Greenhouse Gases and Climate Change

Description:

We hear about greenhouse gases, but what exactly are they? Students explore the metaphors and models surrounding the causes of climate change through hands-on demonstrations and modeling.

Skills & Objectives

SWBAT

- Explain how greenhouse gases trap heat
- Understand why certain atmospheric gases are considered "greenhouse gases"
- Create a model to explain the greenhouse effect.

Skills

- Modeling
- Following a protocol
- Communication

Students Should Already Know That

- Invisible gases make up the atmosphere and can interact with each other and with light and heat.

Standards Alignment:
HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.
L.9-12.5 Demonstrate understanding of figurative language, word relationships, and nuances in word meanings.
L.9-12.6 Acquire and use accurately general academic and domain-specific words and phrases.

Disciplinary Core Ideas:
PS1.A: Structure and Properties of Matter
ESS2.A Earth Materials and Systems
ESS3.D Global Climate Change

Greenhouse Gases

How To Use These Activities:

Pages with the circular "TILclimate Guide for Educators" logo and dark band across the top are intended for educators. Simpler pages without the dark band across the top are meant for students.

Each of the included activities is designed to be used as a standalone, in sequence, or integrated within other curriculum needs. A detailed table of contents, on the next page, explains what students will do in each activity.

A Note About Printing

All student pages are designed to be printable in grayscale.

The worksheets do not leave space for students to answer questions. Students may answer these questions in whatever form is the norm for your classroom – a notebook, online form, or something else. This allows you, the teacher, to define what you consider a complete answer.

A Note About Materials

The materials for the two hands-on demonstrations are designed to be low-cost and to use supplies you may already have in your classroom. Beakers can easily be replaced with a mason jar or similar vessel.

For the sealable flasks:

- A conical (Erlenmeyer) flask, either with a built-in tubing attachment point or a stopper with tubing.
- A plastic water bottle. Drill a hole in the lid and feed flexible aquarium tubing through.
- A takeout soda cup with a lid. Feed flexible aquarium tubing through the straw hole.

For the DIY spectrophotometer:

- A mug warmer can be purchased online for less than $20. Another heat source could also be used, as long as it can maintain a relatively constant temperature for 5 minutes.
- Infrared (IR) thermometers can be purchased from a hardware store or online for less than $20 and are useful for a number of climate-related investigations.

Share with us! We would love to hear any podcasts or see any other projects you or your students create! Email us at tilclimate@mit.edu, tweet us @tilclimate, or tag us on Facebook @climateMIT.

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Greenhouse Gases

Detailed Table of Contents

A Note On Models

The demonstrations on pages 4a-6c each take roughly the same amount of time to perform (after setup). You may choose just one activity, depending on your time, space, and materials needs. Alternatively, you may have teams of students performing all three demonstrations simultaneously.

Greenhouse Gases

Greenhouse Gases and Modeling

This Educator Guide includes two hands-on demonstrations, an online model, and a design challenge. Educators may pick and choose among the pieces of the Guide, as suits their class needs.

Parts of this Guide may align with the following topics:

- Physical science: Chemistry and physics of light and molecules.
- Life/environmental science: Use of models.
- ELA/Humanities: Use of metaphors for communication.

MIT Resources

We recommend the following as resources for your own better understanding of climate change or as depth for student investigations. Specific sections are listed below:

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. https://climateprimer.mit.edu/
    - Chapter 02, The Greenhouse Effect and Us

- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. New Explainers are posted monthly. https://climate.mit.edu/explainers
    - Greenhouse Gases
    - Climate Models
    - Radiative Forcing
    - The Intergovernmental Panel on Climate Change

- MIT professors can answer your and your students' questions about climate change! Submit your questions or see other answers at https://climate.mit.edu/ask-mit-climate
    - "How can such a small amount of carbon dioxide in the atmosphere—only around 420 parts per million—cause so much warming?"

Greenhouse Gases

Wrap-Up Discussion Questions

- What parts of the electromagnetic spectrum have you experienced today?
- Which metaphor do you prefer – the greenhouse or the blanket? Why? Do you have another metaphor that you think works better?
- How do the physical and digital models of the greenhouse effect reflect what is actually happening on Earth?
- Explain greenhouse gases and the basics of climate change in a way that an elementary school child could understand.
- Why do scientists and policymakers focus on carbon dioxide as a key driver of climate change?

