Connecticut Energy Education
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LESSON 4: Where in the World is Carbon Dioxide?

Teacher Guide

From The National Center for Atmospheric Research and the UCAR Office of Programs (http://www.ucar.edu/learn/1_4_2_17t.htm)

Modified with permission from: Global Climates - Past, Present, and Future, S. Henderson, S. Holman, and L. Mortensen (Eds.), EPA Report No. EPA/600/R-93/126. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC, pg. 65 - 76.

The Greenhouse Effect: Global Climate Change, M. C. MacCracken, W.E. Pence, and S.J. Armstrong (Eds.), Lawrence Livermore National Laboratory, Department of Energy, Livermore.

In this multi-part activity, students will set up experiments to help them better understand the atmospheric portion of the carbon cycle.

Background

Carbon dioxide (CO_2) provides the bubble in your soda pop and the "rise" in your baked goods. But it is also a very significant greenhouse gas. Carbon dioxide is important in maintaining the earth's average temperature of about 15°C (59°F). The CO_2 traps infrared energy emitted from the earth's surface and warms the atmosphere. Without water vapor, CO_2, and methane (the three most important naturally produced greenhouse gases), the earth's surface would be about -18°C (0°F). At this temperature, it is doubtful that complex life as we know it would ever have evolved.

Where does CO_2 come from? Plants and animals give it off when they extract energy from their food during cellular respiration. Carbon dioxide bubbles out of the earth in soda springs, explodes out of volcanoes, and is released when organic matter burns (such as during forest fires).

- Anything that releases CO_2 into the atmosphere (living, dead, or non-living) is considered a **source**
- Anything that absorbs and holds CO_2 from the air or water is considered a **sink** (because, like a sink in your home, it acts as a "holding reservoir")

Over geologic time, CO_2 sources and sinks generally balance. In today's atmosphere, however, CO_2 levels are climbing in a dramatic and easily measurable fashion, providing evidence that there are now more CO_2 sources than sinks.

What are the sources for this 'extra' CO_2 **?** Human activities are thought to be primarily responsible for the observed increases. Of the human sources of CO_2 :

- Fossil fuel combustion accounts for 65%
- Deforestation (CO_2 released from trees that are cut and burned or left to decay) accounts for 33%
- The by-products of cement production account for the remaining 2%

There are natural sources of CO_2 as well. Plants and animals give off CO_2 while alive and respiring and when dead and decaying (bacteria that consume the dead bodies respire too, after all). Carbonate rocks contain CO_2 that can be released by exposure to acid and/or weathering. Certain naturally carbonated spring waters (for example, Perrier water) contain CO_2 because the water has passed though carbonate rocks on its way to the surface. Volcanoes are also a source of CO_2 . However, these geological sources are insignificant when compared to the human sources.

Plants (both terrestrial plants and marine phytoplankton) are the **most important carbon sinks**, taking up vast quantities of CO_2 through the process of photosynthesis. To a lesser extent, atmospheric CO_2 can also be dissolved directly into ocean waters and thereby be removed from the atmosphere. While plants also release CO_2 through the process of respiration, on a global, annual basis, the amount of CO_2 taken up by plants through photosynthesis and released through respiration approximately balances out. Thus, the CO_2 released from human activities is truly the 'extra' CO_2.

Scientists typically monitor the concentration of CO_2 in atmospheric samples by using sensitive devices called infrared gas analyzers. These devices pass a beam of infrared (IR) light through a sample of gas. The amount of IR that reaches a detector on the other side can be used to determine the amount of CO_2 in the sample. A worldwide network of CO_2 monitoring stations currently tracks the earth's rising CO_2 levels.

Carbon dioxide has another characteristic that enables students to detect CO_2 themselves. When dissolved in water, carbon dioxide forms a weak acid, called carbonic acid. The chemical bromothymol blue (BTB) is a sensitive indicator of the presence of acid. When gas containing CO_2 is bubbled through a BTB solution, carbonic acid forms and the indicator turns from dark blue to green, yellow, or very pale yellow depending on the CO_2 concentration (lighter colors mean higher concentrations).

