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

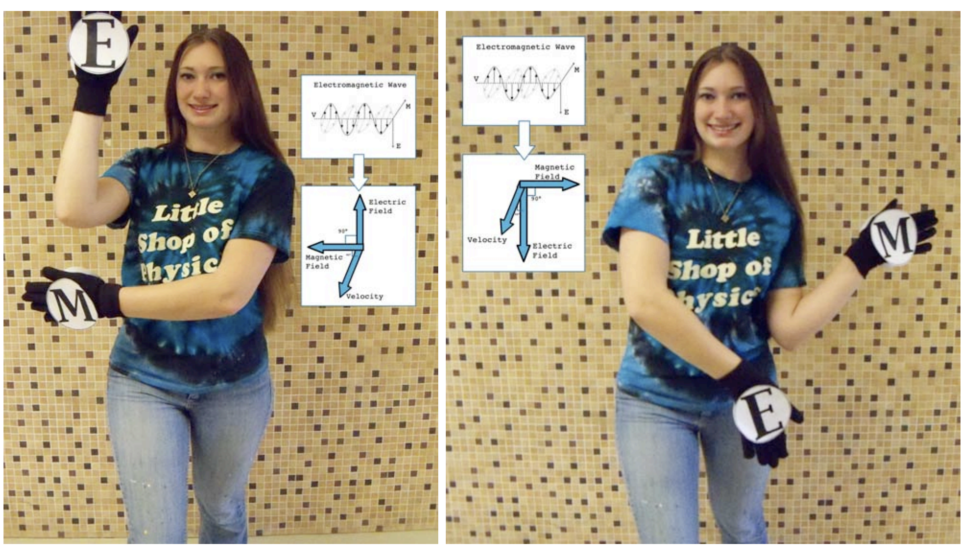
The earth's atmosphere is composed of a variety of gases–in fact, 99% of the Earth's atmosphere consists of two gases: nitrogen (N_2), which makes up 78%, and oxygen (O_2) which accounts for 21%. The other 1% is a mix of argon, neon, ozone, carbon dioxide, water vapor, methane and other trace gases.

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.

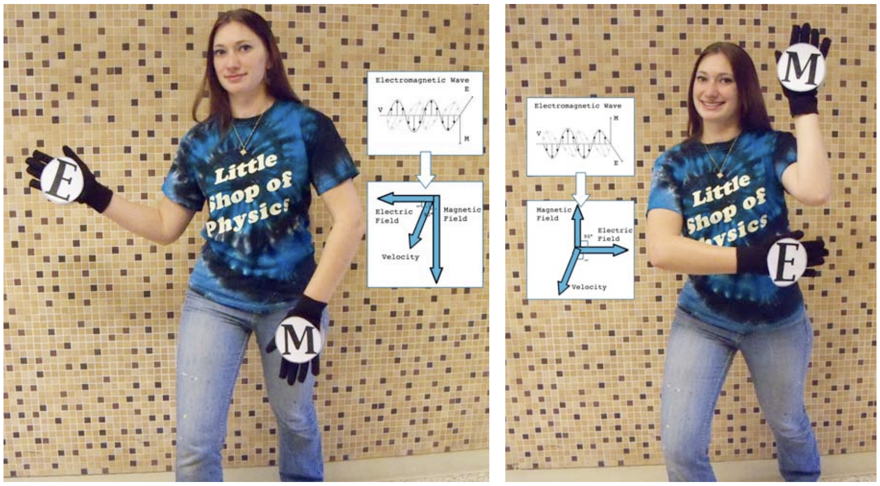


In this simulation of an electromagnetic wave, the wave is traveling out of the page toward you. The electric field is oriented up and down, as the magnetic field moves from side to side.

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



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

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.

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 does the atmosphere keep the earth warmer?

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

Overview

The earth cools by radiation. That's the only way that the earth can exchange energy with space. But the atmosphere is not transparent to the far infrared that the earth emits, and so the earth is warmer than it would otherwise be.

Theory

We can simulate the energy exchange of the earth and the atmosphere with space by using a stack of glass plates for this simple reason: Glass is transparent to the visible light and the near infrared emitted by the sun (and the lamp!), but opaque to the far infrared, the thermal radiation, emitted by the earth. So energy gets in but can't get out—at least not so easily.

Necessary materials:

- Four identical pieces of glass (You can use glass from the same size picture frames.)
- We use 4 clear rubber feet on the bottom of each piece of glass as spacers.
- Spray one side of one glass plate with flat black paint.
- Infrared thermometer
- Desk lamp with an incandescent or halogen bulb

IR thermometers can be found at www.harborfreight.com under "non-contact pocket thermometer".

