Ocean Acidification in a Cup

Ocean acidification is a problem that humans will have to deal with as we release more and more carbon dioxide into the atmosphere. This activity demonstrates how water can become acidic with the introduction of CO_2.

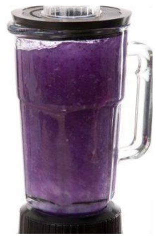
During the lab exercise, students will change the atmosphere to change the water below. Students will create a carbon dioxide–rich atmosphere in a cup and watch how it changes the water beneath it. This model of ocean-atmosphere interaction shows how carbon dioxide gas diffuses into water, causing the water to become more acidic. Ocean acidification is a change that can have big consequences.

Materials

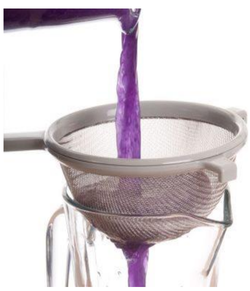
- Safety goggles
- An acid-base indicator such as bromothymol blue, diluted with water: 8 milliliters bromothymol blue (0.04% aqueous) to 1 liter of water (The acid-base indicator WILL BE MADE IN CLASS using purple cabbage. Instructions are provided below.)
- Two clear 10-oz plastic cups (the tall ones)
- Paper cups, 3-oz size (you'll only use one in the experiment, but keep a few extras at hand just in case)
- Masking tape
- Plain white paper
- Permanent marker
- Baking soda
- White vinegar
- Two Petri dishes to use as lids for the plastic cups
- Graduated cylinder or measuring spoons
- Gram scale or measuring spoons

Procedures

Creating an Acid-Base Indicator



Step #1: -Peel off three or four big cabbage leaves and put them in a blender filled one-half full with water. Blend the mixture on high until you have purple cabbage juice.



Step #2: -Pour the purplish cabbage liquid through a strainer to filter out all of the big chunks of cabbage. Save the liquid for the experiments to follow.

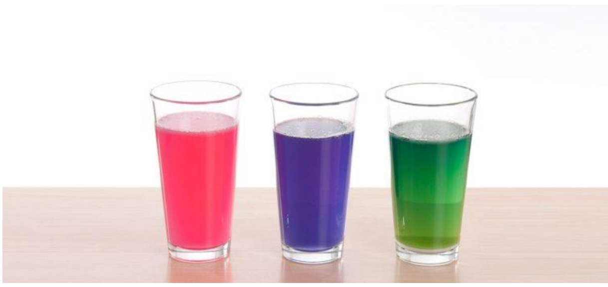
Step #3

Set out three glasses, side by side. Fill each glass three-fourths full with cabbage juice.

Step #4

Add a little vinegar to the first glass of cabbage juice. Stir with a spoon and notice the color change to red, which indicates that vinegar is classified as an acid. All acids will turn red when mixed with cabbage juice.

Step #5: - In the second glass, add a teaspoon of washing soda or laundry detergent. Notice how the liquid turns green, indicating that this chemical is a base.



Step #6: -Keep the two glasses of red (acid) and green (base) liquid for future reference. Fill the third glass of purple cabbage juice to show the color of a neutral solution.

HOW DOES IT WORK

Some substances are classified as either an acid or a base. Think of acids and bases as opposites—acids have a low pH and bases have a high pH. For reference, water (a neutral) has a pH of 7 on a scale of 0–14. Scientists can tell if a substance is an acid or a base by means of an indicator. An indicator is typically a chemical that changes color if it comes in contact with an acid or a base.

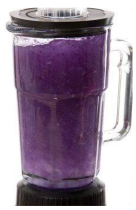
As you can see, **the purple cabbage juice turns red when it mixes with something acidic and turns green when it mixes with something basic.** Red cabbage juice is considered to be an indicator because it shows us something about the chemical composition of other substances.

What is it about cabbage that causes this to happen? Red cabbage contains a water-soluble pigment called anthocyanin that changes color when it is mixed with an acid or a base. The pigment turns red in acidic environments with a pH less than 7 and the pigment turns bluish-green in alkaline (basic) environments with a pH greater than 7.

Red cabbage is just one of many indicators that are available to scientists. Some indicators start out colorless and turn blue or pink, for example, when they mix with a base. If there is no color change at all, the substance that you are testing is probably neutral, just like water.

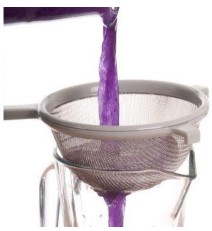
Creating an Acid-base Indicator for the Completion of the Lab Exercise

Once you have made the indicator for different pH levels, to complete the lab as shown below, students will need a solution that only corresponds to ONLY steps 1 & 2 of making the acid-base indicator. This solution will be used during the lab. Upon completion of the exercise below, students will then compare their results to the colors that indicate whether the solution is acidic or basic.



STEP #1

Peel off three or four big cabbage leaves and put them in a blender filled one-half full with water. Blend the mixture on high until you have purple cabbage juice.



