What makes a gas a greenhouse gas?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

Greenhouse gases and their role in climate change has become a heated topic of discussions, news reports, magazine articles and books. There are many different types of gas molecules in the atmosphere. Why are some greenhouse gases and others not?

Theory

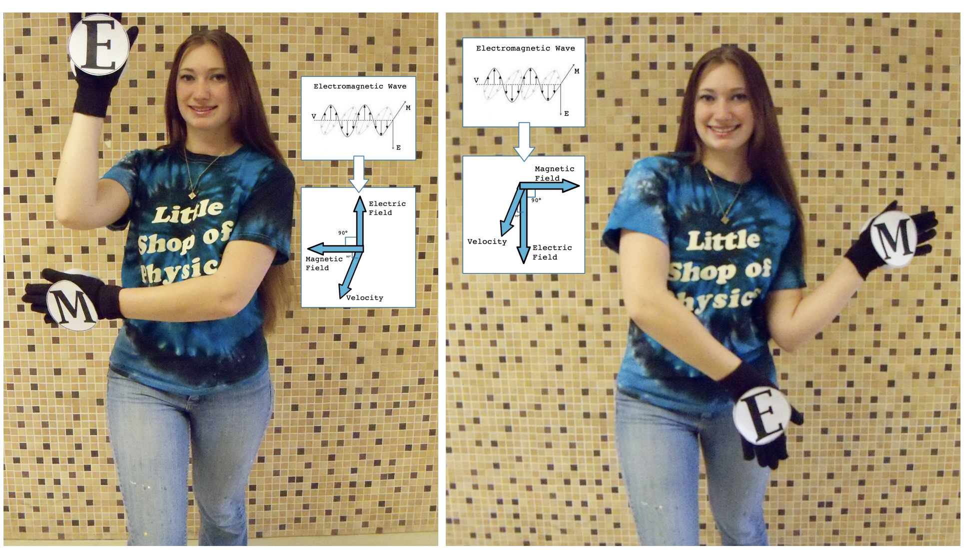
The earth's atmosphere is composed of a variety of gases–in fact, 99% of the Earth's atmosphere consists of two gases: nitrogen (N_2), which makes up 78%, and oxygen (O_2) which accounts for 21%. The other 1% is a mix of argon, neon, ozone, carbon dioxide, water vapor, methane and other trace gases.

Necessary materials:

- A large open area for your students to move about freely in groups of 2 and then 3
- 2 gloves–one marked E on both sides and one marked M on both sides
- Stickers, hats, wigs, or other ways to designate what type of atom each student is portraying.

Check out Scott Denning, Professor of Atmospheric Science at Colorado State University, and education director of CMMAP demonstrating the "dances" of atmospheric molecules at

http://changingclimates.colostate.edu/movies/scott_denning_796kbits.

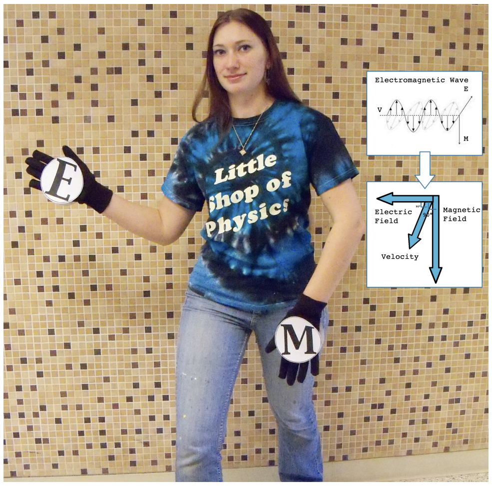


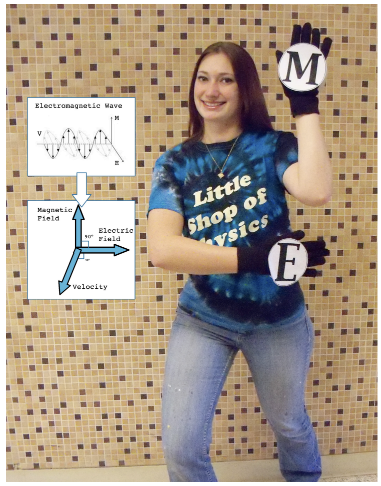
In this simulation of an electromagnetic wave, the wave is traveling out of the page toward you. The electric field is oriented up and down, as the magnetic field moves from side to side.