This activity has multiple parts:

- In Part 1, students will gain experience in detecting CO_2 through the BTB reaction by using a pure CO_2 gas made from the reaction of baking soda and vinegar

- In Part 2, students will collect and detect relative CO_2 concentrations from a number of natural and human sources
- In Part 3, students will use a simple titration procedure to quantify the amounts of CO_2 that they collected

Note: For the activity to be most effective, students should have a working knowledge of the carbon cycle. Activity 15 provides a good overview of the cycle.

Learning Goals

1. Students will be able to explain the concept of 'sources' and 'sinks' as they relate to CO_2.
2. Students will understand the use of an indicator solution (BTB) to reveal the presence of CO_2.
3. Students will understand the qualitative differences between animal and fossil fuel sources of global CO_2.

Alignment to National Standards

National Science Education Standards

- Earth and Space Science, Structure of the Earth System, Grades 5 to 8, pg. 160, Item #11: "Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere, producing some types of rocks, and contributing to the weathering of rocks."
- Earth and Space Science, Geochemical Cycles, Grades 9 to 12, pg. 189, Item #2: "Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life."
- Science in Personal and Social Perspectives, Environmental Quality, Grades 9 to 12, pg. 198, Item #2: "Material from human societies affects both physical and chemical cycles of the earth."

Benchmarks for Science Literacy, Project 2061, AAAS

- The Physical Setting, Processes That Shape the Earth, Grades 6 to 8, pg. 73, Item #7. "Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed the earth's land, oceans, and atmosphere. Some of these changes have decreased the capacity of the environment to support some life forms."

Grade Level/Time

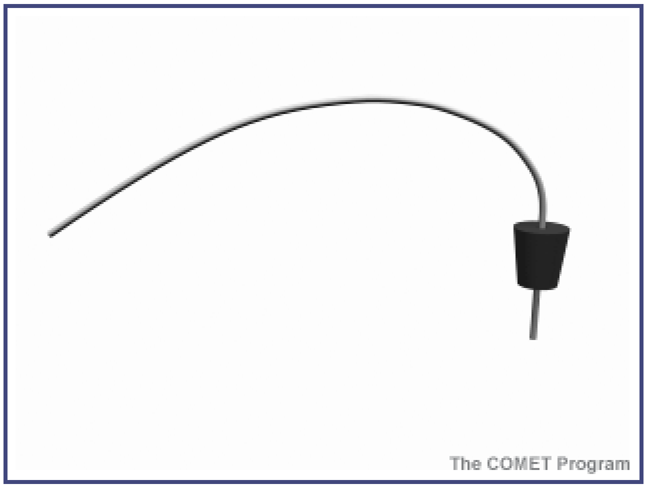
- **Grade level:** 6 to 10
- **Time:**
  - Materials preparation: 20 minutes
  - Introduction: 20 minutes
  - Part 1 activity: 25 minutes
  - Part 2 activity: 30 minutes
  - Part 3 activity: 20 minutes
  - Discussion & review: 30 minutes

Materials

For each two-student team

- Test tube rack
- Six test tubes

- One hole stopper with tubing attached



- Baking soda
- Vinegar
- One-inch square of aluminum foil
- Cotton balls
- Bottle of BTB working solution
- Air pump (bicycle pump or sportsball pump will work)
- Squirt bottle of dilute ammonia
- Masking tape
- Duct tape
- Three balloons (different colors)
- Markers
- Balloon-size template (directions below)
- Three straws
- Pipette or eye dropper
- Ten twist ties

- Newspapers
- Student instructions and data charts (in student guide)

Procedure

This activity requires significant preparation. This section addresses teacher preparation only. Detailed procedural instructions for the three parts of the activity are in the student guide. It is strongly suggested that teachers read the student guide prior to implementing this activity.