Climate Solutions

Climate solutions can be thought of as falling into four categories outlined below. Across all categories, solutions at the community, state or federal level are generally more impactful than individual actions. For example, policies that increase the nuclear, solar and wind mix in the electric grid are generally more effective at reducing climate pollution than asking homeowners to install solar panels. For more on talking about climate change in the classroom, see "How to Use This Guide".

•**Energy Shift**

How do decision-makers make the switch from carbon-producing energy to carbon-neutral and carbon-negative energy?

•**Energy Efficiency**

What products and technologies exist to increase energy efficiency, especially in heating and cooling buildings?

•**Adaptation**

How can cities and towns adapt to the impacts of climate change?

•**Talk About It**

Talking about climate change with friends and family can feel overwhelming. What is one thing you have learned that you could share to start a conversation?

TILclimate

Guide for Educators

What solutions are the most exciting in your classes? We would love to hear from you or your students! Images, video, or audio of student projects or questions are always welcome. Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.

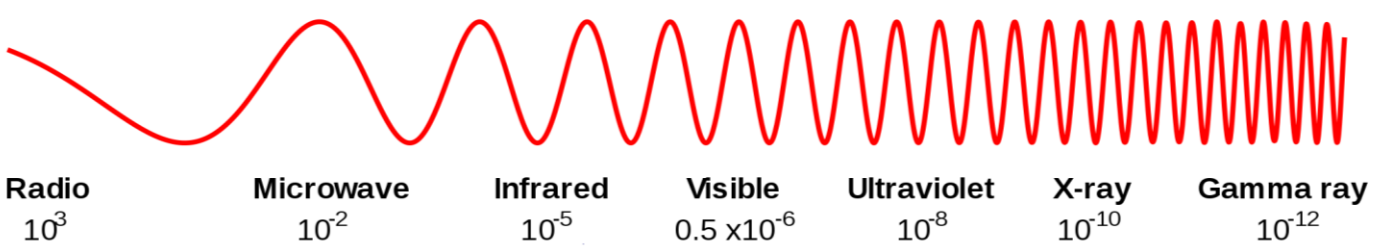
Greenhouse Gases

"If we think about solar energy coming to the earth, it comes to the Earth mostly in the ultraviolet and the visible range, loses a little bit of energy and is reradiated to outer space as infrared."
Prof. Desiree Plata, MIT Department of Civil and Environmental Engineering
TILclimate podcast: Wait, how do greenhouse gases actually warm the planet?

Light, Heat, and Rays – Oh My!

You wake up on a chilly day, grateful for the heat from your heating system. Going into the kitchen, you flip on a light and microwave your breakfast. Stepping outside, you feel the sun's rays on your face and take in the colors on the trees and bushes along the street. In the car, you turn on the radio to hear the news. You go to the dentist, where they take x-rays of your teeth.

In our lives, we experience light, radios, heat, microwaves, and x-rays as very different things. In fact, it's all the same energy along the *electromagnetic radiation (EMR) spectrum.*



The Electromagnetic Spectrum. Wavelength per meter.

Consider

Place each of the actions in the imagined morning above along the electromagnetic spectrum. Can you think of ways that you have experienced EMR today?

As EMR interacts with objects, surfaces, and atmospheres, it changes its wavelength. On Earth, about half the sun's energy arrives as visible and ultraviolet light. When it hits surfaces, it loses energy and becomes infrared, much of which we experience as heat.

Consider

Think about a dark surface, such as an asphalt parking lot, on a cool but sunny day. The sun's light hits that surface as visible and UV light. You can then feel the warmth coming back up off the ground. Can you think of another experience you have had that demonstrates this shift from visible light to heat energy?

Image by Inductiveload under Creative Commons license

Greenhouse Gases

Greenhouse Effect? How Does a Greenhouse Even Work?

You may have heard the term "Greenhouse Effect" or "Greenhouse Gases" – but most people have not had very much experience with a greenhouse.

Learn More

Watch the video "Seeing (Infra)Red (In the Greenhouse #1)" from the Paleontological Research Institution at https://www.youtube.com/watch?v=TFqEmlTLTmQ

The greenhouse metaphor is not a perfectly accurate description of what is happening on Earth. In a glass greenhouse, the glass traps warmed air, stopping it from transferring heat to the outside world. In the atmosphere, gases such as carbon dioxide and methane absorb infrared energy (heat) and radiate some of it back toward Earth.

