



The Greenhouse Effect

Part One: Warming the Earth Experiment

By conducting a simple experiment, students are introduced to the natural greenhouse effect of Earth's atmosphere. A clear plastic bottle and lamp simulate the interactions between the Earth and incoming solar radiation. Students vary the conditions within the bottle to observe and measure the changes in the air temperature, leading to an understanding of how the reflective (albedo) and absorptive surfaces on Earth play a role in the greenhouse effect.

Activity Time

- Warm-up: 20 minutes
- Activity: 30 minutes
- Wrap-up: 30 minutes (including data analysis)

Setting

- Classroom and/or science laboratory

Materials

- For class demonstration:
 - 2-litre clear plastic soft drink bottle, label removed
 - 2 glass thermometers
 - one-hole stopper, cap, or small lump of modeling clay (e.g., plasticine)
 - lamp: incandescent (100 watt bulb) or flood • stand for lamp if needed (e.g., ring stand)
 - tape
 - string
 - clock or watch with second hand
 - thermometer clamp or ring
 - ring stand for thermometer

- For each group of students:
 - 2-litre clear plastic soft drink bottle, label removed
 - glass thermometer
 - one-hole stopper, cap, or small lump of modeling clay (e.g., plasticine)
 - lamp: incandescent (100 watt bulb) or flood
 - stand for lamp if needed (e.g., ring stand)
 - 1 sheet of black or white paper, 20 cm x 20 cm
 - scissors
 - tape
 - string
 - clock or watch with second hand
 - paper or notebook to record data
- For each student:
 - graph paper
 - notebook

Subjects

Science, Social Studies, Language Arts, Math

Keywords

Matter, gas, visible light, infrared energy, atmosphere, greenhouse effect, greenhouse gas, albedo, climate change

Prescribed Learning Outcomes - Science

Life Science

- Assess the requirements for sustaining healthy local ecosystems
- Evaluate human impacts on local ecosystems

Physical Science

- conduct investigations into properties of matter

Process and Skills of Science

- Test a hypothesis by planning and conducting an experiment that controls for two or more variables



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- Create models that help to explain scientific concepts and hypotheses