We purchased our frames at a dollar store, which made them quite reasonable!

Doing the Experiment

We'll start with a simple experiment that shows how the atmosphere keeps the earth warmer. This can be done as a demo, but is more effective when small cooperative groups work to collect data and then compare with others. Once you set the experiment up, you'll need to let the lamp shine on the stack of plates for 20 minutes.

SAFETY NOTE I: The desk lamp with the incandescent or halogen bulb can get very hot. Be sure students are careful when working around the lamp

SAFETY NOTE II: The glass plates have sharp edges, so students need to be especially careful when moving and lifting the plates. You may want to keep the picture frames on each glass plate and put the rubber feet on the frames instead.

- Have your students make a stack with the 4 glass plates. They should put the black painted glass plate at the bottom of the stack. Place the desk lamp over the stack of glass plates and discuss how close you want the light bulb to be to the top of the stack.Turn the desk lamp on and let it shine on the stack of plates for approximately 20 minutes.
- While you are waiting for the experiment to be ready, model for your class, what they will be doing once they begin. Explain to your students that they are setting up a model of layers of the atmosphere. Show them how they will have to work as a group to conduct this experiment. There will be four jobs per group. One student will turn off the desk lamp and turn it away so that it doesn't keep

warming the plates with infrared radiation. The second student uses an infrared thermometer immediately to measure the temperature of the top plate, while the third student records that temperature, while the fourth student pulls the top plate off. The process is repeated by students 2, 3, and 4 until they have measured the temperature of all the plates in the stack. We recommend that you have a group of students practice this, so they all realize how quickly they have to do this. The plates start cooling immediately, so the quicker they are, the better.

- While you are still waiting for the experiment to be ready, have students predict what they think will happen with the temperatures. Which plate do they think will be the warmest? The coolest? etc.
- Conduct the experiment and have students report and compare their data. Discuss what they think is happening. They will probably find that the bottom plate is the warmest, the one above a little cooler, and the one above that cooler yet. How about the very top plate? This will depend on the light source. Why might this be?
- This will be a great place to explain how the glass plates are like layers of the atmosphere. The visible and near infrared radiation from the lamp (sun) can pass through the layers, but once this energy is absorbed by the earth (the black plate) the radiation emitted is thermal radiation and is a longer wavelength. It cannot pass through the layers as easily, so the earth gets warmer.

Activity Variation 1

- Put two glass plates painted black on a table. Put a desk lamp over them.
- Turn on the desk lamp and leave it on for at least 5 minutes.
- As soon as you turn off the desk lamp, use the infrared thermometer to take a temperature of both black plates and record.
- Immediately place a clear glass plate over one of the black plates.
- Wait one minute, remove the extra frame, and then take the temperature of both black plates again and record.
- Quickly put the extra frame back on the black felt frame and repeat the procedure again.

Activity Variation 2

- Have one student hold up his/her hand and take the temperature of the hand and record.
- Have another student hold a glass plate in front of the student's hand. Use the infrared thermometer to take the temperature again and record. The temperature reading of the hand with the glass plate in front should be much cooler.
- Discuss what they think is happening.

Summing Up

This is a good simulation that can show how the layers of the atmosphere keep the earth warmer than it would otherwise be.

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 do long and short EM waves interact with the Earth's atmosphere?

A laboratory experiment from the Little Shop of

Overview

Shortwave radiation emitted by the sun, and longwave thermal radiation emitted by the earth interact very differently in the atmosphere. This kinesthetic activity will allow your students to experience the difference, and reinforce their understanding of greenhouse gases as well.

Necessary materials:

- A large open area for your students to move about freely
- Props or signs to represent the Earth, Sun, and Space
- Party hats in 2 different colors to represent the short EM waves from the sun and the long EM thermal waves from the earth. We used gold and silver, but the important thing is to associate one color of hat with short wave radiation and another color with long wave radiation.
- Headbands with ears to represent some of the different greenhouse gase. We bought ours at a party supply store.
- A whistle or signal to stop the action

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 (N2), which makes up 78%, and oxygen (O2) which accounts for 21%. The other 1% is a mix of argon, neon, ozone, carbon dioxide, water vapor, methane and other trace gases.

