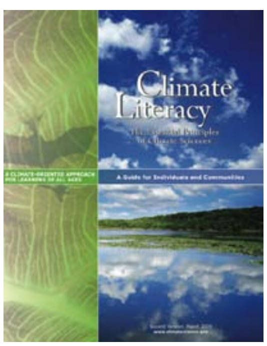
Greenhouse Gases

Description of the Activity

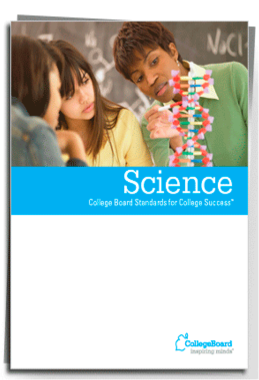
Students observe and contrast thermal properties of three major greenhouse gases. Using simple, readily available materials students collect temperature change over time for dry air, water saturated air, carbon dioxide, and methane.

Reason for Doing the Activity

Climate change is a major global issue of our time. Understanding the essential principles of climate science will enable students to better assess information and to contribute to what will be ongoing climate discussions as informed citizens. Climate literacy is supported by all the science education standard initiatives including the earlier National Science Education Standards (NSES), the American Association for the Advancement of Science (AAAS) Benchmarks for Science Literacy, and more recent educational guideline documents such as the U.S. Global Change Research Program's *Climate Literacy Essential Principles* and the College Board's *Science Standard's for College Success*.



The amount of solar energy absorbed or radiated by Earth is modulated by the atmosphere and depends on its composition. Greenhouse gases—such as water vapor, carbon dioxide, and methane—occur naturally in small amounts and absorb and release heat energy more efficiently than abundant atmospheric gases like nitrogen and oxygen. Small increases in carbon dioxide concentration have a large effect on the climate system.



ESM-PE.2.1.2 Make a claim, using representations and models of incoming solar radiation (insolation) and the greenhouse effect, how changes in the atmosphere (i.e., atmospheric composition, cloud coverage) and in Earth's surface (i.e., glacial coverage) will affect the energy budget. ESM-PE.2.1.2a Identify major greenhouse gases (e.g., water vapor, carbon dioxide, methane, ozone) and their natural and anthropogenic sources. Interpret the long-term annual flux of the Keeling Curve.

However, in so many science education standards documents, textbooks and curriculum guides alike, greenhouse gases are merely identified – facts to be taken at face value – with little or no opportunity presented as to how their thermal properties might be explored, measured and contrasted. Although there are many complex and dynamic interactions between greenhouse gases and with all other components of Earth's climate system, this activity provides an opportunity for students to ask questions, take measurements, make observations, and interpret findings.

Background

Earth's atmospheric gases are often divided up into constant and variable components. The major constant gas components remain the same over time and location are:

Nitrogen (N_2)	78%
Oxygen (O_2)	21%
Argon (Ar)	1%

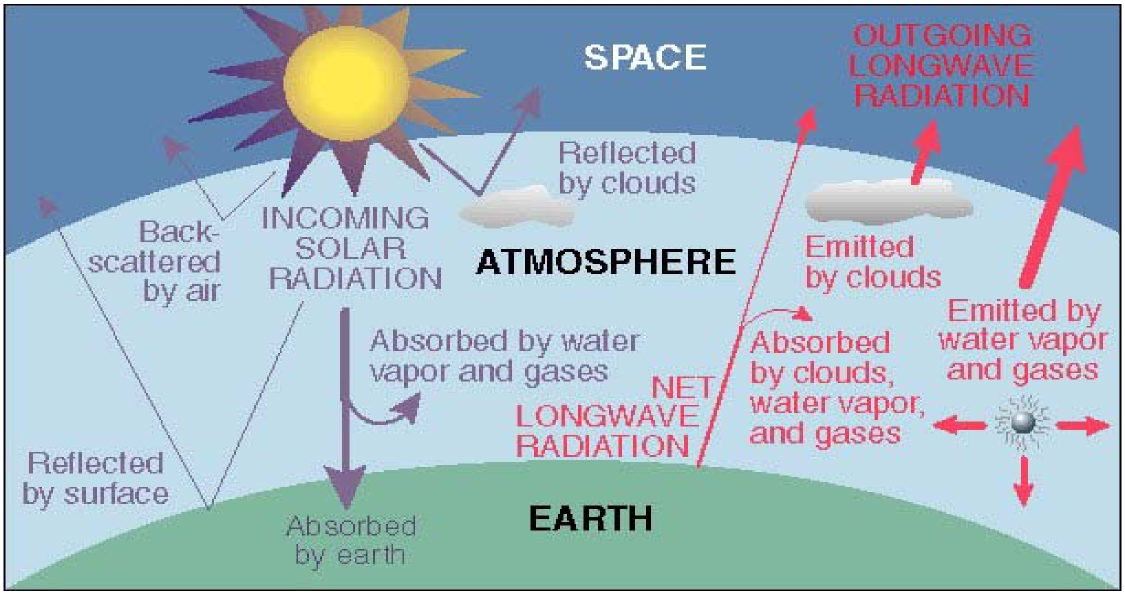
The major variable gas components that vary over time and location are:

