

PhysicsQuest Extension Activities

About the extensions

The extension activities are supplements to PhysicsQuest 2006: Benjamin Franklin's Secret Message. Each of the four PhysicsQuest activities has its own set of extensions, which can be used to create more in-depth lessons on the topics introduced in the PhysicsQuest activities.

The extensions vary in both difficulty of execution and of the scientific concepts involved. Some are simple to construct and use, but teach more complex scientific concepts. Others are difficult to construct and use, but demonstrate simple ideas. Levels (1-2, 2 being most appropriate for advanced students) are assigned to each activity, but this is a loose guide. Please try each extension before using it in class so that you can adjust the procedure to fit students' needs.

Some extensions are best performed as demonstrations, some as whole class experiments, and others as hands-on group activities. The instructions and discussion questions for most of the activities are on a separate page from the logistical information and background, so that you can copy and distribute the instructions to students if desired. This is not the case for activities more appropriate for demonstrations (usually due to safety).

We hope that you will use these ideas to create fun, science-rich lessons for your students. For additional background on the concepts shown in the extensions and for references, see the "For further information" section at the end of each extension activity.

About the materials

Most of the materials needed for the experiments in this guide are not included in the PhysicsQuest kit. However, most are easily and inexpensively available at grocery or hardware stores. Links to suppliers for hard to find items are included within the instructions.

The materials list for each experiment provides the items necessary for one set-up of the activity. If you have students working in groups, you will need to multiply the amount of materials needed by the number of groups that will be performing the activity. All materials used in the extension activities that were included in the original PhysicsQuest kit are marked with an asterisk (*).

ACTIVITY 1

Opposites Attract

(Static electricity)

Table of contents

Page 2: Dancing Fleas: Watch as objects dance underneath a charged plate (level 1).

Page 4: Electrophorus: Make a static electricity generator out of household items (level 2).

Page 6: Leyden Jar: Use this jar to have fun with the charge from your electrophorus (level 2).

Page 8: Franklin Bells: Construct a simple device for detecting static electricity (level 2 demonstration).

Safety

Please note that while following the precautions in this guide can help teachers foster inquiry in a safe way, no manual could ever predict all of the problems that might occur. Good supervision and common sense are always needed.

Warning: These activities work best in low humidity. If humidity in your classroom is high, consider relocating to an air conditioned room or rescheduling these activities for another day.

Dancing Fleas

Use static electricity to make objects dance.

Safety

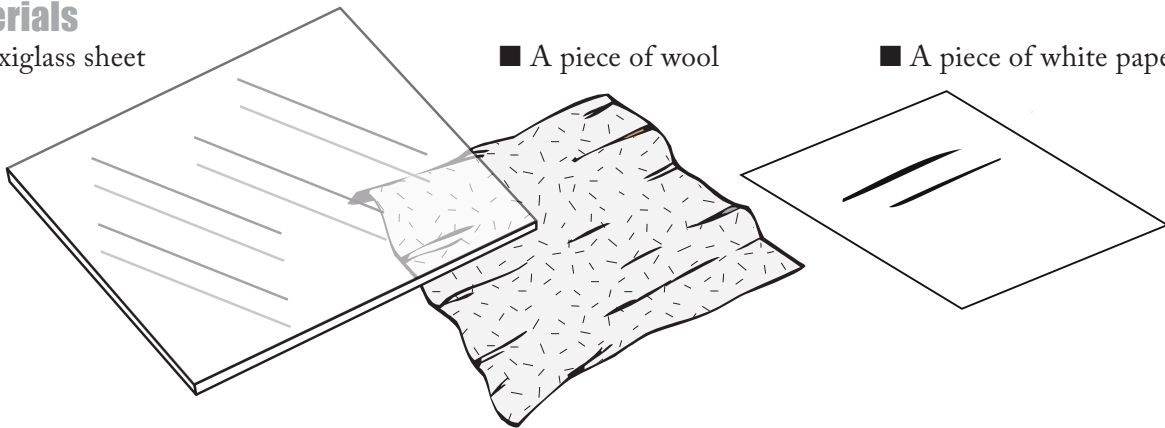
The edges of the plexiglass sheet may be sharp, especially if it was cut down to size for you, so be careful.