The energy from the sun travels to the earth as electromagnetic radiation. These short EM wavelengths traveling from the sun pass easily through the earth's atmosphere, for they are transparent to the gas molecules of the atmosphere and don't interact with them. The earth then absorbs these short wavelengths and warms up. The earth in turn, cools itself off by radiating long wavelengths of thermal radiation back to space.

Certain gases in the atmosphere, the greenhouse gases, absorb these outgoing long electromagnetic wavelengths. It turns out that a gas molecule that has more than two atoms has the capability of vibrating in different ways and can absorb different wavelengths. It then can emit heat back to warm the earth.

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.

Doing the Experiment

Students play different roles in this kinesthetic activity and will benifit from an expalantion of the many parts before starting model. If you take the time to practice and review each step before running this model, it will run quite smoothly.

The sun is positioned on the opposite end of a large open area from teh earth.

Sun, Earth, & Space

Gather your students in a large open area so they can spread out as needed. Choose one student to represent the sun, another to represent space, and another to represent the earth. Give them signs or props so the rest of your class knows what role each of these students is portraying. Have the sun and earth stand on opposite ends of the large open area with space somewhere beyond the sun.

The Atmosphere

Remind students that most of the atmosphere (99%) is made up of 2-atom molecules of nitrogen, N2, and oxygen, O2, but that 1% of the atmosphere is composed of trace gases, some of which are greenhouse gases. Now choose several of your students to represent greenhouse gases. We have our students that represent carbon dioxide or water vapor wear headbands with ears on them to help simulate the number of atoms in the molecule. For carbon dioxide, the student's head is symbolizing carbon, and the two ears on the headband represent oxygen. For water vapor, the student's head symbolizes oxygen and the ears on the headband represent hydrogen. Have them spread out in the area between the earth and the sun, but put all the water vapor in the lower atmosphere closest to the earth. Have carbon dioxide there as well, but also some can be a bit higher in the atmosphere. Greenhouse gases will let the short waves by, without interacting. When the long wave radiation from the earth passes by, each greenhouse gas will interact with every other one coming directly toward them, and send them back towards the earth. To interact, greenhouse gases should put their hands up at shoulder height and press their hands to the long wavelength's hands, moving hands around for a few seconds like dancing. Then let go giving them a push back to the lower atmosphere and earth.

Greenhouse gases spread out in the atmosphere near the earth.

Short wave radiation from the sun moves energetically through the atmosphere. Note that the greenhouse gases don't interact with them.

Short Wave Radiation from the Sun

Explain to the rest of your class that they each get to act out two different wavelengths–the short wave radiation coming from the sun that warms the earth and then the long wave thermal radiation emitted by the earth that radiates to space, thus cooling the earth.

The short wavelengths from the sun and the long wavelengths from the earth behave very differently. Have them practice being short wavelengths by moving their arms and legs quickly and taking a lot of tiny but fast steps. Then have them practice long wavelengths by acting like they are in slow motion as they move very slow and deliberate.

The student has changed hats. The energetic radiation from the sun has been absorbed by the earth and now thermal radiation is emitted by the earth.

Note that the students are moving in slow motion to simulate the thermal radiation emitted by the earth.

Run the "Long and Short of It" Kinesthetic Model

It is suggested that you have a practice run of the activity, following the directions below, with just one or two students as wavelengths, so your other students in the class can observe before participating in the model with everybody.

To start the activity, have your students line up behind the sun and have them each put on a gold party hat to symbolize that they are short wavelengths radiating from the sun. One by one they will travel through the atmosphere as they practiced, acting out very energetic radiation from the sun. They will travel past the greenhouse gases, without interacting with them. Once they get to earth, they will press into it (the sign or globe), simulating that they are absorbed by the earth. They then exchange their gold hat for a silver one, indicating that they are now long wave thermal radiation from the earth. They should move slowly as practiced through the atmosphere and out toward space. Now they will most likely have chances to interact with greenhouse gases. It they are directly in the path of a greenhouse gas, the gas may press his/her hands against the long

The greenhouse gas interacts with the long wavelength emitted by the earth.

Be sure to stop the action throughout the activity so students can have time to observe and discuss the concentration of longwave thermal radiation.

Summing Up

This is a great activity to do after *What makes a gas a greenhouse gas?* and *How does the atmosphere help keep the earth warm?*

You may want to discuss the importance of the interactions of the thermal radiation with the greenhouse gases. What would the world be like if the greenhouse gases didn't interact with the thermal radiation? What is happening now with more greenhouse gases in the atmosphere? Your class could suggest changes with the model and try them out to illustrate these two scenarios.