Carbon Dioxide (CO_2)	0.038%
Water Vapor (H_20)	0-4%
Methane (CH_4)	trace
Sulfur dioxide (SO_2)	trace
Ozone (O_3)	trace
Nitrogen oxides (NO, NO_2, N_2O)	trace

While nitrogen and oxygen comprise 99% of the atmospheric gases, they have little effect on atmospheric processes and consequently little to no effect on weather or climate. The gases which make up far less than 1 percent of the atmosphere have a much greater influence on both short-term weather and long-term climate. The less abundant gases (water vapor, carbon dioxide, methane, nitrous oxide, and sulfur dioxide all have an important property. These gases have the ability to absorb thermal energy (heat) emitted by the earth and thus are able to warm the atmosphere. This warming is what is popularly called the "greenhouse effect." There are obvious benefits to these so-called greenhouse gases as without them the surface of the earth would be about 30 degrees Celsius cooler, and far too cold for life, as we know it, to exist. On the other hand, these greenhouse gases are so thermally potent that even proportionately small amounts can cause *Earth's* lower atmospheric temperature to rise.

Current concern about global climate change refers to the altering of temperature and precipitation resulting from the anthropogenically induced accumulation of greenhouse gases. Greenhouse gases, which include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3) and chlorofluorocarbons (CFCs), are relatively transparent to incoming solar radiation but they absorb outgoing infrared radiation emitted from Earth's surface.

Greenhouse Effect



Most of the incoming solar radiation (short wavelength, shown in purple) is absorbed and converted to long wavelength radiation (shown in red), at or near the Earth's surface. Thermal energy (heat) results from the absorption of some long wavelength radiation by atmospheric gases, including water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The greenhouse effect is the retention of this heat in the atmosphere. Some human activities increase the amount of greenhouse gases, primarily CO_2.
USGS Fact Sheet 137-97. Helaine Markewich, Norman Bliss, Robert Stallard, and Eric Sundquist.

What is it about these gases that allow them to retain heat in the atmosphere?

Long wave radiation emanating from Earth's surface causes molecules of a specific size and structure to vibrate. The greenhouse gases are of the right molecular size and structure for this to occur. This vibration or resonance allows the molecules of these gases to heat up.

Grade Level

Secondary School (depth of interpretation and analyses of results can be adjusted accordingly.)

Materials

Clear plastic water bottles with hole drilled into cap (recommend one bottle for every 3 students). The bottles should all be the same type, have clear plastic sides (remove any labels), and all be approximately 20 ounces in size.

Thermometers (analogue, digital or digital recording; one for each bottle).

Vinegar

Baking Powder

Methane Gas (from laboratory gas jet)

Light source (clamp lamp or goose neck) and bulb (standard incandescent or directed spot; one setup for each bottle).

