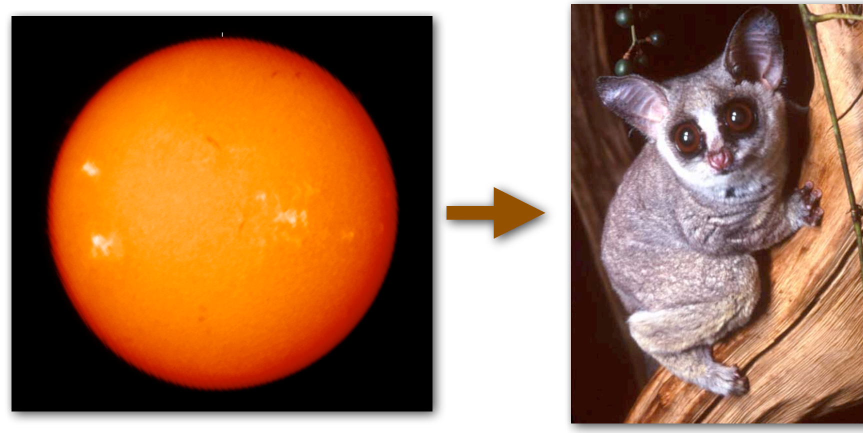
Law of Physics #4

Energy and the Conservation of Energy

The most important organizing principle in all of science.

Energy can't be created or destroyed.
It can only change from one form to another.
Anything that happens involves a change in energy from one form to another.

Energy Transformations

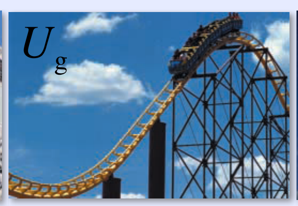


Energy is the "universal currency for making things happen."

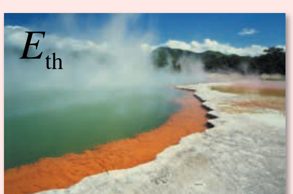
Understanding the world means understanding how and why energy changes from one form to another.

Energy comes in many different forms.

Mechanical energy:



Thermal energy:

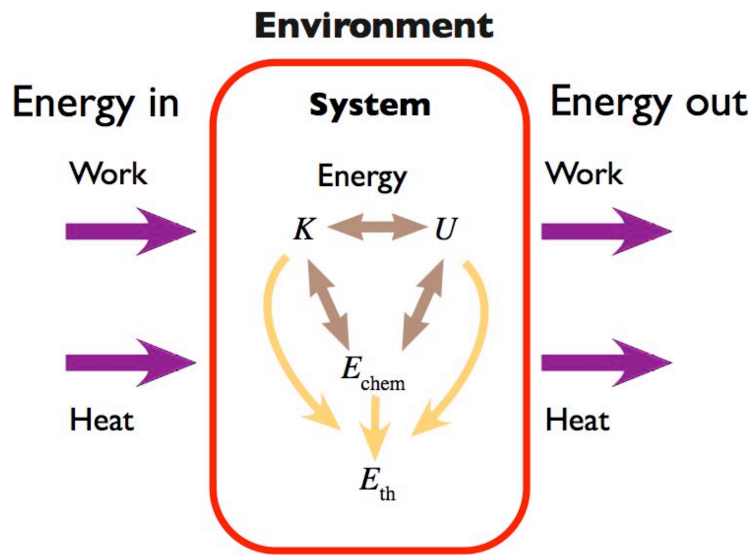


Other forms include:

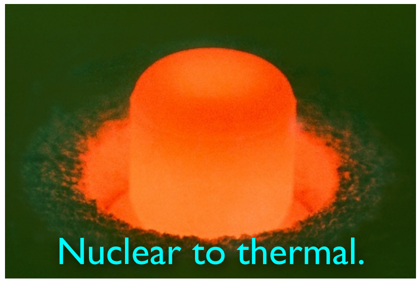
E_{chem}

$E_{nuclear}$

The Basic Energy Model



Thermal Energy is Special.



Kinetic to Thermal.

Equations: Energy

$$K = \frac{1}{2}mv^2$$

Kinetic energy of an object of mass m moving with speed v

$$U_g = mgy$$

Gravitational potential energy of an object of mass m at a height y (assuming $U_g = 0$ when the object is at $y = 0$)

$$U_s = \frac{1}{2}kx^2$$

Elastic potential energy of a spring displaced a distance x from equilibrium (assuming $U_s = 0$ when the end of the spring is at $x = 0$)

Equations: Work

Energy can be transferred into or out of a system by a force. The amount of energy transferred is the **work**.

$$W = Fd$$

Work done by a constant force $\vec{F}$ in the direction of a displacement $\vec{d}$

$$W = F_{\parallel}d = Fd\cos\theta$$

Work done by a constant force $\vec{F}$ at an angle θ to the displacement $\vec{d}$