IRP Curriculum Organizers

Language Arts

- Oral Language
- Reading and Viewing
- Writing and Representing

Social Studies

- Human and Physical Environment

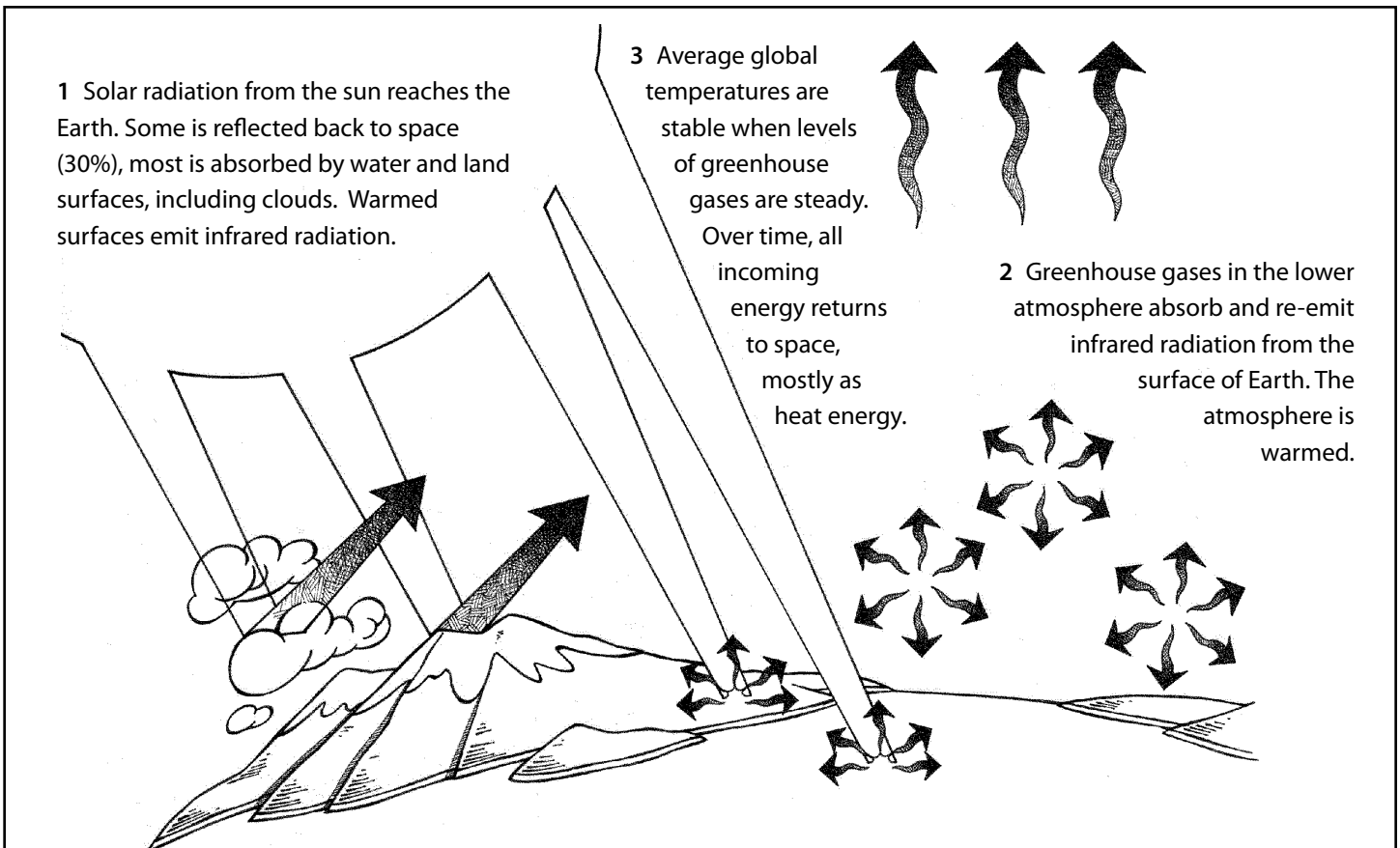
Introduction and Background

The greenhouse effect is a natural phenomenon that helps Earth to maintain an average global temperature that is hospitable for life. The atmosphere of Earth is a gaseous

mixture made up primarily of nitrogen (N_2 ; 78%), oxygen (O_2 ; 21%) and argon (Ar; 0.9%). The remaining fraction of one percent is a mix of greenhouse gases and trace gases. Greenhouse gases are able to absorb and emit much of the infrared radiation (i.e., heat energy) from Earth's surface and atmosphere before it is lost to space.

In order to understand the greenhouse effect, it is necessary to understand what happens to the energy Earth receives from the Sun (solar radiation). Short-wave energy in the form of visible light reaches the lower atmosphere and surface of Earth. Approximately thirty percent of the visible light is reflected back out to space by clouds and particles in the atmosphere and by snow, ice, and ocean and lake water at Earth's surface. In the atmosphere, clouds, gases and particles absorb twenty

Greenhouse Effect Diagram





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percent of the incoming visible light and the remaining fifty percent is absorbed at Earth's surface.

Once absorbed, the visible light energy is transformed into infrared radiation, which can be emitted in all directions. While some of the heat energy immediately escapes into space, most is absorbed and emitted back to Earth and into the atmosphere by gases that naturally occur in the atmosphere – the greenhouse gases. This process is known as the natural greenhouse effect and it is responsible for keeping the Earth's temperature warm enough to support life. Without it, the average temperature on Earth would be -18°C and could not sustain life systems.

Overall, the energy entering Earth's atmospheric system is balanced by the energy leaving it. The pre-industrial level of atmospheric greenhouse gases kept the average global temperature relatively stable. Unfortunately, human activity is altering the composition of the atmosphere by increasing the amount of greenhouse gases. For example carbon dioxide (CO_2) has increased by approximately 31% since the Industrial Revolution began in the 1750's. The result is that more infrared radiation is retained in the Earth's atmosphere for a longer time, leading to an increased average global temperature – this is called the enhanced greenhouse effect. In other words global warming is occurring and it is directly associated with changes in our global climate system referred to as climate change.

See the *Primer and Resources* for more information.

Gas is the most energetic phase of matter commonly found on Earth. Particles, either atoms or molecules, in the gaseous phase have enough energy that they do not come close enough to other particles to be attracted by them. External sources of energy (e.g., solar radiation from the Sun) maintain the gaseous phase; more energy excites the gas particles more and they move faster and further apart. The "temperature" of matter is a measure of its kinetic energy (i.e., the energy associated with molecule or atom motion) and the density of the gas particles. Materials in the gas phase have no shape of their own, that is, they take on the shape of their container. In the atmosphere, gases are held close to the Earth's surface by

gravity. There is a higher density of gas atoms and molecules near Earth's surface, with a gradual transition from the atmosphere to gasless space.