Learn More

Read "Ask MIT Climate: How do greenhouse gases trap heat in the atmosphere?" at https://climate.mit.edu/ask-mit/how-do-greenhouse-gases-trap-heat-atmosphere

However, the result is similar. Heat, which would otherwise have radiated back out into space (or outside the greenhouse) is kept inside, warming the atmosphere and Earth.

Some scientists and science communicators use a different metaphor to talk about the effect of these gases in Earth's atmosphere: the heat-trapping blanket.

Greenhouse Effect

As we burn fossil fuels like coal, oil, and natural gas, and cut down trees, we add greenhouse gases such as carbon dioxide to the atmosphere.
Like the glass in a greenhouse, these gases trap heat, warming Earth and changing the climate.

Heat-Trapping Blanket

As we burn fossil fuels like coal, oil, and natural gas, and cut down trees, we add carbon dioxide and other gases to the atmosphere. These gases act like a blanket around Earth, trapping heat. This trapped heat is warming Earth, changing the climate.

Discuss

Read both explanations.

- Which metaphor do you like better? Why?
- Which metaphor have you heard more often in the media or other sources?
- Try it out: explain the basics of climate change using one of the metaphors. How well did the person you talked to understand?

Greenhouse Gases

"That infrared outgoing energy is in a sweet spot for absorption by methane and CO2 and other greenhouse gases in our atmosphere. So what happens is that infrared energy gets absorbed by the molecule. And that molecule enters an excited state. As it's relaxing back down, it releases some of that energy as heat, and that heat can go to outer space or can come back to planet Earth."

Prof. Desiree Plata, MIT Department of Civil and Environmental Engineering

TILclimate podcast: Wait, how do greenhouse gases actually warm the planet?

Modeling the Greenhouse Effect

Most of the 'players' in the story of climate change (gases, infrared energy, etc.) are invisible to the human eye. They take place on scales either much smaller (light wavelengths) or much longer (hundreds of years) than humans are used to. To help us understand these ideas, we develop models – simplified versions of a thing that make the invisible visible.

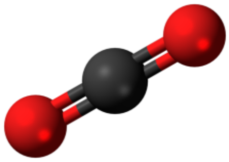
Models can be visual, three-dimensional, demonstrations, digital, physical, or a mix of all of these. We use models frequently, such as maps and globes to study land areas too large to see at once, diagrams of cells or molecules to understand their structure, or reenactments of historic events that we could not have witnessed.

As we simplify ideas or processes to make a model, they become less accurate. When using a model, it is important to recognize where it is accurate and where it isn't. For example, in the globe above, consider the following questions:

- How well does this model match what is actually happening on Earth?
- What do you already need to know to make this model make sense?
- What can you learn from this model that you didn't already know?
- How can you use this model?

Greenhouse Effect in a Beaker

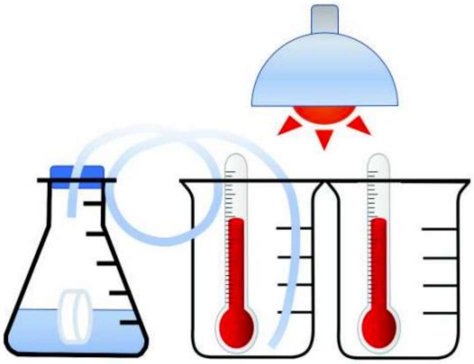
A Simplified Greenhouse Effect



Carbon dioxide is a very effective trap for heat. In this demonstration, we will test the difference between a high concentration of carbon dioxide and untreated air.

Carbon dioxide is much heavier than air, so the beakers do not need to have lids – carbon dioxide will flood the stoppered flask, flow down the tubing to the experimental beaker, and stay in the experimental beaker for the duration of the demonstration.