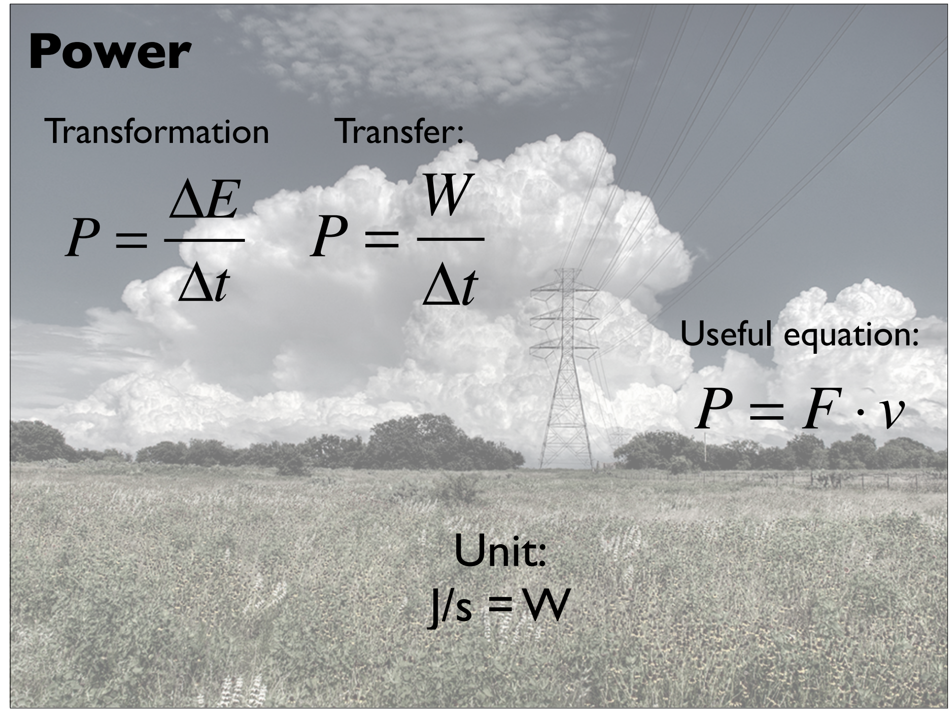
Energy Conservation.

$$K_i + U_i + W = K_f + U_f + \Delta E_{th}$$

A few things to note:

- Work can be positive (work in) or negative (work out)
- We are, for now, ignoring heat.
- Thermal energy is... special. When energy changes to thermal energy, this change is irreversible.

Power



Transformation

$$P = \frac{\Delta E}{\Delta t}$$

Transfer:

$$P = \frac{W}{\Delta t}$$

Useful equation:

$$P = F \cdot v$$

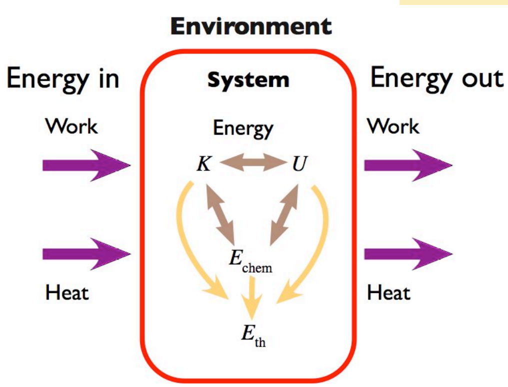
Unit:
J/s = W

Warming Up...

Recall:

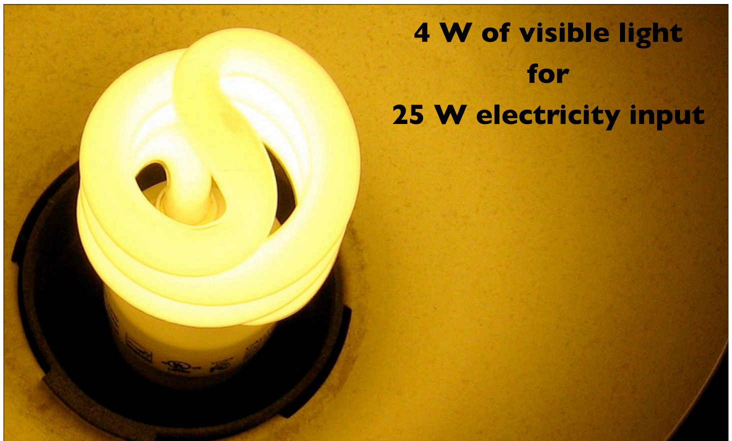
$$W = Fd$$

Work done by a constant force $\vec{F}$ in the direction of a displacement $\vec{d}$



$$P = \frac{\Delta E}{\Delta t}$$

$$K_i + U_i + W = K_f + U_f + \Delta E_{th}$$



4 W of visible light
for
25 W electricity input

$$e = \frac{\text{what you get}}{\text{what you had to pay}}$$

How Much Power Does it Take to Move One Person Down the Road?

Recumbent bicycle with fairing at 65 mph: 0.5 hp

Maximum "engine" power: 1.0 hp

Late-model Corvette at 65 mph: 12 hp

Maximum engine power: 350 hp

Process Limitations

A 70 kg kangaroo can bounce 10 km using half the energy that a 70 kg human takes to run this distance.