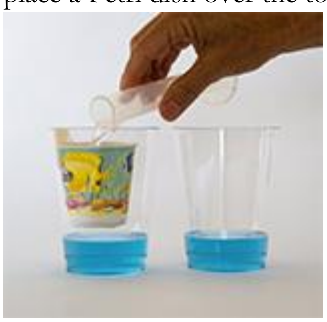
STEP #2

Pour the purplish cabbage liquid through a strainer to filter out all of the big chunks of cabbage. Save the liquid for the experiments to follow.

Procedures for Ocean Acidification

Assembly

1. Put on your safety goggles.
2. Pour 1 1/2 fluid ounces (40–50 mL) of acid-base indicator solution into each of the two clear plastic cups.
3. Add 1/2 teaspoon (2 grams) of baking soda to the paper cup.
4. Tape the paper cup inside one of the clear plastic cups containing the indicator solution so that the top of the paper cup is about 1/2 inch (roughly 1 centimeter) below the top of the plastic cup. Make sure the bottom of the paper cup is not touching the surface of the liquid in the plastic cup—you don't want the paper cut to get wet. The second plastic cup containing indicator solution will be your control.
5. Place both clear plastic cups onto a sheet of white paper and arrange another piece of white paper behind the cups as a backdrop (this makes it easier to see the change).
6. Carefully add 1 teaspoon (about 5-6 mL) of white vinegar to the paper cup containing the baking soda (image below). Be very careful not to spill any vinegar into the indicator solution. Immediately place a Petri dish over the top of each plastic cup.



To Do and Notice

7. Position yourself so you are at eye level with the surface of the indicator solution and look closely. What do you see? Where is the color change taking place?
8. After a few minutes have passed, you should notice a distinct color change at the surface of the liquid. As you continue to observe the reaction taking place, the liquid in other parts of the cup will also begin to change color.
    a. **Take a picture of your results and estimate the pH of the solution based on the change in color from when the cabbage pH indicator was created.**

What's Going On?

This activity illustrates how the diffusion of a gas into a liquid can cause ocean acidification. It also models part of the short-term carbon cycle—specifically the interaction between our atmosphere and the ocean's surface.

Mixing vinegar and baking soda together in the paper cup creates carbon dioxide gas (CO_2). The CO_2 gas then diffuses into the liquid below. When CO_2 gas diffuses into water, the following chemical reaction takes place and results in carbonic acid (H_2CO_3):

CO_2 (aq) + $H_2O \rightarrow H_2CO_3$

Carbonic acid dissociates into H^+ and HCO^{3-}. The increase in H^+ causes the solution to become more acidic.

Carbonic acid is a weak acid. Even so, the presence of this acid affects the pH of the solution. Thus, after a short time, the surface of the indicator solution changes color: from blue to yellow if you're using bromothymol blue or from purple to pale pink if you're using cabbage-juice indicator. This color change indicates a pH change caused by the diffusion of CO_2 gas into the liquid.

Outside of your paper cup, on a much larger scale, atmospheric CO_2 diffuses into the oceans.[1] Oceans are the primary regulator of atmospheric CO_2. Human activities such as burning fossil fuels and changes in land use have increased the amount of carbon dioxide (CO_2) in the atmosphere from 540 gigatons of carbon (Gt C) in pre-industrial times to 800 Gt C in 2015.

Current atmospheric CO_2 levels are greater than they have been in 800,000 years, and as a result, the fast carbon cycle is no longer in balance. From 1860 to 2009, the oceans absorbed an additional 150 Gt C from the atmosphere.

The CO_2 taken up by the oceans reduces oceanic pH through a series of chemical reactions. The first of these is the reaction you just observed: the creation of carbonic acid via the diffusion of CO_2 gas into water.[2]

In pre-industrial times, the pH of the oceans was close to 8.2. In 2005, it was approximately 8.1.[3] While the pH of the ocean is still basic, it is more acidic than it used to be. Since the pH scale is logarithmic, this means that the oceans are 30% more acidic now than they were in pre-Industrial times.[4]

Going Further

Diffusion goes both ways—from the atmosphere into a liquid and from a liquid into the atmosphere. This experiment shows passive diffusion: the CO_2 gas diffuses into the liquid. What experiment might you try in order to show that diffusion also goes the other way—from a liquid back into the atmosphere?

In March 2015, the global monthly average of the atmospheric concentration of CO_2 was around 400 parts per million (ppm), or 0.04%. It is a small amount, but it is increasing by more than 2 ppm every year due to the combustion of fossil fuels such as oil, gasoline, natural gas, and coal, as well as land-use changes such as deforestation.

Increases in the concentration of atmospheric CO_2 have led to increases in the concentration of CO_2 and other carbon-containing molecules in seawater. The CO_2 added to seawater reacts with the water molecules to form carbonic acid in a process known as ocean acidification. The oceans are absorbing about 25% of the CO2 we release into the atmosphere each year. Additionally, as more CO_2 gas enters the atmosphere, the atmosphere gets warmer, causing global temperatures to rise.

Ocean acidification is expected to impact ocean species to varying degrees. Photosynthetic algae and seagrasses may benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live (just like plants on land). On the other hand, studies have shown that a more acidic ocean environment has a dramatic effect on some calcifying species including oysters, shellfish, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled organisms are at risk, the entire food web may also be at risk.