Materials

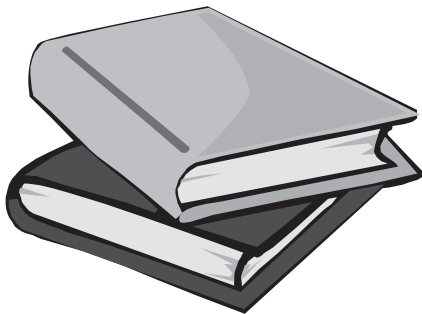
■ Plexiglass sheet

■ A piece of wool

■ A piece of white paper



■ 2 textbooks, each about 2.5-cm thick



An assortment of tiny objects, for example:

■ Paper squares (colored paper is easier to see)

■ Aluminum foil squares

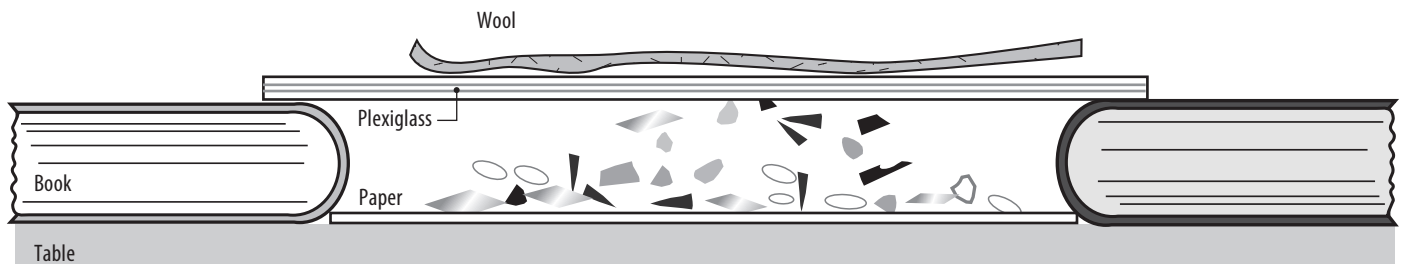
■ Puffed rice cereal

■ Grains of rice



Instructions

1. Tape the piece of paper down on a desk and sprinkle some of the “tiny objects” over the paper.
2. Use the textbooks to suspend the plexiglass sheet directly over the paper, as shown below.
3. Rub the top of the plexiglass sheet with the wool and record what happens.



Graphics by Kerry G. Johnson

Discussion questions

- How can we use static electricity to make objects move?
- What kinds of materials are affected by electric charges?
- How strong is the force of an electric charge compared to the force of gravity?
- How could you test this?

FOR THE TEACHER

(Level 1)

Dancing Fleas

Materials

- 12-inch x 12-inch or larger sheet of 1/8-inch thick plexiglass (acrylic)

Available at hardware stores. Often you order the sheet at the check-out counter and they cut it to size for you. Approximately \$5.

- A piece of wool, approximately 10-cm x 10-cm or larger*

You can purchase wool felt by the yard at most fabric stores. You can also purchase wool cloths from science supply stores, such as Science Kit & Boreal Labs, www.sciencekit.com, part number WW2742300. \$6.60 / 12-inch x 24-inch cloth.

- 2 textbooks, each about 2.5-cm thick

An assortment of tiny objects, for example:

- 1 piece of white paper

- Paper squares (colored paper is easier to see)

- Aluminum foil squares

- Puffed rice cereal

- Grains of rice

Discussion

Materials are attracted to the plexiglass after it is rubbed. This is because the wool deposits extra electrons on the sheet, giving it an overall negative charge. The electrons in the tiny objects are then repelled by the sheet and move to the bottom of the pieces, leaving the positively charged protons near the sheet. The objects move up toward the plexiglass (as long as they are not too heavy) because the protons are attracted to the negatively charged plexiglass.

Students may notice that some of the bits of paper stick completely to the plexiglass sheet while others hang by an edge. The bits that hang by an edge have a high concentration of electrons in part of the paper farthest from the sheet; if you remove the electrons by touching the paper, it will then stick completely to the plexiglass.