Fundamental Limitations

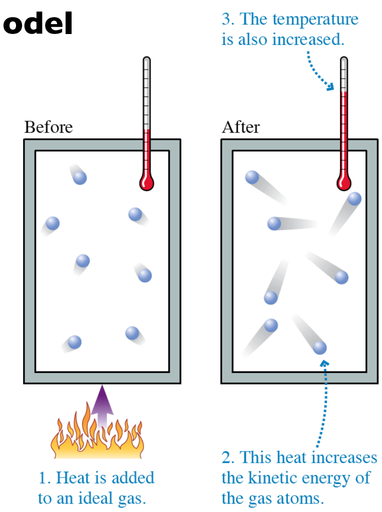
This power plant is about 35% efficient. No power plant does very much better.

The Ideal Gas Model

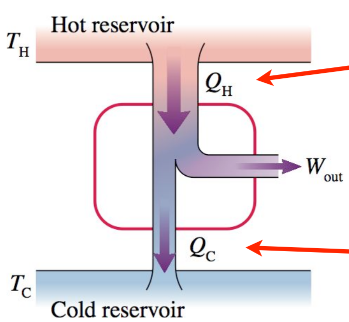
$$T = \frac{2}{3}\frac{K_{avg}}{k_B}$$

$$E_{th} = \frac{3}{2} N k_B T$$

Boltzmann's constant: $k_B = 1.38 \times 10^{-23}$ J/K



Entropy Limits the Efficiency of a Heat Engine



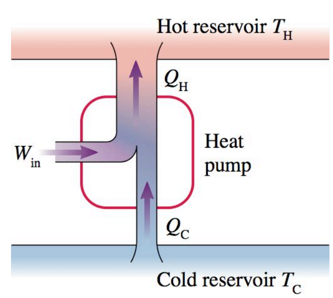
Entropy in: $\frac{Q_H}{T_H}$

Entropy out: $\frac{Q_C}{T_C}$

$$e = \frac{\text{what you get}}{\text{what you had to pay}} = \frac{W_{out}}{Q_H} = \frac{Q_H - Q_C}{Q_H}$$

$$e_{max} = 1 - \frac{T_C}{T_H}$$

Entropy Determines the Efficiency of a Heat Pump



$$\text{COP} = \frac{\text{what you get}}{\text{what you had to pay}} = \frac{\text{energy removed from the cold reservoir}}{\text{work required to perform the transfer}} = \frac{Q_C}{W_{in}}$$

$$\text{COP}_{max} = \frac{T_C}{T_H - T_C}$$

What is Energy?

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

Overview

We often think about energy in personal terms. People comment on the energy young children seem to possess. Others mention that they don't feel they have enough energy to make it through the day. We've heard that the world is running out of certain types of energy.

In spite of all of our everyday use of the word *energy*, it remains an abstract concept, and students may have developed quite a few misconceptions about it.

So, just what *is* energy?

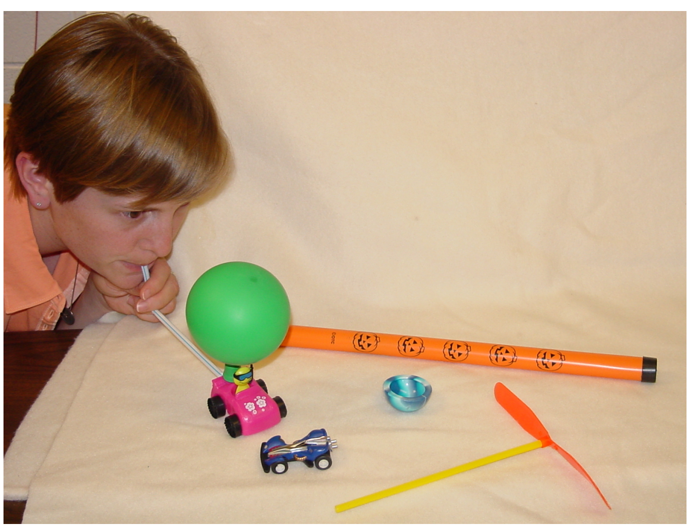
Necessary materials:

- 1 balloon car
- 1 pull-back race car
- 1 popper
- 1 groan tube
- 1 physics flyer

These toys are a great way to start your students' exploration of different energy forms and energy conversions. You can certainly use other toys or examples from the classroom or home as well. All the toys for these activities can be found at the following website: www.orientaltrading.com

Theory

Rather than *define* energy, it's easier to talk about *examples* of energy. When you walk up a set of stairs, you are using energy. When you turn on a light bulb, it is using energy. When you heat up a pot of water on the stove, you are using energy. Basically, *energy is something that lets us do things.*



Using simple toys to explore changes in energy.

Whenever you move or talk, you use energy. Any device or appliance in your house that does something uses energy too; lamps use energy, so does your television, so does your washing machine.