Procedure

Set-up

- 1 Gather all the materials necessary for the demonstration as well as for students working in groups to conduct the experiment.
- 2 Cut the top portion off all the plastic soda drink bottles, approximately 10 to 12cm from the top. This is necessary in order for the students to insert black or white paper for the experiment.
- 3 Set-up the apparatus for the demonstration as shown in the diagram EXCEPT do not add any paper inside the plastic bottle.
 - a To suspend the bulb of the thermometer in the centre of the bottle, hold it in place by using a lump of modeling clay or a stopper with a hole for the thermometer. Use enough modeling clay to ensure no air can escape from the bottle. If using small thermometers, suspend the thermometer on a string held in place with the modeling clay or bottle cap.
 - b Position the outside thermometer as close to the bottle as possible to receive the same amount of light as the bottle. Depending on the thermometers available, you can either use a ring stand and clamp, or a string attached to the top of the bottle to suspend the thermometer along side the bottle.
- 4 Create a table in a place visible to students to record the data from your demonstration. Use the column headings of "Time", "Inside Temperature", and "Outside Temperature". Ensure you include the units of measurement, e.g., minutes (min) and degrees Celsius ($^{\circ}\text{C}$) in your column headings.
- 5 Determine the appropriate distance between the lamp and bottle for the student experiment, where the white or



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black paper is inserted in the bottle. Position the lamp so that when turned on, the system *inside the bottle* achieves a temperature balance (maximum temperature) within 10 to 15 minutes. Note this distance as this will be important to tell students this information for their experimental set-up.

- 6 Create a class data table in a place visible to students for the results from the student experiments. Columns should include: "Group Name", "Variable" (colour of paper), "Start Temperature", "End Temperature", and "Time" (to reach stable temperature). Again, include units.