Procedures

1. Students should be divided up into four different groups (one for each bottle and for each gas). So that all students can be engaged in data collection and recording, it is best that no more than three students are in each group. Each group of students will have one bottle in which one of the gases (regular air, water saturated air, CO_2 or CH_4) will be placed. (For the saturated air, carbon dioxide, and methane filled bottles see below.)
2. Record the starting "room" temperature by holding the bottle cap and temperature probe in the air for 1 minute. Record this temperature. NOTE: Do not just set the probe on a desk. If you do, you'll be recording the desk temperature. Also, don't hold the tip of the probe because then you'll be taking your temperature.
3. Place one of the four gases (regular air, saturated air, carbon dioxide or methane) into each of the designated bottles. (Be certain to follow directions and safety procedures below).
4. Screw the cap on tightly by holding the cap and turning the bottle. (Although in the reverse, counterclockwise direction, this is the way a good bottle of champagne should be opened!)
5. Place all the bottles at a designated distance from the light source (we recommend not less than a foot, and no more than a foot and one-half.)
6. Plug in the lamp and turn it on, and start collecting and recording temperature on the data chart provided every minute for 15 minutes. After 15 minutes, turn the light off and continue recording the temperature for an **additional 10 minutes.**
7. Plot the data you collected down in step 7 for temperature (Y) and time (X) on the data graph provided.

For the bottle with air: Just tighten the cap.

For the bottle with saturated air: Place a piece of saturated sponge in the bottom of the bottle. Make certain it is large enough to cover at least half of the bottom of the bottle.

For the bottle with carbon dioxide and for pouring the gas into the bottle: Carbon dioxide can be easily made with baking soda and vinegar. Vinegar (acetic acid) CH_3COOH, and baking soda (sodium bicarbonate) $NaHCO_3$ produces an acid-base reaction when they come in contact with one another. The fizzing and bubbling indicates that a gas (CO_2) is being produced. Chemically, the reaction is:

$$CH_3COOH + NaHCO_3 \text{ ---> } CH_3COONa + H_2CO_3$$

The H_2CO3 (carbonic acid) quickly turns into carbon dioxide and water.

$$H_2CO_3 \text{ ---> } H_2O + CO_2$$

(The CO_2 is what you see in the foaming and bubbling in this reaction.)

Pour 30 ml (about 1 ounce) of vinegar into a plastic cup or beaker. Spoon in ½ tsp of baking powder. Allow the reaction to bubble and fizz without disturbing it. When the fizzing is over, carefully pour the CO_2 into the bottle. [Adding more vinegar and baking soda will just make the reaction bubble excessively, and the CO_2 will tend to bubble over the beaker and you won't be able to get it into the bottle.] BE CERTAIN NOT TO POUR ANY LIQUID INTO THE BOTTLE! Repeat this process two more times. Put the cap on the bottle.

Note: CO_2 gas is more dense than air. It will stay in the beaker, forcing out the air. Although you can't see it, you can pour CO_2 gas out of the beaker just like you would pour a liquid. By way of teacher demonstration, a match can be lit and placed down into the gas. The match will be extinguished showing that the oxygen in the air has now been forced out, replaced by the carbon dioxide. Students can also feel the CO_2 being poured out of the beaker because it's cold (similar to cold carbon dioxide gas coming out of a fire extinguisher). As the reaction with baking soda and vinegar is "endothermic," meaning that energy (as well as $CO_{2)}$ leaves the products during the reaction cold, care should be taken not to introduce any of the liquid into the bottle as it will continue to keep the temperature of the liquid depressed.

For Methane: As methane is lighter than air, simply invert the bottle over a gas jet in the lab and allow some gas to flow into the bottle for a few seconds. The gas jet needs only to be turned on for a few seconds to replace the air and fill the bottle. **NOTE: as natural gas can be ignited by a flame, extreme care should be taken to keep any lighted material away from the gas jet and bottle. Only the teacher should fill the bottles with methane, and only the closed bottle should be given to the student**.

Analyses and Questions (for students)

1. Describe the general trend in temperature over time that was observed. For example, did the temperature of the gas show a consistent increase, did it show a rapid rise and then level off, or did it reach a peak temperature above which it rose no further? After the light was turned off, how did the trend in temperature drop compare to its rise? (Explain)

2. Compare and contrast the temperature change of your gas with the three other gases? Which one showed the lowest temperature rise? Which one showed the greatest temperature rise?