The weather on Earth is driven by the transfer of energy and the conversion of energy from one form to another, but this will be a difficult concept for students if they don't truly understand energy—its different forms, how it can be converted from one form into another, and the fact that it can't be created or destroyed. We believe the best way to teach students about energy is to simply let them do a variety of experiments with energy, and let them figure out what it is by themselves. In fact, all of the basic energy concepts are perhaps best discovered by exploration. The concepts are abstract, but relate nicely to commonsense notions of how the world works.

Doing the Experiment

This activity is meant to be an exploratory activity where students experiment, observe, and determine how various toys change energy from one form of to another. If this is your students' first time discussing energy, you may want to discuss types of energy, and model with other toys or materials prior to this activity.

You may introduce the toys in any order you prefer. The lesson plan is the same for each toy:

- Allow students to work with the toy.
- Have the students discuss with their neighbors what the toy does and what energy changes it illustrates.
- They should determine what form the energy starts out in, what energy changes occur while using the toy, including what form it is in when the toy stops. (Note: there are a lot of energy changes for each toy, so this can be somewhat open-ended. For instance, for the balloon car shown above, the energy starts as chemical energy in your body, which turns into motion energy of your body, which is stored as potential energy in the balloon. . .)
- It is important to follow this activity with a class discussion, to help students finalize and formalize their findings.

Guide for Specific Toys

Toy: Pull-back Race Car

1. What does the toy do? (You can nudge it forward by hitting it with your finger or you can push down on it and pull it backwards. When you let go, it races forward and you can hear a little mechanical sound.)
2. What energy change/s happen as this toy operates? (As you push down on the car and pull it backwards, you are applying a force to the car and putting some of your energy into elastic potential energy in the car, as a spring is tightly wound during this process. As you release the car, the spring extends, and the potential energy is converted into kinetic energy of the moving car. During this process, friction is at work, and some of the kinetic energy is converted to heat and sound energy.)
3. What form does the energy start out in? (After you've pulled it back, before releasing it,you've given it elastic potential energy, by winding the spring.)
4. What form does the energy turn into? (Kinetic energy of the moving car, plus some sound energy.)
5. What form is the energy in when it stops? (Heat energy. Ultimately, friction between the moving parts turns the kinetic energy into heat.)

Toy: Groan Tube

1. What does the toy do? (When you turn it upside down, a noisemaker inside the tube travels down to the bottom of the tube making a noise as it descends.)
2. What energy change/s happen as this toy operates? (When you flip the tube over in the air, you raise the noisemaker to the top of the tube. When the noisemaker is at the top of the tube, it has gravitational potential energy. As the noisemaker responds to gravity pulling it down, the potential energy is converted to kinetic (moving) energy causing air to move through the noisemaker converting some of the kinetic energy into sound energy. The noisemaker doesn't speed up as it falls, as the lost potential energy turns into sound energy. When it hits the bottom, the remaining kinetic energy is turned into heat in the collision.)
3. What form does the energy start out in? (Gravitational potential energy)
4. What form does the energy turn into? (Kinetic energy and sound energy)
5. What form is the energy in when it stops? (Heat energy)
6. Why do you think one end is open and one end is closed? (There are two reasons for this. The noisemaker makes noise via a reed in the center when there is a pressure difference across it. One side of the tube is open, the other is closed. When the noisemaker falls, air in one side is compressed —and so air is forced through the reed. If both ends of the tube were open, there would be no

compression. If both ends of the tube were closed, you would get a pressure difference—but the tube needs one side to be open so the vibrations inside the tube can be coupled with the air and our ears can perceive them as sound. When both ends are closed (try this with a piece of tape) you can barely hear a sound as the noisemaker falls. When both ends are open (replace the closed end with an open end from another tube), the air doesn't compress, vibrations are not created, so there is no sound.

Toy: Popper

1. What does the toy do? (When you turn the popper inside out and place it on a flat surface, it pops-up in a second or two and falls to the ground.)
2. What energy change/s happen as this toy operates? (You are putting some of your energy from your muscles into the toy initially. When you turn the popper inside out, you are giving the toy elastic potential energy. When the popper reverts back to its original shape the potential energy is converted into sound energy and kinetic energy. It pushes away from the surface, causing it to fly up into the air. Gravity is pulling down on the popper, causing the kinetic energy to convert to gravitational potential energy by the time it reaches its highest point. Then as it is pulled down by gravity, it converts its potential energy into kinetic energy again. When it finally hits the surface and stops, the kinetic energy has been converted into heat energy and sound energy.)
3. What form does the energy start out in? (Elastic potential energy)
4. What form does the energy turn into? (Sound energy, kinetic energy, gravitational potential energy)
5. What form is the energy in when it stops? (Heat and sound energy)