Demonstration



Follow the setup instructions on page 6a, then:

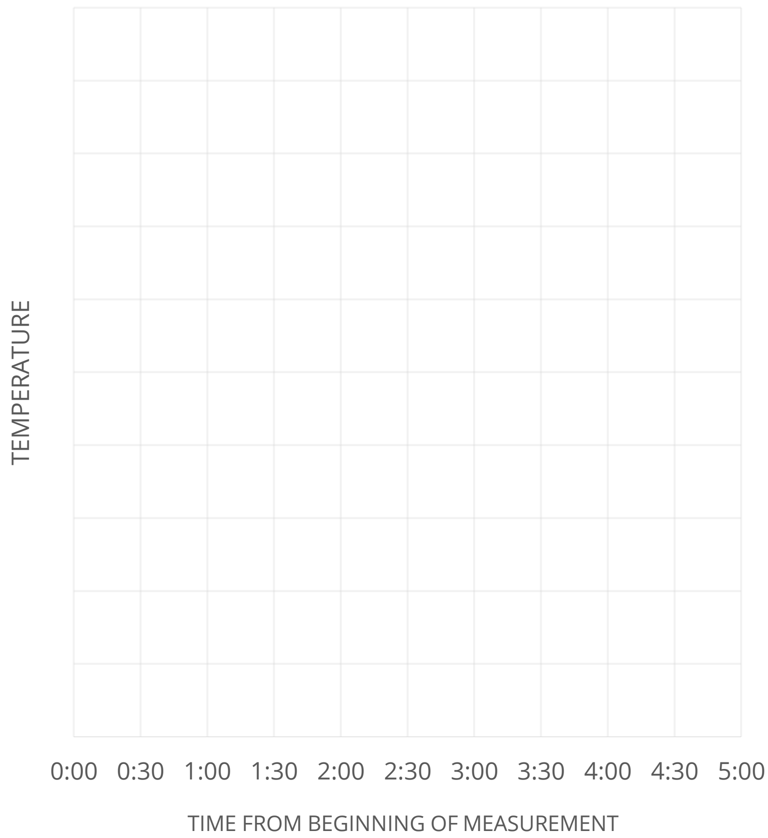
1. Take two baseline readings (0 and 30 seconds) of the temperature in the two beakers. Mark these on your chart.
2. At 30 seconds, quickly add all four tablets to the water and stopper the flask, making sure to keep the free end of the tubing in the experimental flask.
3. Take temperature readings every 30 seconds, marking the data on your chart.

This activity adapted from The Paleontological Research Institution via https://subjecttoclimate.org/resource/climate-change-toolkit-the-greenhouse-effect-in-a-beaker

Greenhouse Effect in a Beaker

Beaker Temperature Graph

Time	Exp. Beaker	Control Beaker
0:00 Baseline		
0:30 Baseline		
1:00 Add CO2		
1:30		
2:00		
2:30		
3:00		
3:30		
4:00		
4:30		
5:00		



Questions

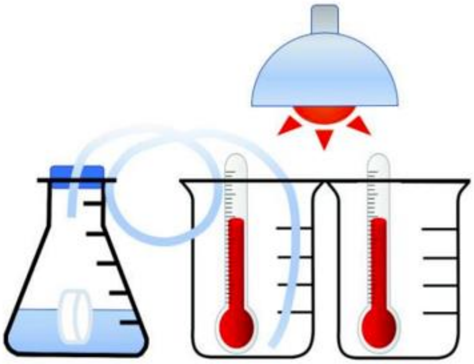
- How well does this model match what is actually happening on Earth?
- What do you already need to know to make this model make sense?
- What can you learn from this model that you didn't already know?
- Could you use this model to help explain climate change to someone else?
- How else could you use this model or tools?

Greenhouse Effect in a Beaker

Materials

- ❑ Two (2) 1-liter beakers or jars with open lids
- ❑ Heat lamp
- ❑ Two (2) digital thermometers (aquarium thermometers with flexible probes work well, but any digital thermometer is usable)
- ❑ Flask or bottle with flexible tubing
- ❑ Four (4) Sodium bicarbonate tablets (alka-seltzer or similar)