PART 1: DETECTING CARBON DIOXIDE GAS

BTB is available in either concentrated liquid or powdered form. Do the following to prepare the BTB solution.

- If you're using the liquid form
  - Fill a gallon bottle nine-tenths full with tap water and add BTB until the solution is a deep, blue color (this is the working solution).
- If you're using powdered BTB
  - Measure 0.5 grams of dry BTB into 500 ml of tap water. This will provide a 0.1% stock solution.
  - To prepare the working solution, mix 1 part stock solution with 20 parts tap water.

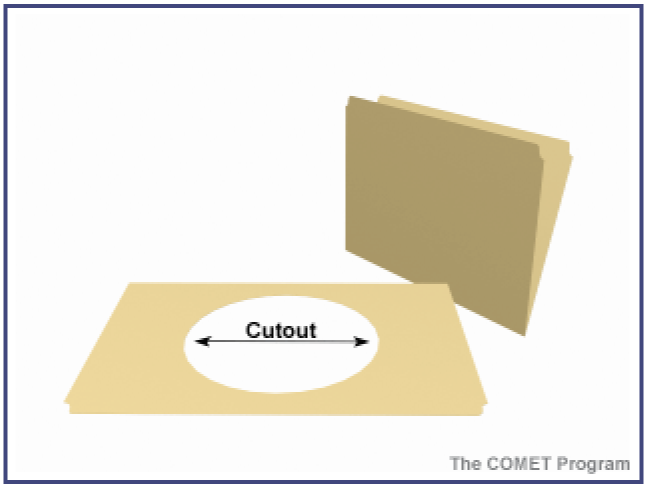
One liter of working solution should serve a class of 30 students, in two-person teams.

In Part 1, the students will conduct an experiment designed to detect the presence of CO_2. When combined, baking soda and vinegar produce pure CO_2. In this experiment, the BTB will dramatically change color (from bright blue to yellow) when introduced to the CO_2. This basic experiment will form the basis of the experiments to follow.

PART 2: COLLECTING SAMPLES OF CARBON DIOXIDE FROM VARIOUS SOURCES (AIR, ANIMALS, AND FOSSIL FUELS)

The students will analyze the CO_2 from **car exhaust** (which will represent fossil fuel), **their own breath** (representing animals), and **the outside air** by bubbling a known amount of each gas though a standard volume of BTB. They will first simply compare how the different sources change the color of the BTB solution as they did for pure CO_2 in Part 1.

To make a meaningful comparison, it is important that students collect equal volumes of gases. We suggest using rubber balloons blown up to the same diameter from each source as collectors. To do this, make a simple balloon diameter template with a piece of cardboard or half of a manila folder. Draw a circle about 7.5 cm in diameter in the middle. Cut out the circle and discard, saving the frame for use as a template.



You will need one of these templates for each group of students. As they collect samples, the students can use these to make sure that the samples are of approximately equal volumes. The templates can be re-used.

A. Automobile exhaust collection

Important note: Teachers should provide students with balloons full of car exhaust. It is not recommended that students participate in filling the balloons with car exhaust. An adult assistant (or two) is necessary, however.

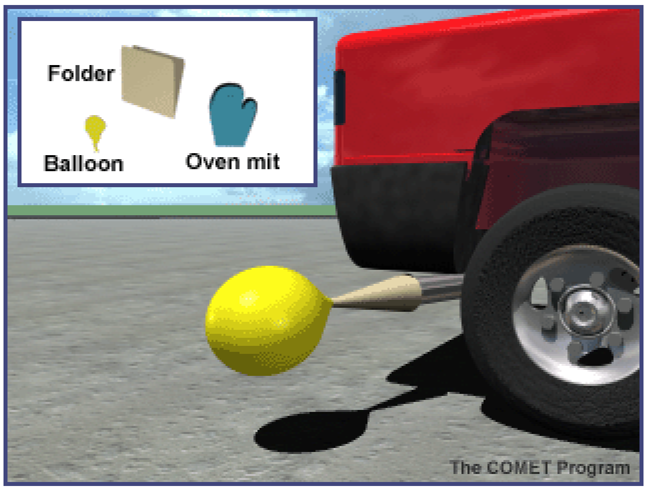
Materials needed for collecting car exhaust:

