

ENV101 - LABORATORY 11:

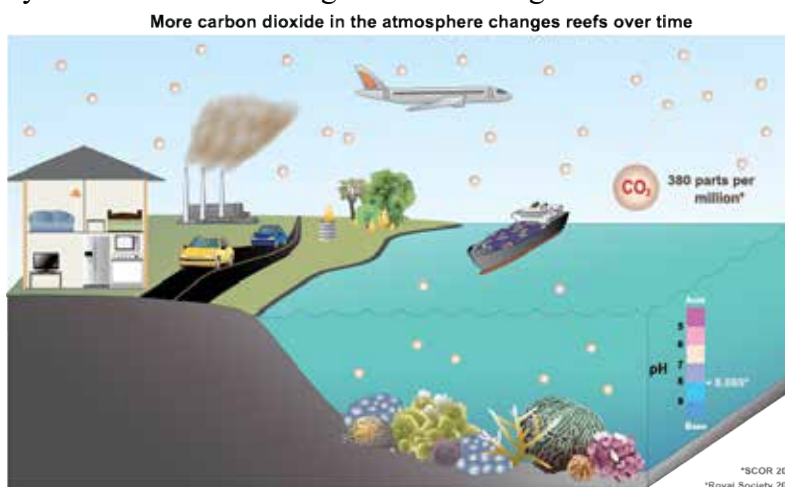
OCEAN ACIDIFICATION: WHAT IT IS & WHO IT AFFECTS?

BACKGROUND

Global climate change, in the form of increasing temperatures due to rapidly elevating atmospheric levels of greenhouse gases, is one of the most significant and pressing issues of our time. Average temperatures across the planet are rising at an unprecedented rate, and most scientists agree that a major contributing factor to these drastic changes is linked to anthropogenic-generated carbon, specifically in the form of carbon dioxide (CO₂). While CO₂ is a naturally occurring and biologically important gas, increased burning of fossil fuels and massive industrialization in the last century has contributed an atmospheric level of CO₂ that Earth has not experienced for at least 650,000 years². In fact, climate change caused by the emission of greenhouse gases is already having noticeable and measurable effects on our society today. A recent comprehensive report by the U.S. Global Change Research Program on the impact of climate change in the United States warns in part that global warming will lead to increased heat waves which will negatively affect agriculture and human health, drought especially in the Western United States, insect infestations, wildfires, sea level rise, and coastal flooding³.

Elevated atmospheric CO₂ is also threatening life in the world's oceans through a process called ***ocean acidification***.

The process of ocean acidification is the progressive decrease in the average pH of ocean waters caused by the excessive absorption of atmospheric CO₂. Over the past few centuries, approximately 50% of the CO₂ produced by humans has remained in the atmosphere, 20% has been taken up by terrestrial ecosystems such as tropical forests, while another 30% has been absorbed by the oceans. These numbers suggest that the effects of climate change would likely be much more severe if the oceans were not able to absorb CO₂ and act as a global buffer.



Unfortunately, the ability of Earth's oceans to absorb excess atmospheric CO_2 is finite and we are quickly approaching their buffering capacity limits.

Currently, the marine environment is undergoing a rapid change because of human activities drastically increasing atmospheric concentrations of CO_2 , that are being absorbed by the world's oceans. Between 1751 and 1994, surface ocean pH is estimated to have decreased from 8.25 to 8.14 (Jacobson, 2005), representing a ~30% increase in hydrogen ion concentrations. A reduction in oceanic pH heavily influences marine organisms that produce shells and skeletons through the process of calcification, which involves the precipitation of dissolved ions into CaCO_3 , referred to as calcium carbonate. Through the process of bio-mineralization, calcium carbonate is deposited within marine calcifying organisms and provides a physical structure for soft tissue to adhere to, in much the same way that bones provide structure for vertebrate organisms. When CO_2 is absorbed by the oceans, resulting in decreased pH, the saturation state of CaCO_3 is reduced, driving the dissolution of calcium carbonate within marine calcifiers, weakening the structures of these animals (Figure 1). Already, experimental work has found that ocean acidification negatively affects many species of marine calcifiers in all eco-regions, (National Research Council, 2011).