Setup



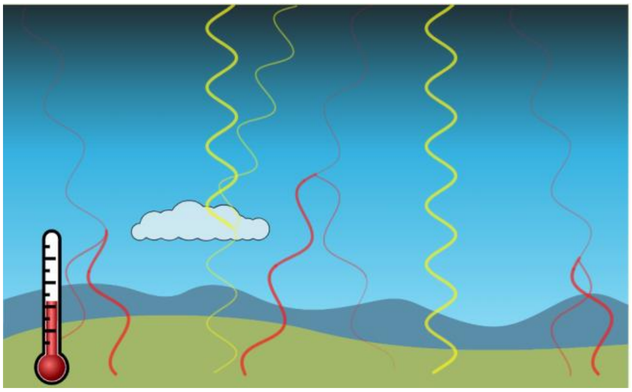
1. Place the two jars/beakers side-by-side, equally under the heat lamp.
2. Place a thermometer in each beaker.
3. Allow the beakers to sit for 10 minutes to assure that they are starting at the same temperature.
4. Add water to the bottom of the stoppered flask and prepare the tablets but do not add them yet.
5. Put the free end of the tubing into one beaker, which will be the experimental beaker.

This activity adapted from The Paleontological Research Institution via https://subjecttoclimate.org/resource/climate-change-toolkit-the-greenhouse-effect-in-a-beaker

Digital Greenhouse Model

Computer Modeling

We use computer models every day, for tasks as simple as directions to and from work or school and as complex as modeling the entire climate system. Computer models often allow us to manipulate many more *variables* than a physical or diagram model.



Explore the Model

1. Visit https://phet.colorado.edu/en/simulations/greenhouse-effect/about
2. Click the Play triangle in the middle of the image.
3. Chose "Waves" (you may come back to this page and choose another option later).
4. Before clicking "Start Sunlight", familiarize yourself with the variables available to you. You can change the Greenhouse Gas Concentration, add or subtract clouds, and show or hide the surface thermometer. For now, leave everything on the default settings.
5. Click "Start Sunlight" and watch the animation for 30 seconds, until the temperature stabilizes. Mark this beginning temperature on your chart.
6. Remove the cloud. Once the temperature stabilizes, mark this on your chart,
7. Use the orange restart button to restart the model and reduce the Greenhouse Gas Concentration to "None". Once the temperature stabilizes, mark this on your chart.
8. Restart the model and raise the Greenhouse Gas Concentration to "Lots". Once the temperature stabilizes, mark this on your chart.
9. Now that you have explored the basic variables available to you, experiment with different combinations of settings. The "Photons" and "Layer Model" versions are available at the bottom of the screen.

ENVIRONMENTAL SOLUTIONS INITIATIVE

Digital Greenhouse Model

Data Notes

Variables Set	Temp	Notes
Default		
Remove cloud		
GHG: None		
GHG: Lots		

Questions

- How well does this model match what is actually happening on Earth?
- What do you already need to know to make this model make sense?
- What can you learn from this model that you didn't already know?
- Could you use this model to help explain climate change to someone else?
- How else could you use this model or tools?

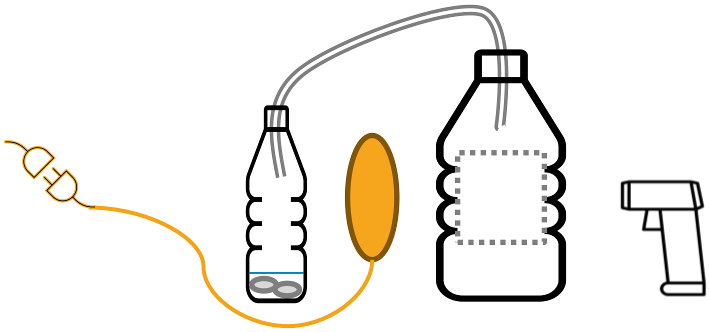
DIY Spectrophotometer and Carbon Dioxide

Carbon Dioxide in the Atmosphere and DIY Spectrophotometer

One of the reasons that scientists focus on carbon dioxide (CO_2) as a major greenhouse gas is that it *absorbs* infrared (heat) energy very well, instead of letting it travel back out into space from Earth's surface. Today, you will create a model "atmosphere" and watch as carbon dioxide absorbs infrared energy.