The energy from the sun travels to the earth in the form of electromagnetic waves and warms it up. The earth in turn cools itself off by radiating long wavelengths of thermal radiation back to space.

Certain gases in the atmosphere absorb these outgoing electromagnetic waves.

This is very important; with no such greenhouse gases, the planet would be a giant ice ball with an average temperature of -18 ° Celsius, or 0 ° Fahrenheit. Life as we know it would not exist! The greenhouse gases are able to absorb the thermal radiation and send some of the energy back down to earth. But why are some gases able to do this and others not? It turns out that a molecule that has the capability of vibrating in different ways can absorb different wavelengths. It then can emit heat back to warm the earth.





Now the magnetic field is oriented up and down, and the electric field moves from side to side.

Doing the Experiment

Before doing this experiment, label one glove or sign with an E on both sides, and then label another one with an M on both sides. Put on the gloves or hold the signs and practice portraying an electromagnetic wave–having one letter go from side to side while the other letter is going up and down. This is a bit trickier than it looks.

Gather your students in a large open area so they can spread out as needed. Explain to them that they are going to act out 4 different molecules that are part of the Earth's atmosphere and discover which ones are greenhouse gases and which ones are not.

N_2 & O_2

Have your students break into pairs and lock arms together to simulate the chemical bonds between them. Each molecule pair can be facing in any direction, but they are to stand still. Tell one half of the class that

N_2 is a molecule with equal charge sharing. Neither atom has a net charge. There is little interaction with electromagnetic waves.

O_2 is also a molecule with equal charge sharing. Neither atom has a net charge. There is little interaction with electromagnetic waves.

they represent nitrogen molecules and the other half that they are oxygen molecules. Explain that these two types of molecules are like two balls on a stick, and that they don't have a net positive or negative charge.

Put on the two gloves that are labeled E and M and tell them that you are portraying an electromagnetic wave. The wave is traveling straight ahead of you. If the individual atoms in the molecule have a net positive charge, they will be pulled in the direction of the electric field (the E on the glove). If they have a net negative charge they will be pulled in the opposite direction.

Use the gloves and have the E and M move back and forth vertically and horizontally as seen in the pictures above. What happens to the N_2 and O2 molecules? Not much! The individual atoms don't have a net positive or negative charge, so they don't interact with the electric field, and neither do the molecules. Net result: *Electromagnetic waves don't interact with the major components of the atmosphere, so the atmosphere is transparent.*

CO_2

Now have the students break into groups of 3. Explain that they are going to portray carbon dioxide molecules. The carbon atom is in the middle with a slight positive charge and there is an oxygen atom on each side with a slight negative charge. Each group of 3 students should lock arms and stand in a line. Simulate an electromagnetic wave and demonstrate with one of your groups of 3 before having your whole group join in the simulation. Here are suggested EM wave movements to try.

H_2O

Have your students stay in their groups of 3 and tell them that they are now going to act out H. Oxygen is in the center and has a slight negative charge. Each hydrogen atom locks an arm with the oxygen and positions him/herself at a 45% angle to the oxygen atom, but 90 degrees from the other hydrogen atom. The hydrogen atoms have a slight positive charge. Demonstrate with one of your groups of 3 how H_2O has many ways to vibrate due to it's shape. If the electric field points down, the O can go up as the two H drop down. If the electric field points up, the two H can go up as the O drops down.

The H_2O molecule can spin, twist & more.

Explain to your class that different vibrations allow a molecule to absorb different wavelengths. The molecule then emits these wavelengths in all directions, with the result that some are sent back down to earth warming the planet. Greenhouse gases have this quality. Discuss which of the four molecules were greenhouse gases. Explain that even though H_2O is a more powerful greenhouse gas than CO_2, water vapor only exists in the lower layers of the atmosphere, where CO_2 exists throughout.

An interesting activity to try is to have 78% of your students act as N_2, 21% as O_2, and then have several in the mix depicting a CO_2 or water vapor molecule as you wield the electric field glove. It might give your students a sense of how powerful greenhouse gas molecules are–even though they make up less than 1% of the atmosphere.

Summing Up

In this kinesthetic activity, students will have an opportunity to act as different molecules in the earth's atmosphere. They will experience why certain molecules are so good at absorbing and emitting thermal radiation and others are not.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

How can you demonstrate the efficiency of different light bulbs?