Another notable result is that the aluminum foil bits often bounce back and forth rapidly between the paper taped to the desk and the plexiglass, while other materials move much slower or stick completely to the plexiglass the first time they hit it. This is because the conducting foil quickly picks up electrons from the plexiglass. This causes the foil bits to be repelled from the sheet, so they fly back to the paper. They deposit the electrons on the paper, and then are attracted to the plexiglass again. To magnify this effect, place a large piece of aluminum foil under the plexiglass instead of the paper.

Suggested resources

Bell, Trudy E. "Crackling Planets" Science@Nasa, 2005.

http://science.nasa.gov/headlines/y2005/10aug_crackling.htm?list78675

Article about charging by rubbing as a concern for exploration of the Moon and Mars.

"Static Electricity: What causes static shocks?" Science Made Simple, Inc., 2005.

<http://www.sciencemadesimple.com/static.html>

Static electricity basics with background information on atoms and charge.

Bibliography

"Electrical Fleas: Start your own electric flea circus." Exploratorium Snacks.

http://www.exploratorium.edu/snacks/electrical_fleas.html

The Electrophorus

Create your own electrophorus – a device developed over 200 years ago for creating static charge.

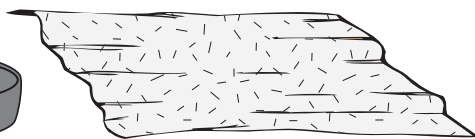
Safety

You will be building up small amounts of static charge in this activity and could receive shocks.

Materials



■ An aluminum pie pan



■ A piece of wool



■ A Styrofoam plate



■ A Styrofoam cup



■ Adhesive tape



■ Aluminum foil



■ A paper clip

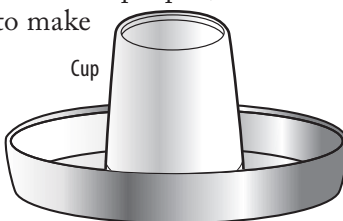
Making the electrophorus

1. Tape the plate upside down to the center of a desk.



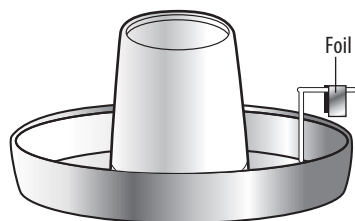
Plate

2. Tape the cup to the middle of the top of the aluminum pie pan, top down, to make a handle.



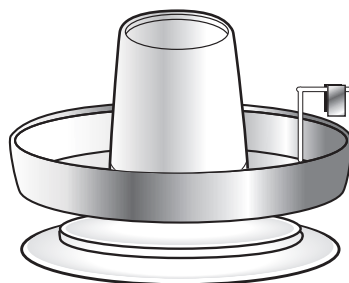
Pie pan

3. Bend the paper clip so that one end is a base and the other makes a horizontal arm.



Foil

4. Tape the base of the paper clip to the top of the pie pan next to the cup, and hang a small strip of aluminum foil (about 0.5-cm x 4-cm) over the horizontal arm.



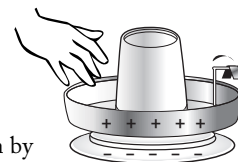
5. Place the pie pan on top of the plate. Your electrophorus should look like the picture above.

Using the electrophorus

A. Set aside the top (pie pan / Styrofoam cup) and rub the surface of the Styrofoam plate with wool for a full minute.

B. Touching only the Styrofoam cup handle, set the pie pan back on top of the plate.

C. Touch the pie pan (you should feel a slight shock).



D. Lift up the pie pan by the Styrofoam cup handle. The foil should flip away from the pan.

E. Touch the pie pan again. You should feel a shock and see the foil flip back down.

The pie pan can be charged multiple times without recharging the Styrofoam plate by rubbing, but the Styrofoam plate will lose charge slowly to the air and surroundings, especially in humid weather.

Discussion questions

- Why doesn't the Styrofoam plate lose all its charge to the pie pan?
- Do you think there is a limit to the amount of charge you can build up on the plate?
- What is the role of the foil strip?
- How can you turn this static electricity into useful energy?