For more on this demonstration, watch the videos from the Paleontological Research Institution at https://climate.earthathome.org/videos/in-the-greenhouse-video-series/

Demonstration



Follow the materials and setup instructions on page 6c. Then:

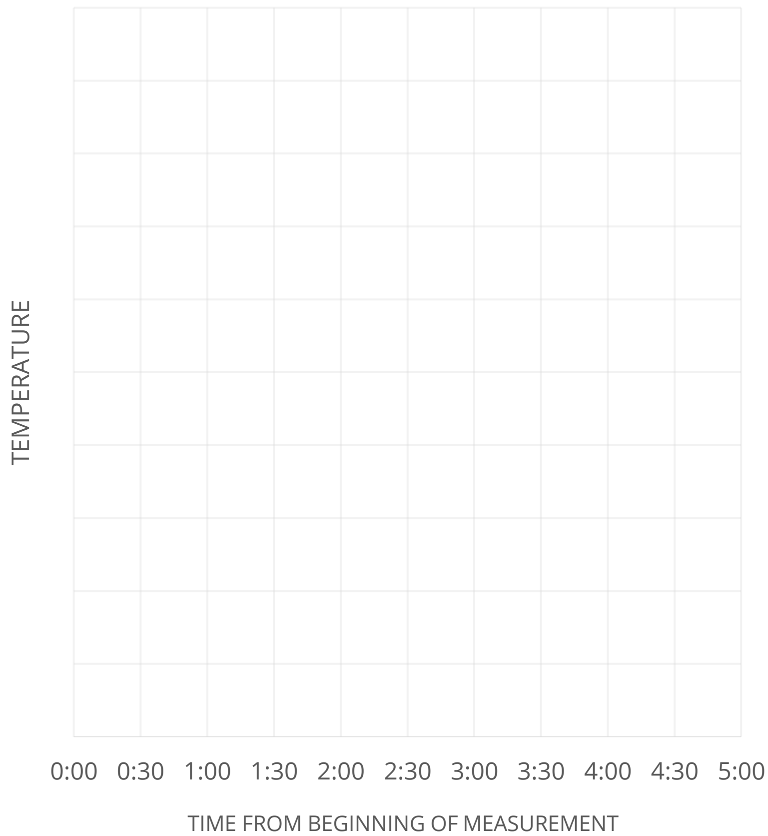
1. Take a reading with the IR thermometer once the mug warmer has achieved a stable temperature. Mark this at Time 0 on the chart on the next page. Take measurements again at 30 seconds and 1 minute to get a stable baseline.
2. Quickly drop two sodium bicarbonate tablets into the bottle with the flexible tubing, close the top, and make sure the free end of the tube is inside the juice bottle.
3. Every 30 seconds for a total of 5 minutes, note the temperature on the IR thermometer on your chart.
4. Based on the lowest and highest temperature measurements, label and chart your temperature data on the graph next to the chart.

This activity adapted from the Paleontological Research Institute video "How to Make a Simple DIY Spectrometer (In the Greenhouse 22)" https://www.youtube.com/watch?v=hbZY8CprqgQ

DIY Spectrophotometer and Carbon Dioxide

Spectrometer Graph

Time	Temp	Notes
0:00		Baseline
0:30		Baseline
1:00		Baseline
1:30		Add CO_2
2:00		
2:30		
3:00		
3:30		
4:00		
4:30		
5:00		



Questions

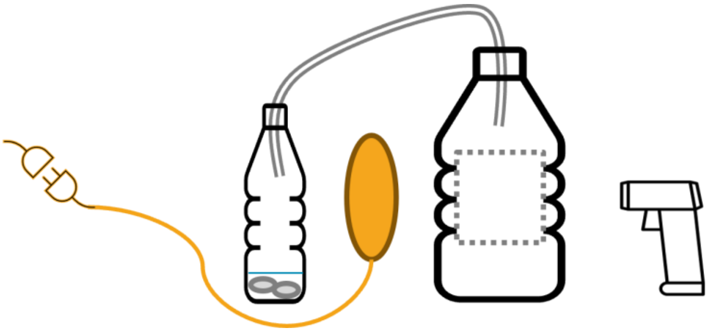
- How well does this model match what is actually happening on Earth?
- What do you already need to know to make this model make sense?
- What can you learn from this model that you didn't already know?
- Could you use this model to help explain climate change to someone else?
- How else could you use this model or tools?