3. What was the apparent effect of adding $CO_{2,}$ CH_4 and H_20 on temperature?

4. Although this activity is an investigation into thermal properties of several gases found in the atmosphere, it is not meant to be a model for what is occurring in the atmosphere. In what way is Earth's atmosphere different than what is found in the bottle? How does Earth's atmosphere differ in composition and what processes are occurring in the atmosphere that are not occurring in the bottle? The phenomenon that this activity explores is typically called the "greenhouse effect." Do you think this is a good term to use? (Explain why or why not.)

A Few Points to Keep in Mind

Temperature is a number. That number is related to energy, but it is not energy itself. It is related to the average kinetic energy of the molecules of a substance. So, temperature is not energy. That's why, technically, we measure thermal energy not temperature.

Incandescent light bulbs give off most of their energy in the form of heat-carrying infrared light photons -- only about 10 percent of the light produced is in the visible spectrum (this is why incandescent light bulbs waste a lot of electricity). However, as greenhouse gases are most responsive to the infrared portion of the electromagnetic spectrum incandescent bulbs are a good choice for this activity.

The term "greenhouse effect" is actually poorly named as one typically thinks of a greenhouse as a place where trapped air is warmed. This is not the case with our atmosphere, which is a porous layer through which electromagnetic radiation, both short wave, visible (and ultraviolet) light energy and longer wave, infrared energy, travel.

Visible light, as well as ultraviolet light, travels from the Sun to the Earth. Some of this energy (about 1/3) is reflected back to space by the upper atmosphere, but most of the rest travels unimpeded to the surface of the earth where it is absorbed, The earth radiates infrared energy out into space. However, some of this energy gets "captured" by a layer of GHG (greenhouse gases) as it leaves Earth. Some of the energy captured by these little critters is sent back into space; but some of it gets deflected back to Earth. The rest is absorbed by other CO_2 (or other GHG) molecules. and the process is repeated.

Even though it's an inaccurate metaphor, the name "greenhouse" effect still persists. And the gases that are part of our atmosphere are sorted out according to the way they redirect energy or let it pass through. Greenhouse gases - carbon dioxide, water vapor, and methane - are champs at capturing the heat energy and redirecting it everywhere, including back towards Earth.

Supporting References and URLs

Science College Board Standards for College Success at: http://professionals.collegeboard.com/profdownload/cbscs-science-standards-2009.pdf

Windows to the Universe: The Greenhouse Effect & Greenhouse Gases at:
http://www.windows2universe.org/earth/climate/greenhouse_effect_gases.html

Climate Literacy The Essential Principles of Climate Science at:
http://www.climatescience.gov/Library/Literacy/