- Manila folder
- Roll of duct tape
- Pair of heat resistant oven mitts
- Balloons (8 or 10-inch diameter)

Procedure:

1. Blow up and allow the balloons to deflate. This will stretch the rubber and make them easier to fill with the relatively low-pressure exhaust.

2. Prepare a cone to collect the car exhaust by rolling up a manila folder lengthwise. One end must be larger than the opening for the car's tail pipe and the other end must be small enough for the balloon to fit over it.



   Use plenty of tape to hold the cone in shape and to make the sides of the cone fairly airtight. Note: the paper funnel will work for several fillings without burning. DO NOT use a plastic funnel. As the exhaust pipe heats up, the plastic may melt. You may use a metal funnel, but be VERY careful to avoid any skin contact with the hot metal.

3. Have an assistant turn on the car (make sure brake is on).

4. Put the balloon on the small end of the cone.

5. Using the heat resistant mitts, approach the exhaust pipe from the side. Place the large end of the cone over the tail pipe. Use the gloved hand to help form a seal between the cone and the exhaust pipe. DO NOT BREATHE THE EXHAUST. The balloon should fill quickly; if not, have your assistant step lightly on the accelerator.

6. When the balloon is filled, have an assistant use a twist tie or two to tightly seal the balloon. Do this by twisting the neck several times and doubling it over once, then place the twist tie around the constricted area.

7. You will want to have at least one balloon for each group of students. It is useful to prepare a few extra filled balloons.

B. Animal carbon dioxide collection

Students will fill up balloons with their own exhalations according to the instructions in the student guide. Emphasize to the students that they should hold air in their lungs for a few moments to allow plenty of exchange between O_2 being absorbed and O_2 being released in their lungs. Breaths that are too rapid will contain less CO_2 than normal exhalations.

C. Outside air collection

Students will collect outside air using an air pump (or bicycle or sportsball pump) to blow up a balloon. The sample collection must be done out-of-doors as inside air can be CO_2 enriched from breath.

At this point, your student teams will each have three balloons, one of car exhaust, one of their own breath, and one of outside air. They will bubble the gases through a BTB solution in test tubes, observing the color changes, according to the student directions. They should clearly observe the rapid and dramatic change with the car exhaust, the less significant change with their own breath, and the minor change with room air. The students will save these test tubes for Part 3.

PART 3: QUANTIFYING CARBON DIOXIDE

As CO_2 is bubbled through a BTB solution, it reacts with the water to form carbonic acid. The more CO_2 in the gas, the more acid is formed. As the pH of the solution goes down (becomes more acid), the BTB changes from blue to green to yellow. In order to measure (approximately) how much CO_2 actually reacted with the solution, we can use a procedure called 'titration.'

To do this titration, we add small volumes of a basic (high pH) solution (such as household ammonia) to the BTB mixture and record how much of this solution it takes to make the BTB return to its original blue color. The more CO_2 that was bubbled through the BTB solution, the more ammonia will be required to restore the original color.

Students will be provided with dropper bottles of ammonia and will be instructed to slowly and carefully, drop-by-drop, add ammonia to the tubes, until the original color returns. In this way they can compare CO_2 content of the sources they tested.

Assessment Ideas

In this activity, the students have examined several sources of CO_2. Ask them the following questions:

- If you wished to reduce the amount of CO_2 increase in the atmosphere, which source would be most important to control? Explain why.
- Would there be problems with such controls? If so, what might they be?