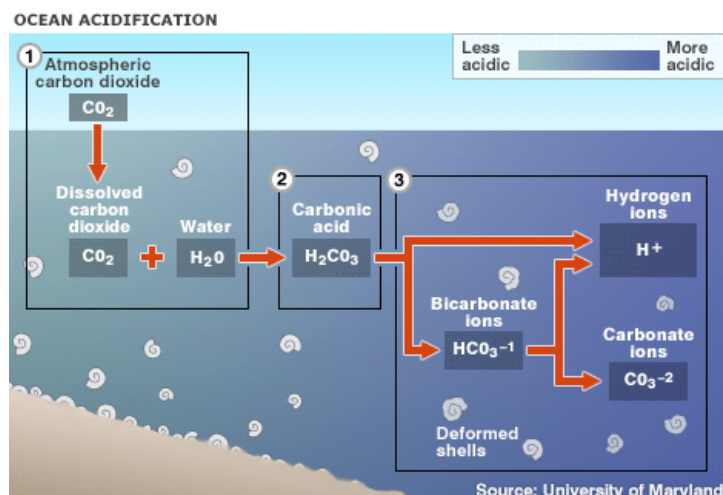
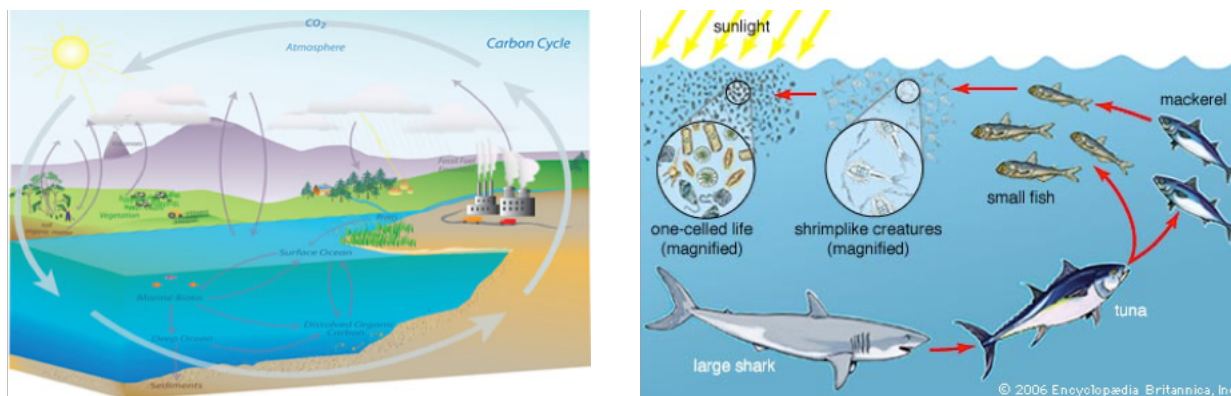


Figure 1: This figure depicts the basic carbonate chemistry involved in ocean acidification; as carbon dioxide (CO_2) is absorbed into seawater, carbonic acid (H_2CO_3) forms. Carbonic acid changes back and forth in equilibrium to bicarbonate (HCO_3^-) + H^+ and carbonate (CO_3^{2-}) + H^+ , lowering the pH due to higher concentrations of H^+ . Then additional carbon dioxide can react with the carbonate. This additional reaction consumes the carbonate availability in the oceans.

There are two major types of zooplankton (tiny drifting animals) that build shells made of calcium carbonate: *foraminifera* and *pteropods*. They may be small, but they are big players in the food webs of the ocean, as almost all larger life eats zooplankton or other animals that eat zooplankton. They are also critical to the marine carbon cycle - how carbon (as carbon dioxide and calcium carbonate) moves between air, land and sea (Figure 2). Oceans contain the greatest amount of actively cycled carbon in the world and are also very important in storing carbon.

When shelled zooplankton (as well as shelled phytoplankton) die and sink to the seafloor, they carry their calcium carbonate shells with them, which are deposited as rock or sediment and stored for the foreseeable future. This is an important way that carbon dioxide is removed from the atmosphere, slowing the rise in temperature caused by the greenhouse effect.



a. b.
Figure 2: a) basic carbon cycle showing both terrestrial and marine components; b) basic marine food web, whose primary producers are phytoplankton.

Ocean acidification could affect marine food webs and lead to substantial changes in commercial fish stocks, threatening protein supply and food security for millions of people as well as the multi-billion dollar fishing industry, worldwide. Coral reefs in the tropics provide fish habitat, generate billions of dollars annually in tourism, protect shorelines from erosion and flooding, and provide the foundation for tremendous biodiversity, equivalent to that found in tropical rain forests.

