What makes a gas a greenhouse gas?

Overview

Greenhouse gases, particularly in relation to climate change, have 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?

Necessary materials:

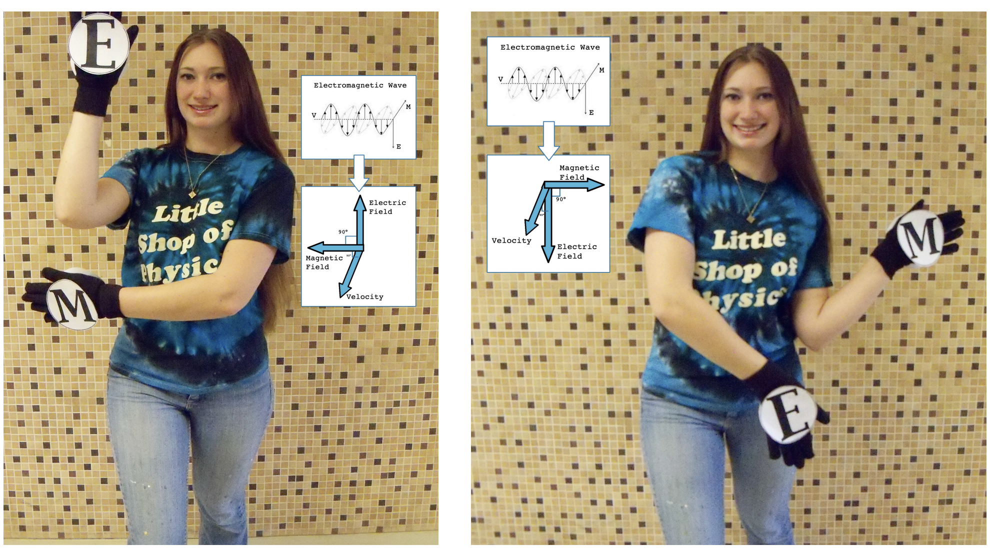
- large open area for your students to move about freely in groups of 2 and then 3
- 2 gloves–one marked E on both sides and one marked M on both sides
- stickers, hats, wigs, or other ways to designate what type of atom each student is portraying

Theory

Just two gases account for 99% of the earth's atmosphere: nitrogen (N_2; 78%) and oxygen (O_2; 21%). The remaining 1% is a mix of argon, neon, ozone, carbon dioxide, water vapor, methane, and other trace gases. Even though these gases are present at much lower concentrations than N_2 and O_2, they can still dramatically affect conditions on the earth…

Energy from the sun travels to the earth in the form of short-wavelength electromagnetic waves. The earth absorbs these waves, and thus warms. The earth in turn cools itself off by radiating long-wavelength thermal radiation back to space. Certain gases — the greenhouse gases — in the atmosphere can 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 in our atmosphere absorb the outgoing thermal radiation and send some of the energy back down to earth. But why can some gases do this while others can't? Molecules that don't share charge equally among atoms can interact with the electric field of an electromagnetic wave, thereby absorbing its energy, then emit thermal radiation to warm the earth.

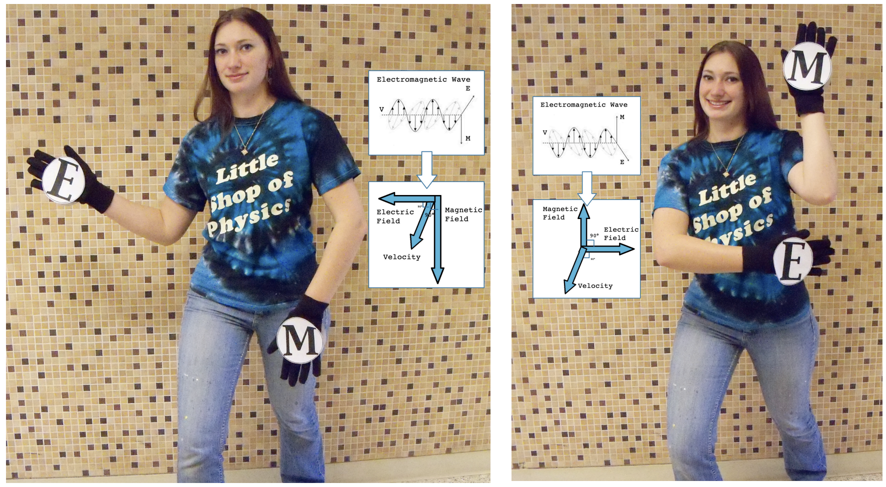


In this simulation of an electromagnetic wave, the wave is traveling out of the page toward you. The electric field is oriented up and down, as the magnetic field moves from side to side.

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 the gloves on or hold the signs and practice portraying an electromagnetic wave: Move one letter go from side to side as you move the other letter 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.



Now the magnetic field is now oriented up and down, and the electric field moves from side to side. The electric and magnetic fields can each move in either plane, but they are always perpendicular to one another!

<u>N_2 & O_2</u>

Have your students break into pairs and lock arms to simulate the chemical bonds between them. Each molecule pair can be facing in any direction, but they need to stand still. Tell one half of the class that 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 there is no positive or negative charge on either atom in either molecule.

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

Use the gloves and move the E and M back and forth vertically and horizontally as in the pictures above. What happens to the N_2 and O_2 molecules? Not much! The individual atoms don't have a 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 to electromagnetic radiation.*

Charges are shared equally between the two atoms in molecular nitrogen (N_2). Neither atom has a partial charge, so there is little interaction with electromagnetic waves. Molecular oxygen (O_2) is similar in this respect.

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; it has a slight positive charge. There is an oxygen atom with a slight negative charge on each side of the carbon atom. 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:

As you point your electric field glove forward, the carbon atom feels a force towards it as the oxygen atoms feel a force back. When you point the glove backward, the carbon atom moves backward and the two oxygen atoms move forward. This sets up a nice flexing vibration of the molecule which happens to be at the perfect frequency to absorb and emit thermal infrared energy. Carbon dioxide molecules do have another interesting vibrational mode: the carbon atom can move away from the oxygen atom on the left and toward the oxygen atom on the right when the electric field is moving to the right.When the electric field is reversed, the carbon atom then pulls away from the oxygen atom on the right and moves toward the one on the left. This makes a nice asymmetrical stretch.

H_2O

Have your students stay in their groups of 3 and tell them that they are now going to act out H_2O. 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° from the other hydrogen atom. The hydrogen atoms have a slight positive charge. With one of your groups of 3, demonstrate the many ways in which H_2O can vibrate given its particular 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 are those which can interact with electromagnetic waves as we have just demonstrated and described. 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, whereas CO_2 exists throughout.

You can try an interesting variation on this activity in which ~78% of your students act as N_2, ~21% as O_2, and several depict 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. What happens if you increase this fraction?

Summing up

In this kinesthetic activity, students 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

Colorado State University College of Natural Sciences: http://www.natsci.colostate.edu

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