Modifications for Alternative Learners

- Use appropriate pairing strategies to pair students with difficulty following complex directions with those who have no such difficulty.
- Students with poor fine motor skills may need assistance in handling the balloons.

When you're finished with the activity, click on To Student Guide or Back to Activities List at the top of the page.

Where in the World is Carbon Dioxide?

Carbon dioxide (CO_2) provides the bubble in your soda pop and the "rise" in your baked goods. But it is also a very significant greenhouse gas. CO_2 is important in maintaining the earth's average temperature of about 15°C (59°F). The CO_2 traps infrared energy emitted from the earth's surface and warms the atmosphere. Without water vapor, CO_2 , and methane (the three most important naturally produced greenhouse gases), the earth's surface would be about -18°C (0°F). At this temperature, it is doubtful that complex life as we know it would ever have evolved.

Where does CO_2 come from? Plants and animals give it off when they extract energy from their food during cellular respiration. CO_2 bubbles out of the earth in soda springs, explodes out of volcanoes, and is released when organic matter burns (such as during forest fires).

- Anything that releases CO_2 into the atmosphere (living, dead, or non-living) is considered a source.
- Anything that absorbs and holds CO_2 from the air or water is considered a sink (because, like a sink in your home, it acts as a "holding reservoir").

In this multiple-part activity, you will explore various sources of carbon dioxide (CO_2) using the chemical indicator bromothymol blue (BTB).

- Part 1: You will detect CO_2 through the BTB reaction by using a pure CO_2 gas made from the reaction of baking soda and vinegar.
- Part 2: You will collect and detect relative CO_2 concentrations from a number of natural and human sources.
- Part 3: You will use a simple titration procedure to quantify the amounts of CO_2 that you collected.

If you're not using a laboratory table, cover your desk with newspapers!

PART 1

Use a chemical indicator (bromothymol blue - BTB) to detect the presence of CO_2.

Work in teams of two.

Materials

Gather three test tubes, a test tube rack, a test tube stopper with a length of tubing attached, a length of masking tape, BTB solution, vinegar, baking soda, a cotton ball, and the data chart.

Data Chart					
Sample code	**Sample source**	**Starting color of liquid in tube**	**Color after treatment**	**Rank (1 = most acid)**	**Number of drops to return to blue**
A					
B					
C					
D					

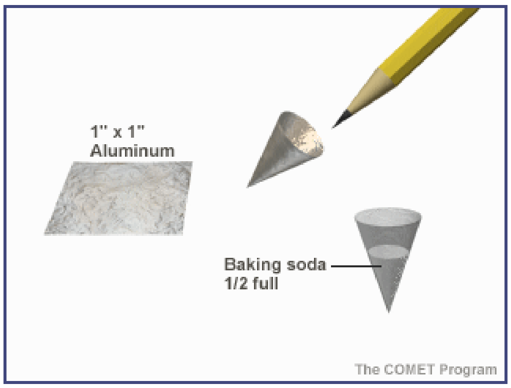
Procedure

1. Use a small piece of masking tape to label two of the test tubes A and B (a third will be unlabeled). Fill tubes A and B approximately 1/3 full with the BTB solution.

2. Record the color of the solution in test tubes A and B on the data chart. Tube A will be the control, tube B will be the treatment. Place the tubes in the rack.

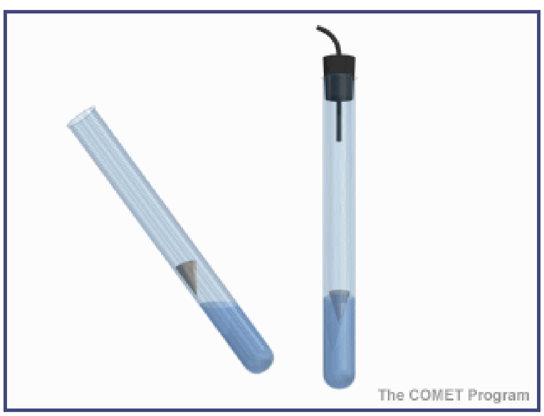
3. Fill the unlabeled tube approximately 1/4 full of vinegar.