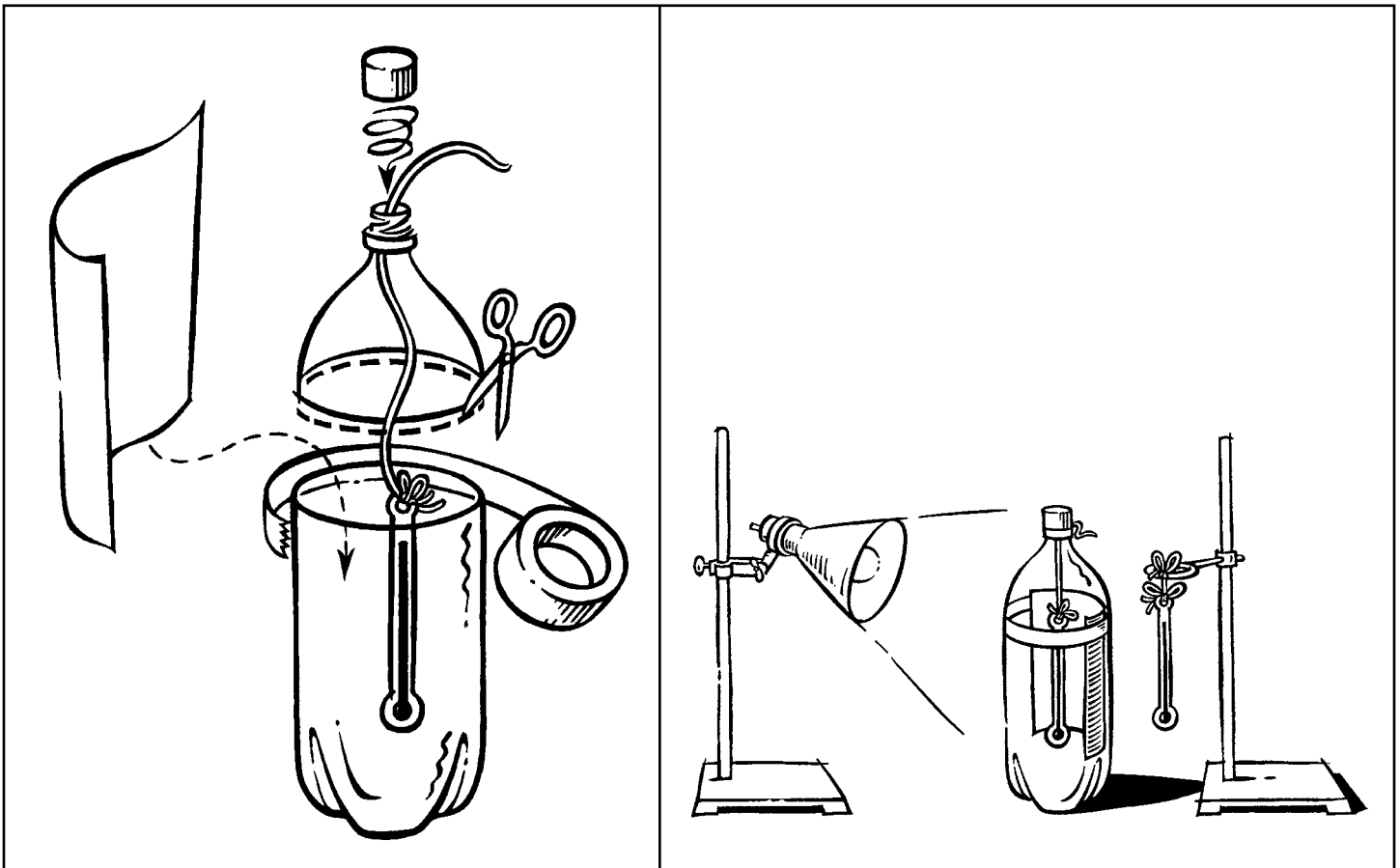
Warm Up & Demonstration

The demonstration has two purposes: first to model the experimental procedure (apparatus set-up, formulating a

hypothesis, and recording results) and secondly as a "control" for the student experiments. While the demonstration is proceeding, explain the natural greenhouse effect by following the suggestions outlined below.

- 1 Show the students the apparatus set up for the demonstration. Explain the air in the bottle simulates Earth's atmosphere and in their experiment, the paper simulates the Earth's surface. The lamp simulates the sun providing sunlight, mostly visible light. Ask the students to predict (i.e., hypothesize) as to what will happen to the air inside of the bottle when the lamp is turned on for 10 minutes or more. Help the students to formulate a reasonable, testable hypothesis (e.g., one that can actually be refuted by collecting data) and record the class hypothesis.

Bottle and Experiment Set-up





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Note: During the demonstration, the temperatures of the air inside and immediately outside of the bottle should increase only slightly and at approximately the same rate. The light energy from the lamp is warming the glass and liquid in the thermometer, and only subtly the air as most of the light is passing through the bottle. In the student experiments, the light from the lamp will be absorbed differentially by the white or black paper, resulting in an increase in air temperature of several degrees within the bottle.

- 2 Start the demonstration by turning the lamp on and recording the start time and temperature of both thermometers. Remember to check and record the temperature in and outside the bottle every few minutes. If possible, ask an assistant or student to do this for you, recording the temperatures every minute on a piece of paper, then transferring the data to the large, visible table at the end of the demonstration and introduction.
- 3 While the demonstration proceeds, explore with the students the metaphor of “greenhouse” to describe the ability of Earth’s atmosphere to retain infrared radiation (heat energy).

Ask the students to describe a gardener’s greenhouse and how it works. Guide the students to an understanding of how visible light can move easily through the glass of a greenhouse and then is absorbed by dark surfaces such as the plants and shelves. Infrared radiation is emitted from these surfaces, warming the air within the greenhouse.

Tell the students there is a natural phenomenon called the Greenhouse Effect that helps to keep the temperatures on Earth at a life-friendly level, in a manner *similar* to a gardener’s greenhouse. Visible light from the sun moves readily through the atmosphere and is either reflected back to space or absorbed by clouds or at the Earth’s surface. Again, infrared radiation is emitted from the surface.

Explain that the difference between a gardener’s greenhouse and the Earth is that it is the glass prevents the

warmed air from leaving the greenhouse. Greenhouse gases in the atmosphere actually absorb the infrared radiation and emit it in all directions, including back into Earth’s atmosphere and towards the surface of Earth.

Ensure the students understand the subtle differences by exploring how temperature can be controlled in a greenhouse by varying the amount of light entering the greenhouse using curtains or shades and/or by releasing heat by opening windows and vents. In contrast, Earth’s greenhouse effect keeps the global average temperature on Earth the same due to the consistent amount of greenhouse gases.