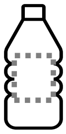
DIY Spectrometer Materials & Setup

Materials

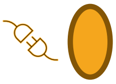
- ❑ Empty plastic juice bottle with flat sides
- ❑ Clear plastic food wrap
- ❑ Scissors or knife
- ❑ Plug-in mug warmer ($10-25 online)
- ❑ Infrared (IR) thermometer ($10-25 online)
- ❑ Recycled materials, clamps, tape, etc, to hold materials in line with one another.
- ❑ Flask or bottle with flexible tubing
- ❑ Four (4) sodium bicarbonate tablets (alka-seltzer or similar)

Setup



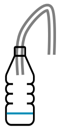


1. Carefully cut windows into both flat sides of the plastic juice bottle and wrap with a single layer of plastic food wrap. Juice bottle sides are thicker than food wrap, and so would block more of the infrared energy.



2. Attach the plug-in mug warmer to a box, block, or other stable object to hold it up at the same height as the window in the juice bottle. Plug it in to preheat.

3. Align another stable object on the other side of the juice bottle to hold the IR thermometer at the same height as the window. Use clamps and/or tape to hold it steady and hold the thermometer trigger in the on position.



4. Add a small amount of water to the flask or bottle with flexible tubing. Feed the free end of the tube into the open top of the juice bottle.

This activity adapted from the Paleontological Research Institute video "How to Make a Simple DIY Spectrometer (In the Greenhouse 22)"
https://www.youtube.com/watch?v=hbZY8CprqgQ
IR thermometer image from The Noun Project by Trevor Dsouza

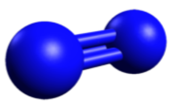
Greenhouse Gases

"And if you think about these geometries, it influences kind of what I like to call the "dance moves" that the molecule has access to. Now scientists call those dance moves *vibrational* and *rotational* modes, and the energy transitions associated with those modes overlap with the energy that can be absorbed in the infrared."
Prof. Desiree Plata, MIT Department of Civil and Environmental Engineering
TILclimate podcast: Wait, how do greenhouse gases actually warm the planet?

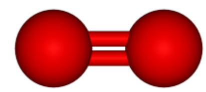
The Dancers

Besides water vapor, which cycles frequently, two molecules make up 99% of Earth's atmosphere – Nitrogen and Oxygen. Other gases are measured in *parts per million* (ppm).

Nitrogen 78%
(N_2, dinitrogen)

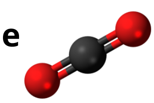


Oxygen 21%
(O_2, singlet oxygen)

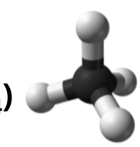


Noble Gases 9,360ppm
(Argon, Neon, Helium)

Carbon Dioxide
415ppm (CO_2)



Methane
1.9ppm (CH_4)



As Professor Plata explains in the podcast episode, carbon dioxide and methane are more effective at trapping heat because their molecular structure is more complex. While oxygen and nitrogen absorb UV light, protecting Earth from harmful UV rays, they allow infrared (heat) energy to pass right through. Noble gases, such as argon, neon, and helium, are non-reactive. Carbon dioxide and methane, on the other hand, are perfectly shaped to trap and reflect infrared (heat) energy.

The Challenge

Professor Plata uses the metaphor of dancers with different "dance moves". How else could you explain or model this effect? Plan out a model that effectively demonstrates how atmospheric gases interact with electromagnetic radiation in Earth's atmosphere.

Keep In Mind

Photons enter Earth's atmosphere at one set of wavelengths (mostly visible and ultraviolet) and are reflected from Earth's surface at slower wavelengths (infrared). Carbon dioxide and methane trap these slower wavelengths, while nitrogen and oxygen let them through.

Consider

For your model, you could use a computer, construction bricks such as LEGO, dancing people, or anything that makes sense to you. It just needs to correctly model reality.