4. Using the foil, make a small "boat" for the baking soda - fill 1/2 full of baking soda.



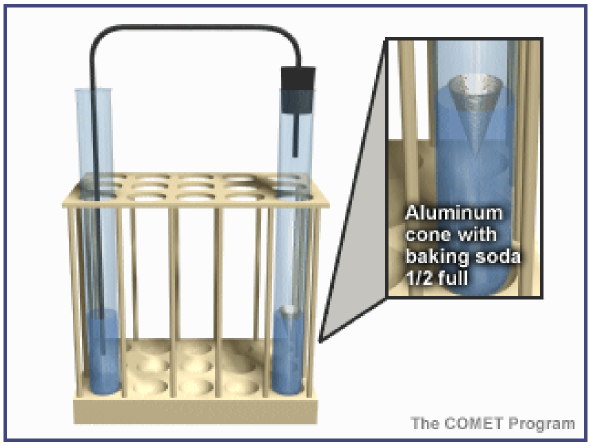
The 'boat' should be small enough to easily fit into the test tube and float on the vinegar.

5. Carefully slide the foil boat inside the unlabeled vinegar test tube (it is useful to tilt the tube at an angle to accomplish this)



6. Plug the tube with the stopper and tubing.

7. Place the free end of the tubing in tube B, making sure the end of the tubing reaches the bottom of the tube.



8. Place a cotton ball into the neck of Tube B.

9. Mix the vinegar and soda together by GENTLY swirling the tube from side-to-side. Don't shake it upside down! Gas bubbles will begin to bubble rapidly out of the tubing into the BTB solution in tube B.

10. After a minute or so, note the color of tubes A and B on the data chart.

Keep test tubes A and B for Parts 2 and 3 of this activity.

Observations and Questions

1. Is there a difference in color between tubes A and B?

2. What was the role of tube A in this experiment?

3. Why might an indicator like BTB be useful in scientific experimentation?

PART 2

In this part, you will collect samples of CO_2 from various sources (air, animals, and fossil fuel). Your teacher will provide the fossil fuel sample. Use a different colored balloon for each sample. Note which color balloon contains which sample by writing on the balloon with a marker. Use the balloon template provided to make sure all of your balloon samples are approximately the same size.

Work in teams of two.

Materials

Begin by collecting two empty balloons, one balloon full of car exhaust (the fossil fuel sample from the teacher), three test tubes, a test tube rack, a supply of BTB, a balloon size template, three straws, and three cotton balls.

Preparation

Outside Air (Sample C)

1. Blow up one of the balloons to stretch out the rubber.
2. Using the pump, fill the balloon with outside air until its circumference is the same size as the balloon template.
3. Secure the balloon with a twist tie. It is important to tie very tightly or use two ties.
4. Label this 'Balloon C.'

Animals (Sample D)

1. Blow up the second balloon to stretch out the rubber.
2. Blow up the balloon once more, using your breath, until its circumference is the same size as the template.
3. Secure the balloon with a twist tie (or two).
4. Label this 'Balloon D.'

Fossil Fuels (Sample E)

Your teacher will provide you with a balloon filled with car exhaust. You will probably need to let some of the air out of the balloon to size it to the template. Do this carefully. BE VERY CAREFUL NOT TO INHALE THE EXHAUST.

Label this 'Balloon E.'

After you have collected the samples, fill out the column on the data chart asking where the sample is from.

Procedure

To detect the CO_2 in each of the three samples, you will bubble the gases through a BTB solution as you did in Part 1.