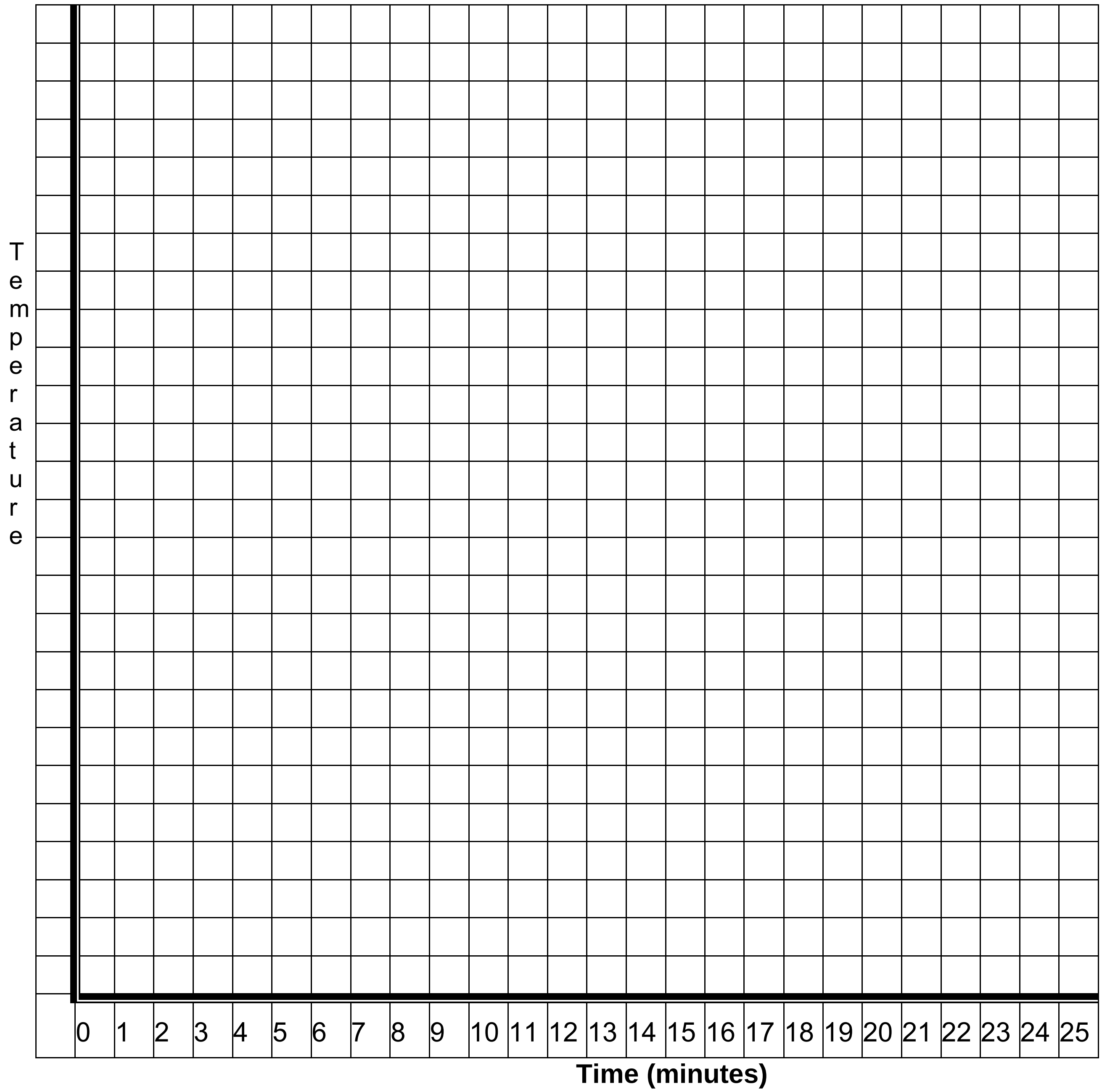
Teachers' Guide to High Quality Educational Materials on Climate Change and Global Warming at: http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm

Activity Sheet A: Time/Temperature Recording Table

Green House Gases Time/Temperature Recording Table				
Time (minutes)	**Dry (air only)**	**H_20 (water vapor)**	**CO_2 (Carbon Dioxide)**	**CH_4 (Methane)**
0 (room temp)				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15 (turn light off)				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

Activity Sheet B: Time/Temperature Graph

Green House Gases Time-Temperature Graph



Example: Trial Run of Green House Gas Recording Table and Graph

Green House Gases Recording Table				
Time (minutes)	**Dry (air only)**	**H_20 (water vapor)**	**CO_2 (Carbon Dioxide)**	**CH_4 (Methane)**
0 (room temp)	74.8	74.3	74.1	74.6
1	76.1	76.2	75.9	77.1
2	77.5	77.5	77.3	79.3
3	78.8	78.6	78.8	80.4
4	79.7	79.1	79.7	82.0
5	79.7	79.8	80.4	83.1
6	80.0	80.6	81.3	83.8
7	80.4	80.9	81.5	84.3
8	80.6	81.3	82.0	84.7
9	81.1	81.8	82.2	85.1
10	80.9	82.4	82.5	85.1
11	81.1	82.4	82.5	85.8
12	81.3	82.4	82.7	86.0
13	81.3	82.7	82.5	86.5
14	81.5	82.7	82.7	86.7
15	81.5	83.1	82.7	86.5
16	81.6	83.1	82.7	86.3
17	81.6	83.1	82.7	86.7
18	81.8	83.6	82.9	86.7
19 (light off)	81.8	83.6	82.5	86.7
20	81.3	82.9	82.4	85.4
21	80.0	81.1	80.9	81.5
22	79.1	79.7	79.7	80.0
23	78.2	78.6	78.6	78.2
24	77.9	78.0	77.7	77.3
25	77.3	77.1	77.0	77.0
26	77.1	77.0	76.6	76.4
27	77.0	77.0	76.4	76.4