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

Why is it tropical in the tropics?

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

Overview

We have all seen the proverbial "wish you were here..." postcard featuring white sand beaches and palm trees bordering sapphire blue water that stretches as far as the eye can see. Why is it that there are certain regions of the world that never seem to experience winter? Why do some areas of the world have dramatic seasonal variations in temperature and others tend to stay within a smaller range?

This activity will allow students to explore the relationship between angle of incidence, intensity of solar radiation, and how it relates to seasons as well as the general climate of different regions of our planet.

Necessary materials:

Per group of 3 or 4:

- One large inflatable Earth
- A solar grasshopper with leads
- Multimeter
- Alligator clip leads

We purchased the solar grasshoppers from Deal Extreme but you can use any device that acts similarly.

Theory

Our planet is warmed by the sun, but not every part of the planet is warmed equally. The amount of energy transferred depends on the angle that the sun's rays make with the surface. If you hold a flashlight above a table top and shine it straight down you see a circle of light. If you tilt the flashlight, however, the light will stretch out to form an oval, covering a larger area of the table. The amount of light is the same, but it's spread out over a larger area; we say that the **intensity** is less.

The Earth's spin axis is tipped 23.5° from the plane of its orbit around the sun. For folks in southern Florida, during the middle of the northern hemisphere summer, the noonday sun is nearly overhead, so the sunlight is quite intense. But 6 months later, the sun is never higher than a bit more than 40° above the horizon, so even at noon the intensity of sunlight never reaches the peak it does in the summer.

For locations on or near the equator, the intensity of sunlight experiences a much smaller seasonal variation. Equatorial locations are always warm, but they are also always about the same temperature. There's no winter in Mombasa, only a wet season and a dry season, both quite toasty.

Doing the Experiment

Your students will use the large inflatable Earth and the solar grasshopper to determine the intensity of the sun's radiation at a given point on the surface. Most students are familiar with the fact that solar cells use the sun's light to create electricity, but this is a good point to reiterate. The current that the cell produces is, more or less, directly proportional to the captured energy. Have your students do the following:

- Align the Earth so the sun shines directly on the equator, by the Galapagos Islands.
- Attach the clip leads to the solar grasshopper and to the multimeter.
- Set the meter to measure current and adjust the range so that the maximum current stays on scale.
- Place the solar grasshopper in the direct sunlight and measure the current
- Place the solar grasshopper where they live and measure the current. (Note: Fort Collins is about 40° N)

The amount of current you see will be proportional to the intensity of the sunlight. Have your student explore taking readings from different areas on the Earth at different latitudes. The current position of Earth, with the sun on the Galapagos Islands represents how it would be on either of the equinoxes. Think about how to tip the ball to represent northern hemisphere winter and summer; this takes some thought.

Look at the variation in current (and thus received power) over the course of one rotation (representing a day) for the northern hemisphere winter and summer. The key is to measure the seasonal variation. How much do things change between winter and summer. For latitudes of 40° N, a good deal. For the equator... Not so much.

Summing Up

When the solar grasshopper is at the equator, the angle between it and the sun isn't greatly affected by the precession of the planet and so students should see values that vary over a small range compared to the data from the higher latitude position. For the latter, students should be getting higher values when the solar grasshopper is tilted towards the sun and lower values when it is tilted away. This is not due to the fact that the grasshopper is closer or further from the sun, as per the common misconception, but due to the changing angle and therefore changing intensity of the solar radiation. This yields the vast seasonal variation experienced at the higher latitudes. The solar intensity at the equator stays high and relatively stable throughout the year making it a rather postcard-worthy region of the world.

For More Information

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

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

In an Alaskan summer, the sun is up 24 hours a day. Why isn't it hotter?

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

Overview

Alaska, known as the land of the midnight sun, attracts tourists and adventurers alike at all times of the year. If you happen to be planning a summer getaway there, however, you might want to consider packing more jackets than sun tan lotion. In the city of Barrow, which is at 71° North, the sun does not set between the middle of May and the beginning of August but their average high temperature is only 45° F (7.2° C)! How can an area of the world that experiences 24 hours a day of sunshine still be so brisk?