Toy: Physics Flyer

1. What does the toy do? (You hold it between your two hands and launch it by pushing your right hand past your left hand. The physics flyer starts spinning and lifting higher in the air. It keeps moving forward but starts slowing down and dropping.)
2. What energy change/s happen as this toy operates? (When you move your right hand past your left hand, you are putting energy into the Physics Flyer from your muscles. By moving your hands that way, you cause the fl yer to spin in one direction (to the left) so you're giving it rotational kinetic energy. It moves forward but climbs to a higher height due to the tip of the blades on the propeller. They are tipped upward when moving to the left. Gravity is pulling down on the flyer, so some of the rotational kinetic energy is converted to gravitational potential energy, but not all of it, as it continues to spin.
3. The gravitational potential energy converts to kinetic again, but its spin starts to slow down and it eventually starts dropping to the ground, dealing with friction and buoyancy of the air. By the time it stops, its energy has converted to heat energy.)
4. What form does the energy start out in? (Rotational kinetic energy)
5. What form does the energy turn into? (Gravitational potential energy and then kinetic energy again)
6. What form is the energy in when it stops? (Heat energy)

Toy: Balloon Car

1. What does the toy do? (After you have blown up the balloon, you cover the hole where the straw was attached. When you let the car go, it moves forward and you can hear the sound of the air pushing out the back of the car and a sound of the tires spin.)
2. What energy change/s happen as this toy operates? (As you blow up the balloon, you are putting some of your energy into potential energy as you've created an area of high pressure in the balloon. As you release the car, the air under high pressure in the balloon moves to an area of lower pressure outside the balloon, thrusting the car forward. The potential energy is converted into kinetic energy of the moving car. During this process, friction is at work, and some of the kinetic energy is converted to heat and sound energy.)
3. What form does the energy start out in? (You've given elastic potential energy, by increasing the pressure in the balloon.)
4. What form does the energy turn into? (Kinetic energy of the moving car, plus some sound energy.)

5. What form is the energy in when it stops? (Heat energy. Ultimately, friction between the moving parts turns the kinetic energy into heat energy.)

Summing Up

This suite of activities on energy changes is largely qualitative, but it can be adapted to make it more quantitative as well. Doing this science lab with toys also encourages students to think *outside the walls;* to think of science as something that applies to the world beyond the classroom.

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

6.

Can energy be created or destroyed?

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

Overview

Energy is the single most important science concept your students will Understanding conservation of energy is vital as students study the earth's energy budget and make informed decisions for the future.

Theory

Conservation of energy is another concept that is difficult to explain but easy to grasp through experimentation. We say that *energy is conserved*: you can convert energy from one form to another, but it cannot be created or destroyed. In this set of activities, students can make quantitative comparisons which work quite well. They can explore the rate at which energy is used: a one-minute charge of the battery via solar cell will run a flashlight for several seconds but will run a clock for quite a bit longer.

Necessary materials:

- 1 solar cell night light device, with battery
- time-keeping device (clock or stop watch)
- 1 one-battery flashlight
- 1 one-battery clock
- 1 one-battery toy car

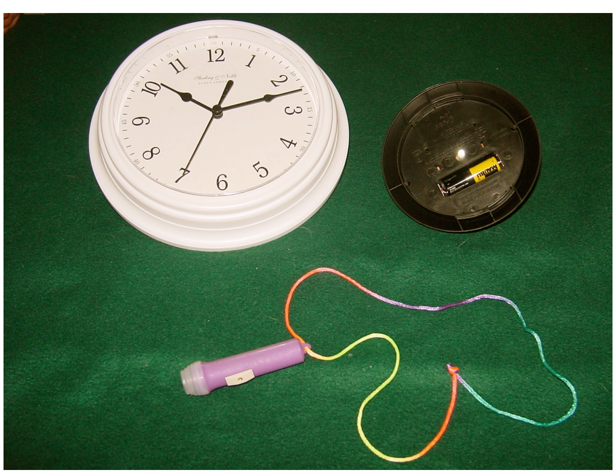
The solar cells are part of solar garden lights available at hardware and variety stores. The batter, in the top of the unit, is a NiCd battery that can be charged and discharged repeatedly. It's a standard AA battery that can run many different things.

When you put the battery in a toy or a clock or a light, you see how long the stored energy will last.

Doing the Experiment: *Part 1: First Steps*

This activity requires sunlight to charge the battery using the solar cells. You can use the sun coming in a window, or have the students take their solar cells outside for charging. We prefer the latter. When students take their solar cells outside for charging and then bring them in, it helps them see that they are bringing the energy of the sun indoors!

Now close the curtains in your classroom and turn out the lights. The lights in the solar cell night light units will come on! If the lights don't come on, it may be because there is still light hitting the top of the unit. Cover this with your finger, and the white light will come on. Have students see how long the lights will stay lit. Have them discuss: where did the energy come from to make the units light?



The battery from the solar night light can run other things as well.