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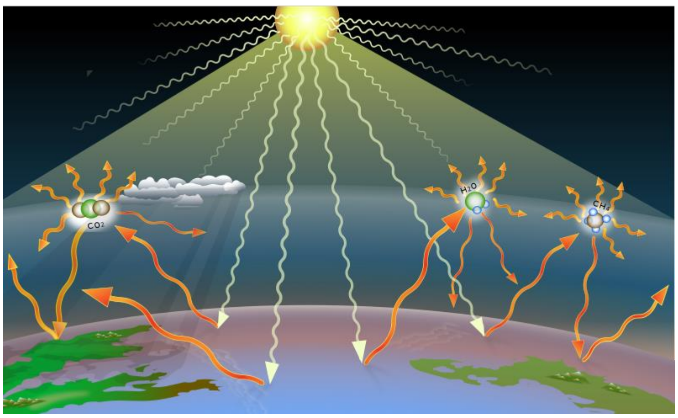
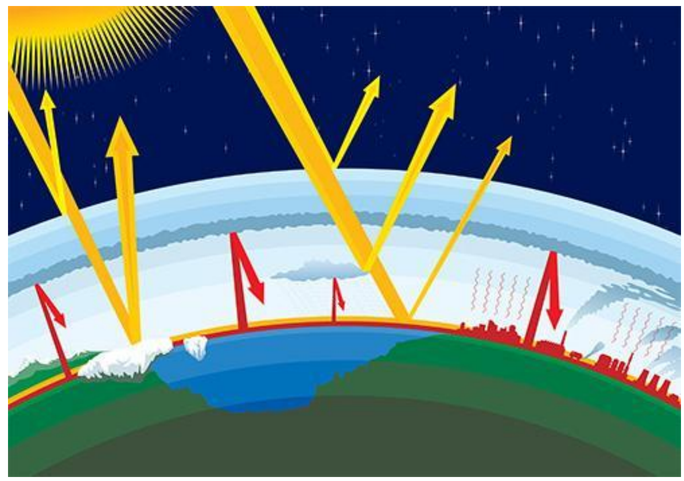
Greenhouse Gases

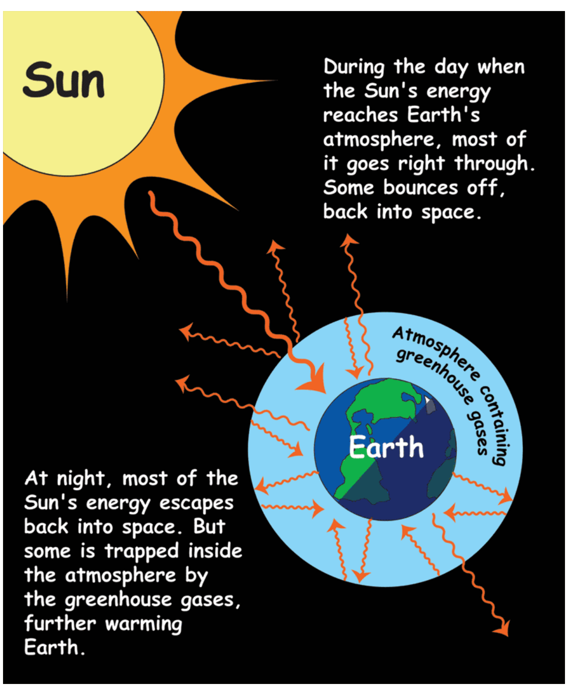
Standard Models of the Greenhouse Effect

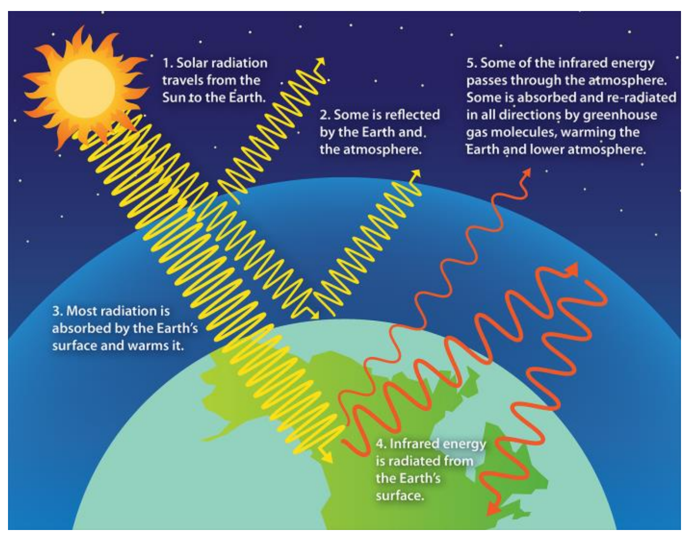
To help you plan your model, study a few different diagrams of the greenhouse effect.

All models must simplify a complex idea. Which of these diagrams do you think does the best job explaining the heat-trapping effect of carbon dioxide and methane?









Images by A loose necktie (Wikimedia commons), National Institutes of Health, Environmental Protection Agency, and NASA