Necessary materials:

Per group of 3 or 4:

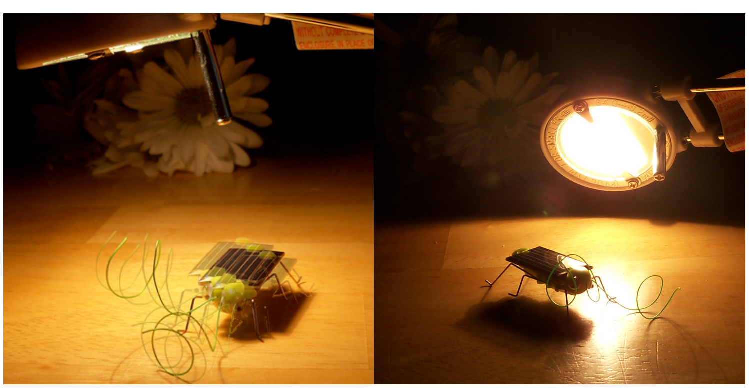
- One solar powered grasshopper
- One halogen or incandescent lamp

We purchased the solar grasshoppers from Deal Extreme but you can use any device that acts similarly.

Theory

Our planet is warmed by the sun, but not every part of the planet is warmed equally. The amount of energy transferred depends on the angle that the sun's rays make with the surface. If you hold a flashlight above a table top and shine it straight down you see a circle of light. If you tilt the flashlight, however, the light will stretch out to form an oval, covering a larger area of the table. The amount of light is the same, but it's spread out over a larger area; we say that the **intensity** is less.

Due to the tilt of the earth and the precession of the planet, the far North and South don't experience day and night as we do in the middle latitudes. During the summer in Barrow, the earth is tilted toward the sun. As it rotates the sun never sinks below the horizon—but the sun is always at a very low angle in the sky. The intensity is never very great.



The solar cell generates electricity that depends on the intensity of the light. So it generates more electricity when the lamp is directly overhead than when it is at an angle.

Doing the Experiment

Each group should set their lamp so that the light shines directly down on the solar powered grasshopper. This will be the highest intensity possible. The grasshopper will hop and shimmy as the solar cell runs the motor, a vibrating motor from a cell phone.

Now, using the lamp's base as a pivot point, tilt it slowly back and fourth in an arc so that the light falls on the solar cell from directly horizontal on one side to the other side. Ask your students to note how the intensity changes given the change in behavior of the solar grasshopper. They should have observed a greatly reduced activity level of their insect when the light was coming in from a low angle across the "horizon" of the solar cell.

Most of us would associate a scene like this with dawn or dusk. This photograph, however, was taken at 10 am on a summer day in Barrow, Alaska

Summing Up

Equatorial areas do experience the sun directly overhead but the further north or south you are from the equator, the lower the sun sits in the sky. In Barrow, the sun never gets higher than approximately 30˚ above the horizon. There might be 24 hours a day of sunshine in the summer but they never the intense sunlight you'd experience at the equator.

A low intensity for 24 hours still does lead to a significant amount of incoming energy. In fact, the total energy from the summer sun in Barrow right at the summer solstice is more than that at the equator. But there are other climate factors at work. The cooling during the long winter night takes a long time to offset, particularly for a coastal city.

This experiment is a good way to introduce seasonal variability as well as reinforce the concept of intensity.

For More Information

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

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

How does the earth cool itself off?

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

Overview

The earth gets energy from the sun. The sun shines on the earth's surface, warming it.

If the earth had no way of cooling off, it would simply keep getting hotter and hotter. So the earth must have some way of cooling off, some way of losing energy to space...

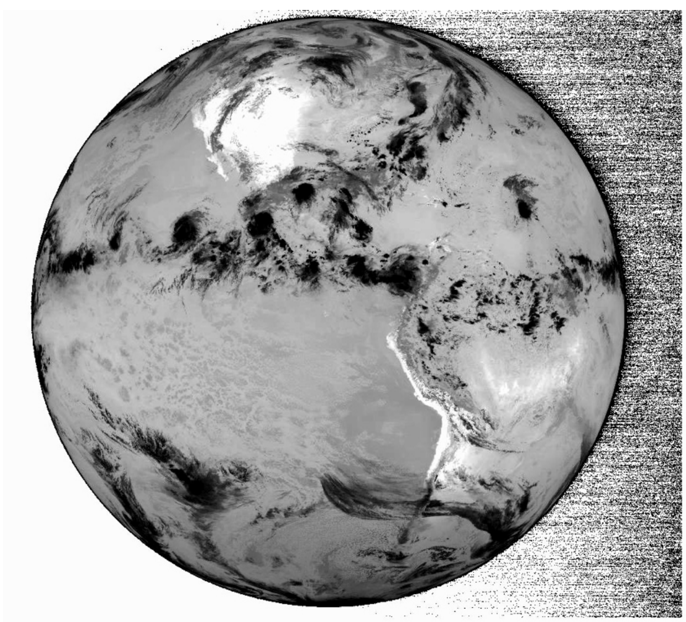
Necessary materials:

- World map placemat
- Desk lamp
- IR thermometer
- 3 squares of standard transparency

The infrared thermometer is the key item; it measures temperature by measuring an object's emitted thermal radiation. They can be found at www.harborfreight.com under "non-contact pocket thermometer". The desk lamp is used to heat up the surface; any lamp will do, though an incandescent or halogen lamp is best.

