water alter the pH of the water? Please explain.

PART 4 » THE IDEAL GAS LAW

The ideal gas law allows us to determine the amount of gas in a container. We will use a simplified version of that law to calculate how changes in the amount of CO_2 in the atmosphere affect the acidity of the ocean.

Instructor Note: This is one area in the lab where, depending on the level of students, the lab can be made more complicated. As noted in the article, the majority of CO_2 gas dissolving in water remains $CO_{2\,(aq)}$, with only 1 in 400 actually becoming HCO_3^- and releasing a proton in the process.

SUPPLIES

- » 2 1 L plastic bottles
- » 2 modified bottle caps
- » 500 mL graduated cylinder
- » Approximately 1 L of warm water (~50°C)
- » Approximately 1 L of cold water (~10°C)
- » Tire pressure gauge
- » pH paper (optional)

Note: We use an old percolator coffee pot to make hot water. This very hot water is then diluted with tap water to obtain the desired temperature. The cold water is created by putting ice in tap water.

CHEMISTRY REFRESHER

Scientists use moles to describe the number of molecules or atoms because if they were to list the actual number of molecules present in something, it would be an enormous figure!

1 mole of any element is equal to 6.02×10^{23} molecules

The ideal gas law ($PV = nRT$) can be used to calculate the number of moles of gas (O_2, CO_2, N_2, etc.) present in a particular volume. Units are as follows:

P = kPa V = liters n = mole R = J mole K^{-1} T = K

For Question 10, use a room temperature of 298 K (25°C) and pressure of 101.3 kPa (which equals 1 atm or 14.7 psi). R is a constant, R = 8.431 J mole K^{-1}.

Hint: You are calculating the moles of gas in the headspace of the bottle (not the entire bottle).

SHOW ALL CALCULATIONS*

QUESTION 8 » Fill the bottle all the way to the top with tap water and then pour the water into a graduated cylinder to determine the volume in liters. What is the total volume of your bottle in liters?

QUESTION 9 » For the next activity, you will be adding 0.8 L of water back in to your bottle. What volume of gas will remain in your bottle once the water has been added? (This volume is called the headspace.)

QUESTION 10 » Use the ideal gas law to calculate the number of moles of gas in the headspace of your bottle after 0.8 L of water has been added to the bottle.

QUESTION 11 » The atmosphere is approximately 0.038% CO_2, and the headspace of your bottle is filled with air from the room.

a » How many moles of CO_2 are present in the headspace of your bottle? (Show work)

b » If all of the CO_2 molecules in the headspace of your bottle (calculated above) dissolved into the water, how many moles of H^+ would be released into the water? Please explain. *Note: This is an unrealistic assumption because in reality the CO_2 would reach equilibrium between the headspace and the bottle.*

c » There are 1×10^{-7} moles of H^+ in 1 L of pure water. Your bottle contains 0.8 L of water, which means before any CO_2 dissolution into the water, your bottle of water contains 8×10^{-8} moles of H^+. How many moles of H^+ would be in your water bottle if all of the CO_2 from the headspace dissolved into the water? (Add the amount of H^+ already in the bottle with the moles of H^+ you calculated from the headspace in part b of this question.)

QUESTION 12 » $pH = -\log(\text{concentration of } H^+) = -\log(\text{moles } H^+/\text{liters } H_2O)$

a » Calculate the pH of pure water:

b » Calculate the pH of water if all of the CO_2 from the headspace of your bottle dissolved into the water (quantity from Question 11c):

PART 5 » CO_2 DISSOLUTION

For this part of the laboratory, we will be dissolving CO_2 into warm water and cold water. Before you begin this exercise, you will make a hypothesis, predicting what you think will happen.

Instructor Note: This write-up includes both the use of a pH meter/pH paper and hand calculations of pH, which makes the lab calculation heavy.

QUESTION 13 » *Hypothesis:* Write a hypothesis about how the dissolution of CO_2 will differ between the bottle with warm water and the bottle with cold water. How will this change the pH between the bottles?

Note: Once you have written your hypothesis you can continue with the steps below.

STEP 1 » Add 0.4 L of hot water and 0.4 L of tap water to one bottle.

STEP 2 » Add 0.8 L of cold water to another bottle.

STEP 3 » Loosely screw the bottle cap on each bottle.

STEP 4 » Squeeze each bottle so all air is removed (without spilling the water).

STEP 5 » Securely tighten the cap onto each bottle.

QUESTION 14 » After squeezing out all of the air from the bottles, how many moles of CO_2 are there in each of the bottles? Assume no CO_2 from the atmosphere has dissolved into the water.

QUESTION 15 » What is the pH of the water?

STEP 6 » Take the bottles to your TA for pressurization with pure CO_2 gas.

STEP 7 » After pressurization, you can use the tire gauge to measure the pressure inside the bottle.

Note: If you do not make an immediate seal on the valve with the pressure gauge, CO_2 will be lost from your bottle. Also, if you measure the pressure more than once, CO_2 will be lost from the bottle, and the pressure will drop.

QUESTION 16 » Initial pressure in bottle: ____ psi

QUESTION 17 » The pressure in the room is 14.7 psi (101 kPa). Why is CO_2 lost if an exact seal is not made on the bottle with the pressure gauge?