Lastly, help them to understand that temperature of the atmosphere is part of a complex system called the global climate system.

- 4 When the temperature in the bottle has reached a balance (no change in temperature readings for five minutes), turn off the lamp and record the final time and temperatures. If necessary, transfer the data. Graph the results (temperature inside the bottle versus time and temperature outside the bottle versus time) to help the students visualize the data.
- 5 Ask the students to explain what occurred. Was the class hypothesis supported or refuted? Why? (*The slight increase in temperature is due to the warming of the thermometers themselves, but not the air in the bottle as most of the light went through the bottle.*)
- 6 Ask the students if they can think of an experience they have had where air trapped inside a container is warmed by sunlight to a greater extent than outside the container. *Examples include cars with closed windows, playhouses/forts, and of course, greenhouses.* Ask the students to explain why the air is warmed, drawing on their understanding of energy, temperature, and matter (in this case, solid and gaseous matter).
- 7 Using the car example, ask the students if they think the colour of the car and/or seats inside the car make a



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difference as to how hot the air becomes inside. Encourage explanations for their answer, especially those that connect how visible light can be either reflected or absorbed depending on the colour of the surface and the matter involved.

- 8 Ask students how they might conduct an experiment to test their explanation, guiding them to realize they could use the apparatus set up for the demonstration and adding different coloured paper. Keep the experiment simple by using only two colours of paper, e.g., black and white. Ask the student to formulate a hypothesis and to record it in their notebooks.

Activity: Student Experiment

- 1 Divide the class into groups and provide each group with the equipment to set up their experiment. Explain that each group will set up their experimental apparatus exactly like in the demonstration EXCEPT they will add paper to the back of the plastic bottle to test their hypothesis. Also, they will not need the external thermometer, assuming all groups are working in the same room as the demonstration and under similar light and heat conditions. If not, an outside thermometer will need to be used as a control.
- 2 One half of the groups should use white paper, the other half black paper. If not already done, direct students to cut the paper so it is 20cm x 20cm. Show the students how to insert and tape the paper inside the bottle. Remind them the importance of carefully taping the two halves of the bottle together in order to get a good seal.
- 3 Consider safety: remind the students that the lamps will become very hot, and they should not touch the glass bulb, lamp socket or lamp cover. Also, remind them to keep hair, paper, and other flammables away from the glass bulb.
- 4 Tell the students the distance between the bottle and the lamp that was pre-determined in Step Five of the Set-up. They should ensure they have the correct positioning **before turning on the lamp**.

- 5 Ask the students to create a table in their notebooks to collect their groups' data. The table should be similar to the one used in the demonstration (column headings of time, temperature in bottle). They should also record the experimental variable (white or black paper).
- 6 Before turning on the lamp, students should record the temperature inside the bottle. Once the lamp is turned on, students should take a temperature reading every minute until the temperature has not changed for at least five minutes and record the results in their data table. Remind them to turn their lamps off once they are finished the experiment and all the data has been recorded.
- 7 Ask students to calculate the time it took to reach a stable temperature and record this in their notebook.
- 8 If not already done, create a class data table that is visible to all students. Columns should include: "group name", "variable" (colour of paper), "starting temperature", "ending temperature", and "time to reach stable temperature". Each group should add their results to the class data table. Note: starting temperatures should all be the same as the room temperature (assuming all groups worked in the same room).
- 9 Instruct each group to graph the results and discuss the outcome in their group. Discussion should include whether or not their class hypothesis was supported or refuted and possible explanations.

Wrap-up

- 1 Begin to analyze the class results by asking the class "At what temperature(s) did the air in the bottle stabilize for each variable (black or white paper)?" Calculate the class average for each variable.

The temperature of the air in the bottles with black paper will be higher than the bottles with white paper. Results will vary slightly, but assuming the set-ups were similar, the temperature recorded by each group within each variable should be very close to each other. If they are highly



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different, look for possible reasons why (e.g., heat was able to escape due to air leaks, differences in the distance from the lamp to the bottle, etc.).

- 2 Ask the students, “Why is there a difference between the final temperatures of the air in the bottles with white and black paper?” Explore possible explanations.

Help the students to understand that the black paper absorbs more visible light energy and emits more infrared radiation (heat energy), warming the air in the bottle. The white paper reflects more of the visible light energy and consequently, less heat is produced.

- 3 Ask the students to compare their results with what they know about the interactions at the surface of Earth and sunlight.