Theory

When light shines on the earth, different places heat up by different amounts. Snow reflects most of the incoming light, so snowy areas tend to stay cool. Dark areas, like black parking lots, absorb incoming light, and so will warm up.



GOES-9 11 July 1995, 1800 UTC 12 micron IR GOES Project, NASA-GSFC

An infrared view of the earth, at 12 microns. The atmosphere is transparent to infrared of this wavelength. White is bright, black is dim. Look for hot spots and cold spots. Deserts are hot, and emit a lot; clouds are cool, and emit very little.

In order to keep at a relatively constant temperature, the earth must get rid of energy too. And it does: As emitted thermal energy, infrared, that is transmitted to space.

The hotter something is, the more infrared emitted. So a picture of the infrared that the earth emits shows us the hot spots and the cold spots. Look at the satellite photo at left; the American west is clearly pretty hot, as is appears quite bright. Cloudy patches appear dark; clouds absorb or reflect the infrared from the surface, so we only see the infrared they emit. Clouds are cool, so clouds appear as dark spots. Deserts are hot during the day, because they absorb a lot of incoming radiation, but at night they radiate energy back to space, so they get quite cool.

The same principles work on a smaller scale as well, of course. And this lets us do a simulation of these principles on a tabletop scale.

Doing the Experiment

In this experiment, students will simulate the energy transfer between the earth and space by using the light from a desk lamp to warm up a placemat. The placemat will warm up, so it will emit infrared, which they can detect with an infrared thermometer. The hotter the surface, the more energy emitted, which the thermometer will show. Adding an "atmosphere" can reduce the transmission of infrared, holding heat in, another thing that the experiment can show.

> **SAFETY NOTE: The desk lamps get hot, and if they are too close to the placemat, they can melt it. Please be careful!**

The experiment goes like this:

- Have students shine the light on the placemat for a few minutes, allowing it to warm. (Note: You can also do this experiment outside, letting the placemat warm up in the sun. That's actually a better way to do it, if you can get your class outside!)
- Now have them use the infrared thermometer to probe the temperature of different places on the placemat. Different colors will absorb different fractions of incoming radiation, and so will be at different energies. Reds will be cool, blues will be warm. (That's because reds tend to reflect infrared too; blues tend to absorb it, and so heat up more.)
- Now, add an atmosphere to a warm spot. While monitoring the temperature with the infrared thermometer, slip three taped-together sheets of transparency onto the placemat. This "atmosphere" will block the outgoing infrared, so the observed temperature will quickly drop. But as the "atmosphere" heats up the emitted infrared (from the transparencies) will come back.

We chose three sheets of transparency for this reason: Three sheets of standard transparency are about the same thickness, relative to the scale of the placemat, as the thickness of the earth's atmosphere. This is another good point to make—just how thin the earth's atmosphere is! (Three sheets of transparency corresponds to about 30 km on the scale of the placemat; 99% of the earth's atmosphere is below this height.)

Summing Up

This is a good way to illustrate in a qualitative manner the radiational warming and cooling of the earth's surface.

You could actually make this quantitative. If you measure the temperature vs. time, you can see that hot spots cool more quickly than cool spots—because they emit more infrared.

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

Why does it get colder on clear nights than on cloudy nights?

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

Overview

You know it's true: If there isn't a cloud in the sky, the air temperature will drop much more over night.

Why? It's all about radiation...

Necessary materials:

- Infrared thermometer
- Sheets of plastic, glass, etc.

The crucial piece is the infrared thermometer. You need one that can measure very cold temperatures, and one with a reasonably narrow field of view. IR thermometers can be found at www.harborfreight.com under "non-contact pocket thermometer".

Theory

All objects radiate electromagnetic waves. And increasing an objects temperature increases the total amount of energy radiated; hot objects "glow" more brightly.