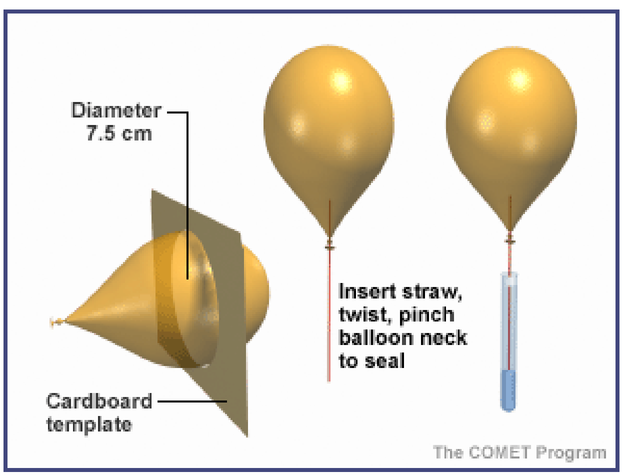
1. Place three empty test tubes in the test tube rack.

2. Using masking tape and a marker, label each test tube (C, D, and E).

3. Fill each of the empty test tubes approximately 1/3 full of BTB. You may want to use the funnel to make this task easier.

4. Begin with the outside air sample (Balloon C). Insert the straw inside the neck of Balloon C and secure it with a twist tie. Do not remove the first twist tie (holding the balloon closed) at this time.

5. Insert the other end of the straw into the BTB solution in test tube C. Insert a cotton ball into the top of the test tube to help hold the straw in place.



6. Gently release air from the balloon by slowly untwisting the neck. Allow the air to bubble out at a steady rate until the balloon is empty. BE VERY CAREFUL TO ALLOW A SLOW AND STEADY GAS RELEASE.

7. Observe the color change (if any) and compare the color to CONTROL test tube A (From Part 1). Record your observations on the data chart.

8. Repeat steps 4 to 8 for each of the remaining balloons.

9. Compare the results of the test tubes. Arrange the test tubes in order by color (yellow to blue). Hint: It may be useful to hold a blank sheet of white paper behind the test tubes to better observe color differences. Record your observations.

10. Keep the samples for part three below.

Observations and Questions

See the end of Part 3.

PART 3

In this part, you'll determine the relative concentrations of CO_2 from samples collected in Parts 1 and 2.

Hint: Make sure your test tubes have equal amounts of liquid solution (some may have bubbled out). A pipette or eye dropper can be used to remove excess liquid.

Materials

You should already have five test tubes, labeled A through E from Parts 1 and 2. Collect a small dropper bottle of household ammonia.

Procedure

1. Using the small dropper bottle, carefully add drops of diluted ammonia to each test tube, except for test tube A. Stir the solution after each drop. Count the drops it takes to return each sample solution to the starting color (see control test tube A for comparison). The number of drops of ammonia needed to turn the solution blue again is directly related to the amount of CO_2 it required to change the BTB color in the first place.

2. Record the results on the data chart.

Observations and Questions for Parts 2 and 3

1. Which source of carbon dioxide was the strongest?

2. How much stronger is the strongest than the second strongest? (Divide the number of drops needed to change the strongest by the number of drops used to change the second strongest.)

3. How much stronger is the strongest than the weakest? (Divide the number of drops used to change the strongest by the number of drops used to change the weakest.)

4. Does the carbon dioxide act more like vinegar or ammonia?

5. What does carbon dioxide do in the greenhouse effect?

6. What does this activity have to do with what you have studied so far? Be specific! List at least three things.

Assessment Ideas

- In this activity, you have examined several sources of CO_2. If you wished to reduce the amount of CO_2 increase in the atmosphere, which source would be most important to control? Explain why. Would there be problems with such controls? If so, what might they be?

<u>Feedback on Where in the World is Carbon Dioxide?:</u>

Share your suggestions to enrich, expand and improve this lesson. How did you use this lesson in your classroom?

Contact Laurel Kohl: KOHLL@easternct.edu or 860-465-0256