Help them to connect how black paper is similar to sunlight being absorbed by land, vegetation, and water which warms up and emits heat energy, while the white paper reflects light similar to sunlight reflecting off ice, snow and water. Tell the students that “albedo” is how reflective a surface is; the Earth’s current average albedo is approximately 30%. Connect this back to the example of cars with different coloured seats and explore the similarities.

- 4 Ask students how this experimental set-up is similar to a greenhouse. Why doesn’t the temperature in a greenhouse, or the air in the bottle, continue to rise? Why did the temperature level off?

Help the students to understand that over time, if all the variables are constant, a balance or equilibrium between the energy in and energy out of the system will be established. Remind students the temperature in a greenhouse or in the bottle can be regulated by releasing the warmed air through openings such as windows.

- 5 Explore how well the experiment simulates or models what is happening on Earth. What variables of Earth’s systems are not included?

The experiment is similar to Earth in that the air in the bottle retains detectable heat just as the atmosphere does, and the process of absorption and emission of heat energy by the white and black paper is similar to what happens at Earth’s surface during a sunny day. The plastic of the bottle held the warmed air in, but did not absorb and emit heat energy like the greenhouse gases do.

The experimental model does not simulate the complexity of Earth’s systems as many variables are not able to be included. Some variables include the effect of greenhouse gases themselves; water vapour; ocean and air currents; differential heating of landmasses; and layers of the atmosphere with slightly different composition of gases. Emphasize how Earth has many systems that are interconnected, making it extremely complex to analyse and accurately predict outcomes of even slight changes in one part of the Earth-Atmosphere system.

- 6 Remind students Earth’s life-sustaining average global temperature of 15°C is due to the natural greenhouse effect. Based on their current knowledge, discuss with the students what might happen if this temperature was to increase or decrease by a few degrees.

*Note: The role of increasing greenhouse gases in creating an enhanced greenhouse effect is explored in **The Greenhouse Effect Part Two: The Role of CO₂**.*

Assessment

- 1 Ask the students to describe several ways to increase the amount of heat inside the bottle and explain why this would work. (Possible responses include increasing the amount of energy received by the system, e.g., moving the lamp closer or increasing the wattage of the lamp, or increasing the amount of heat absorb by increasing the size of the surface area, or using a more absorptive material (e.g., a darker, thicker material). Their responses should provide



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evidence of an understanding of variables in experimental design as well as a beginning understanding of the properties of matter).

- 2 Request each group write a laboratory report of the experiment. The report should include their working hypothesis and the reasons they developed that hypothesis (the relevant supporting evidence), the data collected by their group presented in tabular or graphic form and summarized verbally, and whether or not the data supports the hypothesis and why. A possible rubric for assessing the lab report can be found in the Ministry of Education Integrated Resource Package for Science, Grade 7 (2005) on page 89.
- 3 Ask the students to explain the natural greenhouse effect and how it is important to ecosystems. (*Look for evidence of a basic understanding of how the natural greenhouse effect results in a life-sustaining average global temperature.*)
- 4 Ask the students as to describe the physical changes in the air of their plastic bottle when visible light was added. They can refer to the data collected by their group, as well as other groups. (*Students should be able to describe how the molecules in the air start to move faster when the visible light is absorbed by dark surfaces and heat energy is emitted.*)

Extensions

- 1 Ask the students what variables they might include in the experiment to explore other aspects of Earth's systems and repeat the experiment. Possibilities include changing the composition of the air (e.g., by increasing the amount of water or CO₂ in the bottle), the effect of plants, as well as the effect of various materials such as gravel and soil.
- 2 Build a "biosphere bottle" to more fully simulate Earth's systems, including ecosystems. Biosphere bottles are vivariums or terrariums with plants and simple animals such as the bacteria found in soil and pill-bugs or beetles. Ideally, once the plants and animals are established, the system should be able to be closed (fully sealed) and be able to continue for several months or more. The biosphere bottle provides an excellent visual, tangible example of the basics required to support life, the cycling of matter and flow of energy in ecosystems, and how most systems on Earth are interconnected. If the biosphere bottle fails (plants and/or animals die), this can provide an opportunity to discuss the balance of Earth's systems and how if this balance is tipped too far, the whole interconnected system can fail. See <http://en.wikipedia.org/wiki/Terrarium> for ideas as to how to build and set up a vivarium.

Source

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