Some of the major impacts on these organisms go beyond adult shell-building, however. Mussels' *byssal* threads, with which they famously cling to rocks in the pounding surf, can not hold on to surfaces in acidic water. Meanwhile, oyster larvae fail to even begin growing their shells. Oyster larvae under go a massive growth spurt in their first 48 hours of life, building their shells quickly so they can start feeding. But the more acidic seawater eats away at their shells before they can form; this has already caused massive die-offs of shellfish in the U.S. Pacific Northwest. Not only is this an ecological issue, but also an economic issue for the local shellfish industry. Often lost in the discussions about the ecological effects ocean acidification are the impacts on local human populations. Not only from a standard economic measure, but in many cases coastal indigenous cultures are dependant up the bounty of the coastal environment and its health. For example, in the Pacific Northwest of the United States, shellfish are critically

important to Native American tribes. The possible impacts of reduced ocean productivity to the collapse of ecosystems is a vital consideration for humans around the world, everyone benefits from the sea.

Watch the following two Youtube videos.

Ocean Acidification Video 1: <https://youtu.be/fgBozLCGUHY>

Ocean Acidification and Biodiversity: <https://youtu.be/GL7qJYKzcsk>

EXPERIMENT 1: CHALK-ACID ACTIVITY

This experiment is intended to model how increased atmospheric CO₂ results in an acidic ocean environment, which can affect an animal's calcium carbonate structure. Chalk is made of limestone, a byproduct of the gradual accumulation of minute calcium carbonate plates shed from coccolithophores (*a single-celled marine flagellate that secretes a calcareous shell, forming an important constituent of the phytoplankton.*) over evolutionary time and models the “marine organism” in this experiment. To represent the “acidic ocean,” we will use a number of household items, including lemon juice, carbonated water, and vinegar. These solutions vary slightly in their relative acidity, and all can be used to compare the differing effects that variations in pH can have on the dissolution of the chalk.

First, identify the primary question we are addressing.

PRIMARY QUESTION: _____

Write out a clear hypothesis on how you think lowering the pH of the solution will affect the composition and mass of the chalk based on the reading above and your knowledge.

TESTABLE HYPOTHESIS: _____

Read over the procedures below so you are familiar with the overall experimental conditions and make predictions as to your primary results.

PREDICTED RESULTS: _____

PROCEDURE

1. Using the laboratory tape, label 5 beakers with the numbers 1-5, and the name of the solution to be tested (distilled water, Soda water, Tap water, White vinegar, Lemon juice).
2. Fill each of the beakers with 100 ml with the designated solution.
3. Use the pH testing strips to test the approximate pH of each solution using a plastic pipet and record the results in Table 1.
4. Collect five pieces of the pre-soaked chalk, and gently blot them dry.
5. For each piece of chalk: a) break into 4 even length pieces, b) weigh the four pieces together, c) and then record the weight in Table 2, before placing them in one of the solutions.
6. Place all the chalk in each of the selected solution at the same time and start a timer set for ten (10) minutes.
7. Gently stir the solutions occasionally.
8. After ten (10) minutes, carefully remove each piece of chalk using the provided forceps and carefully blot them — BE CAREFUL NOT TO MIX THEM UP — then weigh each group of four and record the result in Table 2.
9. Return the chalk back into the appropriate solution (Being careful not to mix them up) and reset the timer for ten (10) minutes. Remember to occasionally stir the beakers.
10. Retest the pH of the solution when returning the chalk and record the results in Table 1.
11. Repeat steps 6—10 three more times (until the tables are filled).
12. Once completed, rinse the equipment and beakers, remove the labels, and place the beakers on the drying rack.
13. Finally, calculate you total loss of mass, and convert to a percentage of you original mass.
14. Enter your data into the computer spreadsheet set up by your instructor on the main lab computer.

TABLE 1. RECORD pH OF SOLUTIONS .

Solution	Initial pH	pH 10 min	pH 20 min	pH 30 min	pH 40 min
1.					
2.					
3.					
4.					
5.					

TABLE 2. RECORD MASS OF CHALK (G).

Solution	Initial Chalk Mass	Chalk Mass 10 min	Chalk Mass 20 min	Chalk Mass 30 min	Chalk Mass 40 min	Total Decrease
1.						
2.						
3.						
4.						
5.						

Solutions List

1:Distilled Water (dH₂O) 2:Soda Water 3:White Vinegar 4:Lemon Juice*

Instead, I will provide group data for chalk mass from several previous classes, we will not address the pH changes here.

TABLE 3. CLASS DATA FOR TOTAL MASS CHANGE.