Part II: Concepts

As preparation, you will need to be sure that the batteries from the solar cell night light devices are totally discharged. A good way to do this is to put the batteries in the flashlights and let them run down. You can also let the night lights run overnight. Now, proceed as follows:

•Have the students put the batteries in the solar cell units and put the cell in bright sunlight for 2 minutes then bring the solar cell unit indoors and remove the battery. This is easily done if you turn the units over so that the battery is visible.
•Have the students put the battery from the solar cell unit in the flashlight. Have them turn the flashlight on

and measure how long the energy in the battery can run the flashlight. (This is a good time to have the students think about their experimental methods. As time goes on, the flashlight gets dimmer and dimmer. How do you determine the point at which the flashlight goes out? The main thing is to have a measurement that can be made consistently!)

- Next, have students discuss why the flashlight goes out. They will likely mention energy, that the battery has run out of energy. This is correct, and it leads to consideration of the next segment of the activity, in which students will take quantitative data.

Part III: Data

This section of the activity is a chance for your students to collect data and note a trend. The data isn't perfect, but the trends are clear. This is how real science is often done, with imperfect data from which general correlations are discovered. Have the students proceed as follows:

- Set the solar cell in the sun for 1 minute to charge the battery.
- Measure the time the battery can run the flashlight.
- Set the solar cell in the sun for 2 minutes to charge the battery.
- Measure the time the battery can run the flashlight.
- Set the solar cell in the sun for increasing amounts of time: 3 minutes, 4 minutes...
- In each case, after charging, measure the time that the battery can run the flashlight.
- Finally, have students make a graph or chart of their data, to show the trend. Have them think about what deductions they can make from their data. It will be quite clear that the longer the solar cell charges the battery, the longer the battery can run the flashlight. But given uncertainties in the process, the data won't necessarily show that charging the battery for twice as long will allow it to run the flashlight for twice as much time. (A few things that make a difference: the flashlight draws more energy from the battery at the very start, and then tapers off. Also: the more charge in the battery, the faster the draw. So the time that the battery can run the bulb won't be exactly proportional to the energy in the battery. The battery may have a bit of a "rebound" effect as well, as many batteries do. If you take the flashlight and let it run the battery down and then turn the fl shlight off and turn it on again after a short wait, you may find that the flashlight lights again! This rebound effect will complicate the data.)
- Have the students give an overall conclusion for this experiment. What does the data show? Have them phrase their conclusion in terms of *energy* and *energy conservation*.

Part IV: Differences

The final part of the experiment is designed to show that different devices use energy at different rates. When you charge the battery up with the solar cell for one minute, this puts a certain amount of energy in the battery. If this energy is drawn out slowly, it can last for a long time; if it is drawn out quickly, it won't last very long.

Have your students proceed as follows:

- Set the solar cell in the sun for 1 minute to charge the battery.
- With this much of a charge in the battery, see how long the battery will power the flashlight.
- After the battery is discharged, use the solar cell to recharge it for one minute; this should put the same amount of energy in the battery as before.
- Now, see how long this amount of energy will allow the battery to power the clock. You will likely fi nd that the time is much greater; the clock uses energy at a much slower rate.
- Next, have your students see how long a one-minute solar charge will allow the battery to power the toy car. (A question: which is the best measure of how much energy is in the battery: the time that the car will run, or the distance it will travel?) You might have your students think about this.)
- Finally, have your students discuss what they have observed. Have them phrase their observations in terms of *energy* and *energy conservation*.

Summing Up

This is a wonderful activity for putting a quantitative face on the idea of energy conservation and energy changes.

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

Can you "see" thermal radiation?

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

Overview

A normal incandescent bulb works like this: The filament inside the bulb gets hot. Hot objects emit electromagnetic radiation. And so the bulb glows.

Anything which is warm or hot gives off electromagnetic radiation. Really hot objects emit visible light. Cooler objects emit infrared; we call this "thermal radiation" because it is an important mechanism for transferring thermal energy.

Thermal radiation is much like visible light, but there's one big difference: You can't see it.

Or can you???

Necessary materials:

- Ceramic reptile heater
- Metal lamp stand
- Blindfold (optional)

You can do this experiment with a "heat lamp" which is really just a spotlight with a cooler than usual filament. But the ceramic heater is much nicer, because it has no visible glow at all. It gives off no visible light, but it gives off lots of thermal radiation!

Theory

Here's one vocabulary word that is really important: Radiation. Physicists use this term for whatever is given off by something that glows. The radiation spreads out from a source.

You can clearly see a pit in front of the snake's eye. At the bottom is a patch of tissue that is sensitive to temperature changes, allowing the snake to detect thermal radiation.

Visible light is radiation. So are x rays. Some radiation is dangerous, but most isn't; in fact, electromagnetic radiation is responsible for all life on earth!

Visible light and infrared are both kinds of electromagnetic radiation, but they have very different wavelengths. Visible light has very short wavelength, about 0.0005 mm! A typical infrared source emits electromagnetic waves with a wavelength of 0.010 mm, 20 times longer.

The other big difference is in the energy of the photons. A visible light photon has enough energy to cause a molecular transition, as it does when it strikes the retina of you eye. An infrared photon doesn't; a typical thermal radiation photon can only wiggle molecules, it can't cause a transition. So infrared can only warm things up.

But you can still "see" it...