Increasing the temperature also decreases the peak wavelength of the emitted radiation. The sun gives off visible light. You are cooler than the sun, so you emit energy, and you emit it at a longer wavelength, in the far infrared region of the spectrum.

The sun does glow more brightly than you. But you are still pretty bright! The amount of energy you emit might come as a bit of a surprise.

Here's a remarkable fact: An unclothed human will *emit* a significant amount of electromagnetic energy—about 850 W. Your body's basal metabolic rate is only about 150 W, so something else must be going on. If this was all there was to the story, you'd be losing 700 W more than you generate, so you'd cool off and die.

Taking the temperature of the sky. On this clear Colorado afternoon, it was a frosty -30°C.

But there is a piece we left out: The radiated energy that your body absorbs from the environment. An unclothed human in a room at about 20°C will your *absorb* about 750 W of thermal energy that is emitted by the walls, floor and ceiling of the room. The net loss of energy is only 100 W—enough that you will feel chilly, but not so much that you will develop hypothermia.

If the walls of the room you are in are cold, you will radiate just as much, but you will get less back. If the walls are warm, you will get more back. The temperature of the walls, ceiling and floor in a room are every bit as important to your comfort as the temperature of the air.

Now, let's look at the earth. The only way the earth can gain or lose energy is by radiation. During the day, sunlight warms the earth. At night, the earth radiates—a lot—and it cools. Think about this: The earth, as a whole, stays at about the same temperature from day to day. This means it must be radiating as much energy to space as it receives from the sun. If you were to look at the earth with infrared eyes, it would be really bright.

This emitted infrared carries away energy. But the atmosphere isn't particularly transparent to infrared, so the earth doesn't cool off so much. It ends up being a bit warmer than it would be with no atmosphere. If the earth had no atmosphere, the earth would radiate enough energy to cool off to an average temperature of -18°C. But we do have an atmosphere, and one that blocks infrared. This keeps the earth's temperature at a much more pleasant 15°C. This warming is called The Greenhouse Effect, and it is, undoubtedly, A Good Thing. But as the atmosphere changes, the earth might warm up further... Perhaps catastrophically. This isn't good.

Doing the Experiment

If you point an infrared thermometer at something, it measures the emitted infrared and translates this into a temperature. Some things are transparent to infrared, and some things aren't.

> **SAFETY NOTE: The thermometers we use have lasers on them. The usual precautions regarding lasers in the eyes should be followed.**
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> **EQUIPMENT SAFETY NOTE: The instruments should not be pointed at the sun! This will destroy them.**

Here are some things you can try:

- Point the thermometer at your hand, and pull the trigger. You will measure you hand's temperature by the infrared it emits. Try measuring the temperatures of other things.
- Now, put a piece of glass between your hand and the thermometer. Can it measure your hand's infrared through the glass? Nope. Glass is opaque to infrared.
- Try other things between your hand and the thermometer. What things absorb? what things transmit?
- Can you find surfaces from which infrared reflects? How would you measure this?
- Now, go outside and point the thermometer at the sky. If it "saw" all the way to space, it would measure a really, really low temperature. But it doesn't. It "sees" upper levels of the atmosphere, which absorb (and emit) infrared. These upper levels are cold, quite cold, so, at night, the earth will radiate a good deal of energy while getting little back.
- Now, point the thermometer at a cloud. You will see a much higher temperature—the cloud is warmer, but it also reflects infrared from the surface. If you are underneath a cloud at night, you will get more radiation back, and cool down less.

After some experimenting, you students should be ready to answer the central question of this exercise:

> **How do the observations show us that the earth will cool down more on clear nights than on cloudy nights?**

Summing Up

What happens when the atmosphere as a whole transmits less infrared? Think about it!

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

What is the "greenhouse effect"?

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

Overview

You know that putting on another layer of clothing helps keep you warm on a chilly day. The same thing is true for the earth—the layers of the atmosphere keep the earth from losing so much energy to space, keeping us nice and toasty.

Necessary materials:

- Infrared thermometer
- Cold day
- Students with layers of jackets, sweaters and other warm clothes

The crucial piece is the infrared thermometer. You need one that can measure very cold temperatures, and one with a reasonably narrow field of view.

IR thermometers can be found at www.harborfreight.com under "non-contact pocket thermometer".

Theory

If the earth was bare rock, with no atmosphere, like the moon, the average surface temperature would be about -18°C, about 0°F.