Group	Spring Water	Soda Water	White Vinegar	Lemon Juice
Group 1	7	9	14	5
Group 2	4.69	5.5	5.79	6.8
Group 3	0	3	8	3
Group 4	6	13	16	18
Group 5	4.71	3.01	6.21	9.61
Group 6	4	9	1	9
Group 1	7.23	8.65	9.66	9.94
Group 2	2	10	11	13
Group 3	8	13	14	4
Group 5	2.56	5.01	5.41	6.13
Group 6	5.16	3.73	11.66	5.33
Group 1	10.5	9.8	12	4.2
Group 2	3.95	6.25	6.32	4.6
Group 3	3.14	4.53	6.15	16.4
Group 4	2.06	1.41	4.4	5.85
Group 5	9	9	21	22
Group 6	5.3	0	5	4.8
Means				

HOMEWORK – ACTIVITY 1: QUESTIONS FOR ANALYSIS: CHALK EXPERIMENT

Calculate the means for solutions above, and then create a graph showing the class results for the change in chalk, then use those results to answer the following questions.

- 1) Which solution showed the greatest decrease in mass of the chalk?
- 2) Which solution showed the least decrease in mass of the chalk?
- 3) Assuming the mass of the chalk decreased, explain what was specifically happening to the chalk over the course of the experiment (review the introduction to the lab).
- 4) Which solution is the most relevant to the environmental problem discussed in this lab activity, and why.
- 5) What happened to the pH of the different solutions during the course of the experiment?
- 6) If a decrease in ocean pH led to a decrease in plankton growth, clearly explain how oceanic food chains would be impacted.
- 7) How would these impacts affect people here in the United States? (Think more than just food, but all that goes around its production and presentation.)
- 8) How would these impacts affect indigenous coastal communities here and in other parts of the world?
- 9) Are there other consumer products that might be impacted? What are they?
- 10) How would the loss of oceanic plankton affect the world's atmosphere in the long term?

ACTIVITY 2 – CO₂ INTERACTIONS WITH WATER

Carbon dioxide is a cellular respiration by-product produced by all living cells, and we produce it, too. It is part of the basic carbon cycle and will be used by photosynthetic organisms to produce simple sugars and O₂. When we breathe out, we are releasing tens of thousands parts per million (ppm) with each breath. This means billions of organisms can add up to billions of tons of CO₂. 100,000 vehicles means additional billions of tons of carbon going into the atmosphere, which directly interacts with the oceans of the world.

When carbon dioxide dissolves in water, some of the molecules combine directly with the water (H₂O) to form a new compound called carbonic acid (H₂CO₃). As more carbon dioxide dissolves into the water, the more carbonic acid gets produced, lowering the pH of the water. We will do a simple exercise that allows us to demonstrate the interaction between CO₂ and water it's consequences for acidity.

When we breath out, one of the gasses we release is carbon-dioxide. CO₂ is one of the waste products of cellular respiration that our body has to release. (Remember the yeast respiration lab, we were measuring the gas bubbles and they were full of CO₂.) In this exercise, you will breath out through a straw into a beaker of water to see if can change the acidity of the water. We will use the pH meters from the chalk experiment to measure the pH changes in the water in the beakers. Working as pairs, you will do it several times, using different amounts of water.

PROCEDURE

1. Place 50 ml of distilled water in your beaker.
2. Use the pH meter to measure the pH of the water in the beaker, enter this into Table 3 below.
3. Get a soda straw.
3. Set a timer/stopwatch to zero (watches or phones will work).
4. The student who will be blowing the bubbles must a) hold their breath for 5 seconds and then ——— b) slowly exhale though the straw, blowing bubbles into the water for 10 seconds. Then ——— stop at the end of the 10 seconds.
5. Measure the pH of the water and enter the result into Table 3 (trial 1).
6. Repeat steps 4 and 5 three more times (trials 2, 3, 4).
7. Pour out the water, rinse and dry the beaker, and now fill it with 100 ml of distilled water.
8. Repeat steps 2—6 with the new water, filling in the next column in Table 3.
9. Repeat the entire process one last time using 150 ml of distilled water.
10. Calculate the total change in pH (from start to last bubble event) for each column.
11. Enter your results into the excel file set up by your instructor on the classroom computer.

I will instead provide you with group data from previous Classes, below.

Table 3 – pH Change with bubble blowing.