A laboratory experiment from
the Little Shop of Physics
at Colorado State University

Overview

The answer to this question may be found in the following Confucian proverb:

"I hear and I forget. I see and I remember. I do and I understand."

In this activity, students will actually feel the difference in energy required to light the two different types of light bulbs. We know that one type is more efficient... but feeling the difference helps students really understand.

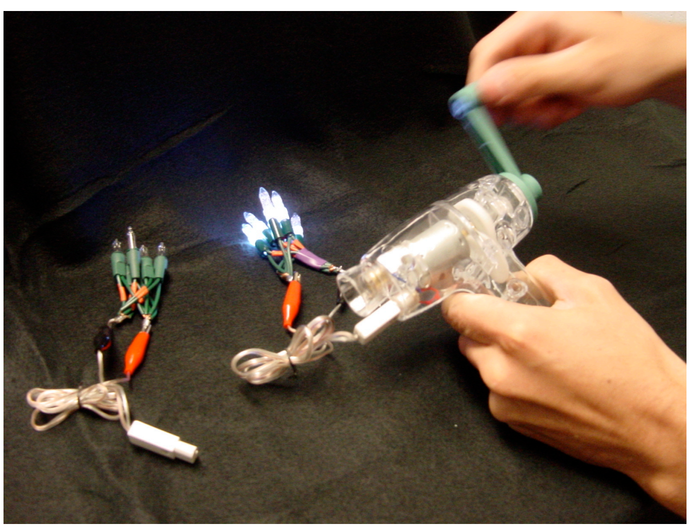
Necessary materials:

- 1 hand generator
- 2 alligator clip leads, 1 black and 1 red
- 1 cluster of 6 white LED Christmas tree lights
- 1 cluster of 6 clear incandescent Christmas tree lights
- Infrared goggles (optional)

Please don't use this activity as a demo. It's crucial that each student experiences cranking the hand generator for both types of bulbs and also gets to observe the brightness each produces. This activity would work well at a learning station or center for your students to rotate through.

Theory

There are two different types of light bulbs. The first type, the kind developed by Thomas Edison, using a simple physical principle: when you get something hot, it glows. The hot wire filament inside an incandescent light bulb gives off visible light, but it gives off a good deal of electromagnetic radiation that you can't see. A light bulb that uses 100 watts bulb of electric power only emits 4 watts of visible light. The other 96 watts are given off in the infrared spectrum. This infrared will end up as heat, so if you are using the bulb to heat something, that's OK, but, it isn't a very energy efficient way to create light. The second way to make something glow is to use electricity to excite individual atoms. This is the technique used in compact fluorescent and the newer LED bulbs. A compact fluorescent bulb can produce 4 W of visible light for an energy input of about 25 W—much



Feeling the differences in energy required to light different bulbs.

more efficient! LED bulbs are more efficient yet.

In this experiment, students will light two different types of bulbs using a generator to provide the power. Students will see that the bulbs are equally bright, but making this light with incandescent bulbs takes much more power input, and so they'll need to work quite a bit harder.

Doing the Experiment

Tell students that they have two jobs to do in this experiment. First they will watch and observe which of the two lights (the incandescent lights or the LED lights) seems brightest to them. Without telling anyone else, they should jot their observations in their notebooks. Secondly, they will each crank the hand generator for both sets of lights and decide which set of lights they think is more energy efficient and why. They should also record this information in their notebooks.

Before they begin, demonstrate how to attach the alligator clip leads to the two nails (electrodes) on the hand generator. Explain that you are attaching the black clip lead to the top nail and that this is the negative end. Now attach the red alligator clip lead to the other electrode, the positive end. Show them how to attach the red lead to one end of the incandescent cluster and the black lead to the other end. Explain that they will crank the generator and take notes on the bulb brightness and how it felt to crank it.

Explain that when they hook up the LED bulb cluster, one end of the cluster is marked positive and the other negative. They will need to hook these ends up accordingly, as in LEDs, the electricity only flows in one direction.

Before they begin, you will probably want to create a cranking rhythm, so your students are all turning the generators at a similar rate. Some teachers play music so that students crank to the beat.

After all of your students have worked with the bulbs and the hand generator, have them meet and discuss their findings. Many may be surprised at how easy it is to light the LED bulbs and how much more effort and energy it takes to light the incandescent. You may want students to slip on a pair of infrared goggles as they crank the generator and light the bulbs. They will notice that they can see which bulbs have wasted energy that we normally can't see.