We know that the earth is warmer than this—quite a bit warmer, as it turns out. The average surface temperature on the earth is about 15°C, or about 60°F. The earth is kept warmer by the insulation of the atmosphere; this is known as the **greenhouse effect**. It's easy to do a simple experiment that gives clues as to how the atmosphere works this magic. The key, just like the key to keeping warm in the winter, is layers.

If you take your warm hand and place it in a cup of cold water, heat will flow from your hand to the water. If you put your hand in a cup of hot water, heat will flow from the water to your hand. That's thermodynamics, specifically the second law of thermodynamics: heat flows from hot to cold. The amount of heat that flows depends on the temperature difference; more heat flows if the temperature difference is large, less if it is small. If you swim in a cool river, you'll get chilly after a while; if you swim in the ocean in the Arctic, you will quickly get hypothermia.

Layers keep you warm. As you "step down" from body temperature to outside temperature, the more steps there are, the smaller the steps.

This dependence on temperature difference is true for all mechanisms of heat exchange, including **conduction** (direct transfer by two objects in physical contact), **convection** (transport of fluids, like water or air), or **radiation** (transfer of energy by emission of electromagnetic waves.) The earth sits in the vacuum of space, so the only way it can gain or lose energy is by radiation. Understanding energy gain and loss by radiation helps us explain why the earth is warmer than it "should" be.

The atmosphere above us has many layers, and there is a variation in temperature as well. The earth gets radiant energy from the sun, and it gives off radiant energy to space. But there's a difference in these two types of radiation. The wavelength of the electromagnetic waves that an object emits depends on its temperature. Higher temperature means shorter wavelength. (That's how the thermometers you will use in this experiment work—they measure the radiation that objects emit. Shorter wavelength means a higher temperature.) The incoming radiation, from the sun, with its 6000°C surface temperature, is mostly visible light. The visible light comes right through the atmosphere. The outgoing radiation, from the surface of the earth, at an average temperature of 15°C, is mostly longer wavelength infrared. Infrared doesn't go through the atmosphere so easily; much is absorbed, largely by water vapor and carbon dioxide. There are layers of the atmosphere between the earth and space that absorb most of this radiation. They are warmer than space, and so their presence keeps us warmer. Above us is a warm layer of atmosphere, not the cold of space.

Doing the Experiment

This lesson gives you a good excuse to teach outside—in the winter! You want your (warmly attired) students to be outside long enough that the temperatures of the layers of their clothes have equilibrated. This will take some time, at least 10-15 minutes. After this time, their garments will be warm on the inside, cool on the outside. You'll get the most interesting results from students wearing layers—a shirt, a sweater and a thin jacket would be ideal. We'll assume this set of layers for the following description. We will mea

- Have one student with a good set of layered clothing serve as the test subject. Pick a spot in the middle of her back and use the infrared thermometer to measure the surface temperature of his jacket.
- Now, have him quickly remove his jacket, and measure the surface temperature of his sweater at the same spot.
- Next, have him quickly remove her sweater, and measure the surface temperature of his shirt at this spot.
- Finally, use the thermometer to measure his skin temperature—ideally, in the same spot, but use your judgement here. The inside of the forearm could work as well.

Look at the range of temperatures, from the warm skin to the cool outside of the jacket. There is a big difference in temperature between the inside and the outside, but each layer sits next to another layer which is only slightly different in temperature. Ask your students to explain how this layering, this "stepped" temperature profile, will help them stay warm.

Now, do this:

- Aim the infrared thermometer at the sky. Space is quite cold—deep space is about -270°C, or -455°F. But the thermometer measures a temperature that is much less frosty; it will probably read about 0°C, or perhaps as cool as -10°C or even -20°C. Cold, yes, but not -270°C!

What the thermometer is measuring is the temperature of a layer of the atmosphere that absorbs the earth's emitted radiation. Because the earth is covered by a layer of atmosphere that is cooler than the earth but warmer than space, it keeps the earth warmer. After making both sets of measurements, you can help your students make this connection.

Summing Up

Now, for the obvious question: If the earth is kept warm by the atmosphere, and if carbon dioxide in the atmosphere is responsible for this warming, and if we are increasing the level of carbon dioxide in the atmosphere, won't that cause the earth to warm up? The answer is: Almost certainly. It's like putting on another layer of clothing on a cold winter day, a simple matter of thermodynamics.

Of course, the atmosphere is more complicated than this; there might be other effects. But the fact is that *we are adding carbon dioxide to the air, and that the climate is changing*. There is clear data to show both effects.

For More Information

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