Group	50 ml	100 ml	150 ml
Group 1	1.35	0.49	0.35
Group 2	0.78	0.75	0.42
Group 3	1.04	1.33	1.28
Group 4	1.43	1.12	1.04
Group 5	1.47	1.55	0.77
Group 1	1.05	0.24	0.11
Group 2	1.05	0.63	0.55
Group 3	0.9	0.58	0.74
Group 4	1.47	1.55	0.77
Group 5	1.17	1.62	1.45
Group 6	1.17	1.01	0.87
Group 1	1.11	0.33	0.37
Group 2	1.35	1.47	0.96
Group 3	1.2	0.75	0.85
Group 4	0.52	0.6	0.58
Means			

HOMEWORK – ACTIVITY 2: QUESTIONS FOR ANALYSIS

Calculate the means (averages) for each of the beakers, create an excel graph using the data (column graph) showing the results. Then answer the questions below

Questions:

- 1) In which water amount did the pH change the most?
- 2) In which water amount did the pH change the least?
- 3) Explain why is the water becoming more acidic the longer you blow bubbles?
- 4) Explain why the pH shift decreased with the increasing volume of solution.
- 5) How does this activity provide evidence that atmospheric CO₂ levels can change the pH of open water?
- 6) Explain how this experiment relates to the gradual pH change in the vast oceans.
- 7) These effects are occurring in freshwater lakes as well as the oceans, do you think freshwater systems are being affected faster or slower? (Carefully explain your response.).

ACTIVITY 3 – REAL SHELLS ANALYSIS

In the chalk experiment above, we used the compressed composite of calcium carbonate from ground up limestone. These products also have other byproducts binding the materials together, which may have affected the results. But what happens when you take real seashells and place them in acidic conditions like the ones we used above? The house-hold ‘acids’ we are using are significantly more acidic than the oceans get (hopefully), but they make the point of how carbonic acid affect the ability of calcium carbonate to hold together. And as discussed in the introduction to this lab, only a slight decrease in pH (increase in acidity) will be enough to affect the planktonic organisms of the oceans.

The goal of this activity is to investigate how changes in the external environment will affect marine organisms with calcium carbonate shells and skeletons. This has real world impacts, as actual shellfish records are already showing decreasing growth rates and weaker shells in areas with unusually acidic waters. The data table below (TABLE 4) contains real data from a simple experiment using seashells and white vinegar. The shells (gathered from local seafood restaurants and beaches) were rinsed, blotted dry, weighed, and numbered(*). They were then placed in buckets of white vinegar (batches of 5) and allowed to soak for one week increments. Then blotted, weighed, and returned to a fresh batch of vinegar. This was repeated for three weeks, the results are as follows. (* Numbers eroded away within a few days.)



TABLE 4 – SEASHELL EXPERIMENTAL RESULTS

Shell no.	Week 0	Week 1	Week 2	Week 3
1	18.29	14.74	12.33	12.33
2	14.74	10.35	9.50	8.93
3	10.06	4.68	1.84	1.70
4	42.95	34.44	34.30	2.72
5	56.98	52.16	44.65	44.08
6	4.96	13.89	11.06	8.65
7	3.54	1.13	0.71	0.14
8	9.92	8.36	7.23	7.09
9	136.79	87.60	60.10	58.12
10	39.83	29.20	29.06	23.53
11	17.58	6.66	6.52	2.83
12	4.96	2.27	0.99	0.85
13	32.74	26.08	25.94	19.28
14	13.47	10.06	9.21	9.07
15	16.44	14.12	13.78	13.32
16	30.62	22.82	22.25	22.11
17	33.31	24.66	19.70	19.56
18	18.71	16.58	15.45	15.45
19	45.08	35.44	30.33	30.19
20	37.28	31.47	26.93	26.79
Total mass				

HOMEWORK ACTIVITY 3: QUESTIONS FOR ANALYSIS: SEA SHELL DATA

Calculate the total mass for each column (week) and then graph the results for 1) total mass, and 2) for the four shells highlighted. Consider and compare the results and then answer the following questions.

1. Was the rate of mass loss constant from week to week (percentage of loss)? How did it vary?
2. Do all shells lose mass at the same rate? What factors might affect these patterns?
3. Do you think the impacts of these problems would be greater for young mollusks or older individuals? Explain your reasoning.
4. How might these problems affect local human populations? (think beyond immediate consumption)
5. Do you think this is also a problem around the Great Lakes or other large fresh-water bodies? Explain why or why not.
6. How do you think these issues would affect human populations in a broader context? (Away from our coasts. Internationally, how might other countries be affected by these issue (review some of the lecture/textbook materials)?)

PRACTICE GRAPHING SPACE