Doing the Experiment

This is a nice experiment to do when you are just beginning your discussion of radiation. Infrared and thermal radiation can seem very abstract; in this experiment, getting a chance to "see" it will help students get a handle on just how real it is!

> **SAFETY NOTE I: The ceramic radiant heaters get very hot! Don't let your students touch them.**
>
> **SAFETY NOTE II: You may choose to have the students do this experiment wearing blindfolds. If you do, please be certain to have your students use caution, so that they don't trip or fall or touch the hot bulb!**

The experiment goes like this:

- Have your students cover their eyes or wear blindfolds, and then hold their hands out in front of them.
- Move the ceramic heater (turned on!) near your students.
- Have them move their hands to see if they can tell where the heater is. It's pretty simple to do if they are close, a bit trickier if they are far away.

Students will quickly figure out how to move their hands to sense the infrared. They detect it by measuring the heating of their palms when the infrared strikes their skin.

This is just how certain snakes can "see" thermal radiation. Pit vipers, such as rattlesnakes, have a second set of "eyes" that contain sensitive tissue that can detect the thermal radiation emitted by warm prey animals. Such snakes can easily detect a warm mammal on the cool sand of the desert even in total darkness! They detect the thermal radiation that their prey emits.

Summing Up

This is a good introduction to thermal radiation. The story of energy transfer within the earth system is dominated by radiation, so it's important that students know that this form of energy is quite real!

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 clouds keep the earth warmer?

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

Overview

Every summer, hundreds of people flock to Rocky Mountain National Park to enjoy a weekend of camping and "being one with nature." One afternoon, I was making check-out line conversation with such a traveler who hoped that the clouds that had been rolling in would disperse to give clear, beautiful night. This situation is ideal for star gazing, but not necessarily favorable for camping. You may have noticed that the clear nights you need an extra jacket but when the sky is clouded over, the temperature drop is much less severe. How do clouds keep the earth warmer at night?

Necessary materials:

- Liquid crystal sheet with transition temperature of 25˚ - 30˚ C
- Heat lamp
- Large tray that can be positioned about 30 cm above the table top
- Ice
- Shapes cut out of thin plastic

Not every type of plastic works for this experiment, and some work better than others. Clear plastic food tray covers from grocery store delis seem to work very well.

Theory

All objects radiate in the thermal infrared part of the electromagnetic spectrum. The earth is no exception. During the day, the sun warms the surface of the earth while the earth in turn radiates thermal energy out to space. The energy coming in exceeds the energy going out, so the earth warms up.

When a cloud passes overhead during the day, it reflects most of the incoming sunlight back to space. Less radiation reaches the surface, so it doesn't warm up as much.

The plastic absorbs and reradiates thermal energy, keeping the sheet below warmer.

At night, the effect of clouds is different. The atmosphere is largely opaque to the outgoing thermal radiation from the earth; it absorbs this energy and reradiates it. Much of the energy is radiated downward toward the earth, keeping it warmer than it would otherwise be. This *greenhouse effect* keeps the earth warmer than it would otherwise be. If there are clouds above the earth, this effect is enhanced. The clouds more strongly absorb emitted thermal radiation, and they do so at lower levels in the atmosphere, where it is warmer. They also radiate, and their relative warmth means that they radiate more than clear air would do.

The net result is this: The downward radiation from the clouds keeps the earth warmer than it would otherwise be. During the day, sunlight warms the earth. On a cloudy night, this "cloudlight" does so too—with dramatic consequences for the surface temperature.

Doing the Experiment

Place the liquid crystal paper on the table with the heat lamp about 30 cm above it. Turn the lamp on and let it warm up the paper. Point out to your students that the color change indicates the temperature change.

Now replace the heat lamp with the tray of ice and have your students hold their plastic shapes over (but not touching) the thermal paper. This transition must be made quickly for the results to be compelling. Instruct your students to watch as the paper cools down—everywhere, but much less so underneath the plastic shapes!

Summing Up

Let's think about what you are seeing with this experiment.

- The paper cools because of thermal radiation. The paper radiates energy upward, but the tray of ice above radiates much less—so the paper cools, much as the earth cools at night.
- The plastic sheets are warmer than the ice tray, and they are strong absorbers of emitted thermal radiation. They absorb the emitted thermal energy, warming further, and reradiate it downward. Since they return some of the emitted energy to the liquid crystal sheet, it stays warmer than it would otherwise be.

It's not the the plastic "blocks" the outgoing radiation, though it does. It's that the plastic absorbs and reemits the thermal radiation. This is a subtle distinction! If you were to cool the plastic so that it was as cold as the ice tray, it would act as if it weren't there, at least until it warmed up.

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

What does color have to do with cooling?

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

Overview

A lot, as it turns out.

You know that something black will warm up more than something white when placed in the sun. That's because a black surface will absorb more radiant energy than a white surface.

But radiation also lets things cool off. All warm objects radiate energy, but different colors will radiate different amounts. And that's why color can affect cooling.

