Carbon Dioxide and Greenhouse Heating

This hands-on activity will help students gain a better understanding of how carbon dioxide (CO_2) contributes to greenhouse heating. At its completion, they should be able to describe the greenhouse effect, how CO_2 promotes heating in our atmosphere, and its effect on global climate change.

Objective

Students will use scientific inquiry and scientific reasoning to understand the greenhouse effect and how it contributes to global climate change. With this activity, students will learn about and be able to answer questions such as:

What is the greenhouse effect?

How do CO_2 and other greenhouse gases contribute to global climate change?

How do their effects depend on visible light and infrared radiation?

Background

Absorption of Electromagnetic Radiation by Greenhouse Gases

The composition of the atmosphere affects global climate change through the absorption of infrared light. Visible light from the sun passes essentially unchanged through the atmosphere, which is why air appears transparent to us. When light strikes the earth's surface, some of it is reflected and some of it is absorbed. The proportion that is reflected from a surface is the albedo.

Reflected light is unchanged as it heads back out to space (or toward some other object). The energy of absorbed light heats the earth's surface. The heated surface then re-radiates that energy, but as infrared rather than visible light. Infrared light passes unchanged through oxygen and nitrogen gas, which are the major components of the atmosphere. However, greenhouses gases absorb infrared light. The energy of the absorbed infrared light then heats the atmosphere.

Greenhouse gases, which are small but growing components of the atmosphere, include carbon dioxide, water vapor, methane, nitrous oxide, ozone, and chlorofluorocarbons. The asymmetry of their molecules is the reason that they absorb infrared light while O_2 and N_2 do not.

The pre-industrial levels of carbon dioxide (280 parts per million) have been responsible for raising the temperature at the earth's surface enough to make it livable. Current levels of carbon dioxide (380 ppm) are starting to raise average temperatures enough to disrupt climate patterns as well as the biological and human systems that depend on them. Human activities continue to add to the levels of these gases. The complexity of the climate systems and its responses is an active area of research.

Materials

- Two empty plastic 2-liter soda bottles
- Two stem thermometers
- Sunlight, or one 150-watt lamp on a stand
- Four cups of dark dry soil
- Two straws or pieces of rubber tubing
- One plastic container (at least a pint) with lid, or a glass flask with a rubber 1-hole stopper

- Three Alka-Seltzer tablets
- Water, about a cup
- Means of recording the data

(If class is too large to fit comfortably around a single table, may be worth making more than one set of bottles.)

Preparation

Beforehand

1. Cut off the tops of the two-liter bottles. They should be about eight inches tall and open mouthed.
2. Punch a small hole for the thermometer about five inches up from the bottom of each bottle. (Alternatively, you can rig some other way to hold the thermometers at this height.)
3. If using the two straws, build an arched tube out of them by inserting the end of one into the end of the other. It will arch over the top of one bottle and down close to the surface of the soil. Next, if using a plastic container, make a hole in the lid and insert one end of the tube into the hole. If using a glass flask, rubber stopper, and rubber hose: connect the hose to the hole in the stopper.

Setup

During this time (or earlier), discuss the greenhouse effect with your students. You should trace the paths of photons of light as they travel from the sun and enter the earth's atmosphere. Ask them whether they think they'll be able to see the air in the bottles heating up or the carbon dioxide within it. Continue the discussion by asking how those answers would change if their eyes were sensitive to radiation. You can also introduce the idea of black body radiation, and the idea that the sun radiates in visible wavelengths, because of its temperature, while cooler objects (such as heated soil) radiate in infrared wavelengths. You can also mention that "night vision" is a means of detecting infrared radiation given off by the warmth of objects. You can show photographs that demonstrate that warmer objects give off more infrared radiation than cooler ones.

Follow these steps to setup the experiment:

1. Place two inches of soil in the bottom of each bottle.
2. Fill the small plastic container or flask halfway with water.
3. Position the flask or the container with water so that the tube arches over the top and is held one inch above the soil in one of the 2-liter bottles. Use any necessary tape, clips, or other means to hold the tube in place.
4. Put the thermometers horizontally through the hole in each bottle, so that the tip is in the middle and not touching the side.
5. Place the bottles in direct sunlight, or place the lamp within a foot of the top of the bottles, at an equal distance from both, and let the light heat the soil for about an hour.

Procedure

Make sure that the tube or straw is inserted into the top of the plastic container (or flask), with its end at least one inch from the surface of the water, far enough that the bubbling water will not pass through the tube into the bottle. Make sure that the other end is within one of the bottles, not far from the surface of the dirt.

Place one Alka-Seltzer tablet into the water, close the container lid (or stopper), and wait 1 or 2 minutes.

Repeat with the second tablet, wait another 1 or 2 minutes, and then add the third tablet. Make sure to keep the container otherwise closed.

Take measurements of the temperature of the air within each bottle at intervals over the next 10 or 15 minutes, or until it stops changing.

Assessment

Discuss with your students what they have learned from this activity. These topics can help guide you in your discussion:

Describe the changes in temperature over time. If it increases and then decreases, have your students explain both the increase and the decrease. (The bottle filled with CO_2, which stayed inside the bottle for a while because CO_2 is heavier than air, and which trapped infrared radiation from the warm soil. Eventually, the CO_2 dissipated.)

Discuss with your students why you put the bottles in sunlight or under the lamp beforehand. (Warmer soil radiates more infrared light, increasing the warming effect of the CO_2.) Would heating them in a slightly warm oven have served the same purpose? (Yes, except that it would not be modeling light energy as the source of heat.)

Discuss with your students the effect on atmospheric temperatures of lowering the albedo of some parts of the earth's surface. (Lower albedo means more light energy is absorbed and then re-radiated as infrared.) What sort of changes might lower it? (Melting ice, changes in vegetation)

Have your students discuss other examples of greenhouse heating. Discuss with them the differences among the greenhouse effects as demonstrated with this experiment, in the atmosphere, and in an actual greenhouse. (Scale, closed vs. open, glass vs. gas, heterogeneous vs. homogeneous)

Vocabulary

greenhouse gas
carbon dioxide
electromagnetic radiation
visible light
infrared light
reflection
absorption
albedo
black body radiation

wavelength
frequency

Extensions

1. Compare carbon dioxide with other greenhouse gases in terms of potential to heat the atmosphere, amount in the atmosphere, and typical residence time within the atmosphere.
2. Find out the albedo of some typical surfaces of the earth, such as bare ground, grassland, forest, ice, and water. Discuss with your students how changes in climate and changes in albedo make a positive feedback loop.
3. Discuss with your students whether the experiment would work as well if, instead of using CO_2 to trap infrared radiation, the opening of the bottle were covered with (1) a pane of glass, or (2) a sheet of clear plastic wrap. Carry out and explain the modified experiment.
4. Discuss how a car with closed windows can act as a greenhouse. Measure how much warmer the inside of a car can be than its surroundings on a sunny day. Measure how much the result is changed if the windows are opened.
5. Discuss with your students whether using Alka-Seltzer as a source of CO_2 is a good model for the increase of CO_2 in our atmosphere. Find out how much anthropogenic and other sources contribute to atmospheric CO_2 and other greenhouse gases.
6. Investigate the relationship between atmospheric carbon dioxide concentration and temperature over the earth's geologic history.
7. Discuss with your students the ethics of conducting an experiment that releases carbon dioxide into the atmosphere.