QUESTION 18 » As before, we can calculate the number of moles of CO_2 in the headspace of the bottle. Keep in mind that we doubled the pressure inside the bottle (from ~ 100 kPa to ~ 200 kPa), and therefore the amount of gas in the headspace is doubled. Using the ideal gas law, calculate how many moles of CO_2 are in the headspace of your bottle?

QUESTION 19 » Shake the bottle (point the valve away from your classmates in case it leaks any water).

a » What happened to the pressure inside of the bottle?

b » Is there a difference in the pressure between the bottles with warm and cold water?

c » Why did the pressure inside the bottle change?

QUESTION 20 » Now we will make a few assumptions about the amount of CO_2 that dissolved into each of the two bottles:

a » Assume that 40% of the CO_2 from the headspace dissolved into the warm water. How many moles of H^+ would be released into the water? What is the pH of the water?

b » Assume that 60% of the CO_2 from the headspace dissolved into the cold water. How many moles of H^+ were released into the water? What is the pH of the water?

QUESTION 21 » Reflect on your hypothesis. What did you learn?

Note: It is important to note that to produce the visible and rapid effect we used a much higher pressure of CO_2 in the bottle than exists in today's atmosphere. However, the same process that you observed between the headspace and water in the bottle is occurring naturally between the atmosphere and the ocean, but at a much slower and less visible rate.

PART 6 » YOUR CO_2 FOOTPRINT

Now that you understand how the pH of seawater changes as CO_2 is added to our atmosphere, we are going to look at how a few human activities affect the concentration of CO_2 in the atmosphere.

Conversions: 1 mole CO_2 = 44.01 g CO_2

Instructor Note: This section has numerous time-consuming calculations. To shorten the lab, split the questions below between different student groups and then share.

SHOW ALL CALCULATIONS*

QUESTION 22 » List three ways you increase the amount of CO_2 in the atmosphere. Hypothesize which activity releases the most CO_2 into the atmosphere.

QUESTION 23 » Every minute, we inhale O_2, and exhale CO_2, a processes called respiration. If you exhale 1 kg (1,000 g) of CO_2 each day, how many moles is that in one day? How many moles in one year?

Note: You can calculate your carbon footprint at: http://www.carbonfootprint.com/calculator.aspx

QUESTION 24 » Another source of CO_2 to the atmosphere is the combustion of fossil fuels (coal, gasoline, natural gas). Driving a car is probably the easiest to grasp, as you pay for gasoline by the gallon. The combustion of one gallon of gas releases 8.8 kg of CO_2.

a » Convert 8.8 kg of CO_2 to moles of CO_2.

b » Now let's look at how many moles of CO_2 are released per mile of driving.

i » A car that gets 15 mpg (6.4 km/liter) (large pickup truck)

ii » A car that gets 30 mpg (12.8 km/liter) (e.g., Honda Civic compact car)

iii » A car that gets 50 mpg (21.3 km/liter) (e.g., Toyota Prius hybrid)

c » If you drive a car 10 miles (16 km) each day, how many moles of CO_2 are you releasing into the atmosphere each year?

i » A car that gets 15 mpg (6.4 km/liter) (large pickup truck)

ii » A car that gets 30 mpg (12.8 km/liter) (e.g., Honda Civic compact car)

iii » A car that gets 50 mpg (21.3 km/liter) (e.g., Toyota Prius hybrid)

QUESTION 25 » Another less noticed source of CO_2 to the atmosphere happens when power is being generated. Even if you do not drive a car (or take the bus), you still contribute to CO_2 from this source. Electricity is measured in kilowatt hours (kWh), and oil is the major source of electricity in many areas. One gallon of oil produces 36 kWh of electricity, and 1 kW is equal to 1,000 watts (W).

a » You are familiar with light bulbs (the old fashioned kind, not the new ones). How many hours can a 100 W bulb burn with 1 gallon (3.8 liters) of oil?

b » Assume the light bulbs in the classroom are 40 W each. If class is 3 hours long, and there are 34 bulbs in the room, how much oil is burned to power all of them?

QUESTION 26 » In the United States, 18,810,000 barrels of oil are consumed every day.

1 barrel = 42 gallons = 159 liters

1 gallon of oil = 8.8 kg CO_2

a » Calculate how many moles of CO_2 are released into the atmosphere in one day.

b » How many moles of CO_2 are released into the atmosphere in one year?

c » How is the increased atmospheric input of CO_2 from humans going to affect the ocean?

QUESTION 27 » What human process from above contributes the most CO_2 to the environment?

PART 7 » SUMMARY

QUESTION 28 » If more infrared radiation is reflected back to Earth because of increased concentrations of greenhouse gases in the atmosphere, how will sea surface temperatures be affected?

QUESTION 29 » How does the anthropogenic input of CO_2 into the atmosphere affect the pH of the ocean?

QUESTION 30 » As sea surface waters warm, how will air-sea CO_2 exchange be altered? Will this alter the rate of CO_2 increase in the atmosphere?

QUESTION 31 » How might calcifying organisms, such as corals, Coccolithophores, and Foraminifera be affected by increased atmospheric CO_2 concentrations?

QUESTION 32 » Was today's laboratory exercise using the bottles a realistic demonstration of how the pH of the ocean will change if we continue to increase the concentration of CO_2 in the atmosphere? Think about the demo at the beginning of the lab. Why did the freshwater change color while the seawater remained yellow?