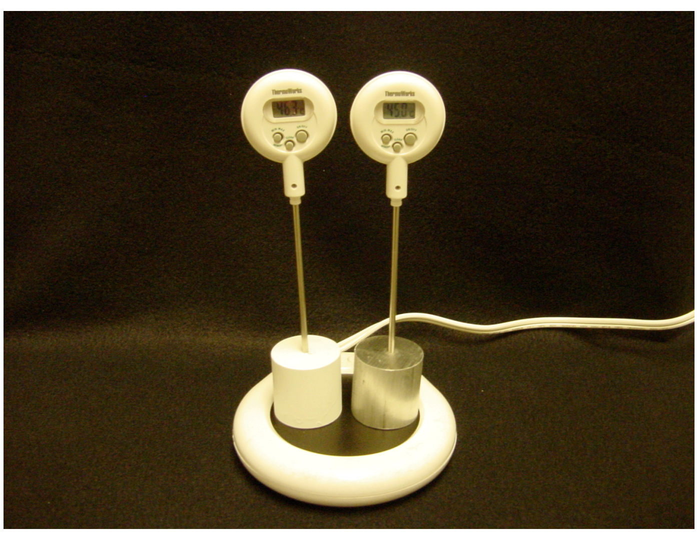
Necessary materials:

- 2 digital thermometers
- 2 aluminum cylinders with holes for the thermometers
- Mug warmer

The aluminum cylinders are the crucial part of this experiment. We used a 1 inch diameter rod from a metal supply company, cut to 1.5" lengths to make two cylinders of identical size. (You don't need to use cylinders; you may prefer cubes.) W drilled a hole halfway down in both pieces so the thermometers would fit nicely. We left one cylinder bare metal and painted the other one white.

Theory

All warm objects emit electromagnetic radiation. Hotter objects emit more radiation, and hotter objects emit shorter wavelengths, but anything warm will "glow." You've no doubt seen red and blue pictures of objects taken with thermal cameras; the hot spots appear bright, the cool spots dim.



Two cylinders on the hot plate. After they are warmed, they will be set aside to cool. Which will cool fastest—the white or the silver?

The radiation that objects emit is a very important part of the energy balance. Objects that emit a lot will quickly cool; objects that don't emit as much will stay warm longer.

Now, let's think about color in this context. You know that the color of an object will affect how much energy it absorbs; black will absorb more than white; shiny objects will reflect energy and not absorb it; a shiny object heat up in the sun much at all.

Color also affect emission. For objects near room temperature, which emit radiation in the far infrared part of the spectrum, most things are very black—that is, they are good absorbers and good emitters. For instance, human skin, regardless of color, is a very good absorber and emitter of far infrared. No matter what color you skin, you are black in the infrared! The same is true of fabrics and of painted surfaces. All colors of clothes and all colors of paint are black in the infrared; they absorb and emit quite nicely.

But silvery metals don't work like this. They reflect visible light and they reflect infrared too. They don't absorb it—and, more importantly, they don't emit it! So, in this experiment, the two cylinders will cool at different rates. The bare aluminum cylinder radiates less and cools rapidly; the white cylinder (and the color doesn't matter—it could be any color at all!) will radiate more and so it will cool off more quickly.

This is a very surprising result that drives home the point about the importance of radiation—emission of thermal radiation—in cooling.

Doing the Experiment

This experiment/demo involves some waiting time. You may want to set up this first part of the demo while your class is engaged in another activity of discussion, and then proceed when ready.

This is a great activity for predictions. You should certainly have students vote: Which cylinder do they think will cool off more quickly? Which will cool off less quickly? Most students will guess that the bare cylinder will cool off more quickly. The painted one seems insulated somehow.... In fact, it is! Painting will provide some insulation, limiting conduction. But the increase in radiation far outweighs this effect.

Run this as an activity or a demo as follows:

- Turn on your mug warmer.
- Place the white and aluminum finished cylinders on the mug warmer with the holes facing up.
- Turn on the two digital thermometer and insert one into each cylinder.
- Wait for about 15 minutes for the cylinders to warm up. They probably won't warm to the same temperature, your first hint that something is up...

When both aluminum cylinders have been warmed, continue the experiment:

- Tell your students that you will be removing the cylinders from the heat source. Have them each predict which cylinder will cool the fastest and why.
- Record the temperature on the thermometers and then set the cylinders on the table or a hot pad.
- Take temperatures at 1 minute intervals and ask: How do the two temperatures vary?
- You can stop taking data in a short time, once it becomes clear that the white cylinder is cooling more quickly. Now it's time to talk about why...

Discuss the results. Some questions you could ask:

- Why did the white cylinder cool more quickly?
- Why are "space blankets" that are used for emergencies made of silvery plastic?
- Why is the inside of a thermos silvery as well?

Summing Up

How does this apply to the earth system? It turns out that there's an important connection. The earth can't exchange energy with its surroundings; it can only lose heat by radiation. As we change the composition of the atmosphere, we make this emission less efficient. When the earth cools less efficiently, it stays warmer. And that's just what we see happening.

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