Summing Up

This is a great activity for students to do as they can actually feel the energy difference it takes to achieve visible light from an incandescent bulb and an LED bulb.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Efficiency & Conservation

Increased efficiency of cars

GOAL

All cars in the world by must have a minimum fuel efficiency of 60 miles per gallon.

COSTS

This will require much more efficient engines and lighter weight vehicles.

Efficiency & Conservation

Reducing miles traveled by cars

GOAL

Reduce the yearly number of miles traveled of every car in the world by half.

COSTS

This will require better urban planning, increased use of telecommunication, and more use of mass transit.

Efficiency & Conservation

Increasing efficiency of buildings

GOAL

Increase (by 25%) efficiency of the space heating and cooling, water heating, lighting, and electric appliances in *all* new and existing residential and commercial buildings.

COSTS

This will require a dramatic increase in the efficiency of the buildings through insulation and other conservation measures.

Efficiency & Conservation

Increased efficiency of electricity production

GOAL

Double the efficiency of every coal plant in the world. (Coal is singled out because it is used to produce more electricity than any other fuel, and it releases more carbon per unit of energy.)

COSTS

A doubling of efficiency will require dramatic changes to the way coal is used to generate electricity.

Fossil-Fuel-Based

Fuel switching

GOAL

Retrofit 1400 coal-fired power plants to run on natural gas.

COSTS

This uses existing technology. Combined-cycle gas power plants produce much more energy per kilogram of carbon than coal plants. Nonetheless, this would be a major effort, and would increase costs.

Fossil-Fuel-Based

Carbon capture & storage (CCS)

GOAL

Capture all of the emissions of 800 coal or 1600 natural gas power plants and store the carbon dioxide underground.

COSTS

This is a technology that is still being developed. There are 3 pilot plants in the world. The technology would need to be scaled up and implemented very widely.

Fossil-Fuel-Based

Coal synfuels with CCS

GOAL

Produce liquid fuels for transport from coal, and capture the carbon dioxide released in the process. 180 plants would be needed.

COSTS

This is a technology that is still being developed. New technologies will need to be developed, scaled up, and implemented.

Fossil-Fuel-Based

Fossil-based hydrogen fuel with CCS

GOAL

Produce hydrogen fuel from fossil fuels, and capture and store all carbon dioxide. Currently, hydrogen is generally produced from natural gas. The scale of this production will need to increase by a factor of 10, and all carbon will need to be captured.

COSTS

We can produce hydrogen, but we need to develop reliable ways to transport it and safely use it to fuel cars.

Nuclear Energy

Nuclear electricity

GOAL

Triple the world production of nuclear energy.

COSTS

This is a proven technology, but it has risks associated with waste storage and the possibility of the diversion of fuel or waste to weapons production.

Renewable Enegy and Biostorage

Wind-generated electricity

GOAL

Increase worldwide wind power capacity by a factor of 30 and displace a corresponding amount of coal-fired power plants.

COSTS

The area required for the windmills would be approximately the size of Germany. Wind turbines are cheap to operate, but they require huge up-front costs.

Increase wind capacity by a factor of 30 and displace the corresponding amount of coal -based electricity.

Renewable Energy and Biostorage

Solar electricity

GOAL

Increase worldwide solar electric power capacity by a factor of 700 and displace a corresponding amount of coal-fired power plants.

COSTS

The area required for the solar cells would be approximately the size of New Jersey. Solar cells are cheap to operate, but they require huge up-front costs.

Renewable Energy and Biostorage

Wind-generated hydrogen fuel for cars

GOAL

Install 4 millions windmills to produce hydrogen from water and use it to power vehicles.

COSTS

The area required for the windmills would be approximately the size of France. This would require changes to cars, fueling systems, and the development of new networks for distributing hydrogen fuel.

Renewable Energy and Biostorage

Biofuels

GOAL

Increase the worldwide production of ethanol for vehicles by a factor of 30.

COSTS

The cropland required would be approximately the size of India. This would have dramatic effects on world food production.

Renewable Energy and Biostorage

Forest storage

GOAL

Halt all reduction in forest cover worldwide.

COSTS

The countries where deforestation is taking place would need to be compensated.

Renewable Energy and Biostorage

Soil storage

GOAL

All cropland in the world would be managed to reduce carbon production.

COSTS

This would be quite difficult to implement.