Graphics by Kerry G. Johnson

FOR THE TEACHER

The Electrophorous

Materials

- An aluminum pie pan. *Available in the baking section of the grocery store for a few dollars.*
- Piece of wool, approximately 10-cm x 10-cm or larger. *You can purchase wool felt by the yard at most fabric stores. You can also purchase wool cloths from science supply stores, such as Science Kit & Boreal Labs, www.sciencekit.com, part number WW2742300. \$6.60 / 12"x24" cloth.*
- Styrofoam plate ■ Styrofoam cup ■ Aluminum foil ■ Adhesive tape ■ A paper clip

Discussion

Rubbing the Styrofoam plate with wool transfers electrons to the plate, where they stay because the plate is an insulator (A). When the initially neutral conducting pie pan is set on top of the insulating plate, its extra electrons move to the top surface because they are repelled by the plate's negatively charged extra electrons (B). This leaves the bottom of the pan positively charged.

When you touch the plate (C) the negative charges on the pie pan are drawn off. This happens because you act as a ground. Even though the body is electrically neutral, its positive charges attract the free electrons in the pie tin. Because you are connected to the ground, the negative charges (electrons) flow through you to the earth without building up a charge on the body. This process leaves the pan with an overall positive charge.

When the pan is lifted, the positive charges redistribute evenly on its surface and the aluminum foil strip (D). This causes the aluminum foil strip to flip up, since it is repelled from the similarly charged pan.

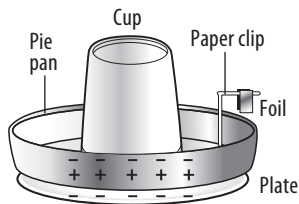
If you (or any other conductor) now touch the pie pan, electrons will flow back to the pan, creating another spark and leaving the pan neutral once again. When the pan discharges, the foil flips back down because it and the pan are now neutral and no longer repel one another.

Note that the Styrofoam plate does not lose any charge in this process; only the charges in the pie pan move around. This is called charging by induction, and explains why the pan can be recharged without rubbing the plate again.

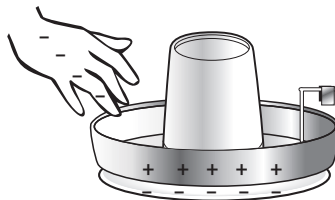
+ Positive
- Negative



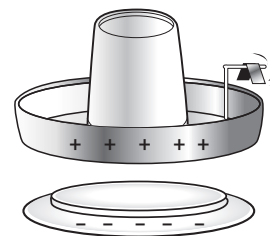
A. The Styrofoam plate is negatively charged by the wool. The electrophorus is initially electrically neutral.



B. Electrons on the electrophorus are repelled by the negatively charged plate and move toward the top surface. This leaves the bottom surface positively charged.



C. Electrons near the top surface of the pan are drawn off by the ground.



D. The electrophorus is left with an overall positive charge that redistributes when the plate is lifted.

Suggested resources

"Charge and Carry: Store up an electric charge, then make sparks." Exploratorium Snacks. http://www.exploratorium.org/snacks/charge_carry.html
Another form of the electrophorus and Leyden jar activities with a good explanation.

"Static Electricity." The Physics Classroom, 2004.
<http://www.physicsclassroom.com/mmedia/estatics/estaticTOC.html>
Use the menu on the left to find out more about various forms of electrostatic induction, including the electrophorus.

Bibliography

"Charge and Carry: Store up an electric charge, then make sparks." Exploratorium Snacks. http://www.exploratorium.org/snacks/charge_carry.html

Graf, Rudolph F. *Safe and Simple Electrical Experiments*. New York: Dover Publications, Inc. 1973. Pages 16-18.

Henderson, Tom. "Charging an Electrophorus by Induction Using a Negatively-Charged Object." Multimedia Physics Studios, 1998.
<http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/estatics/eptn.html>

Jones, Thomas B. "Electrophorus and Accessories." 2005. <http://www.ece.rochester.edu/~jones/demos/electrophorus.html>

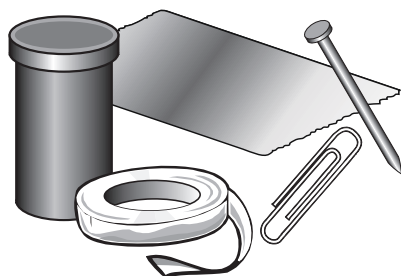
The Leyden Jar

Make your own Leyden jar for storing charge.

Safety

You will be building up small amounts of static charge in this activity and could receive shocks. In addition, be very careful when working with the nails.

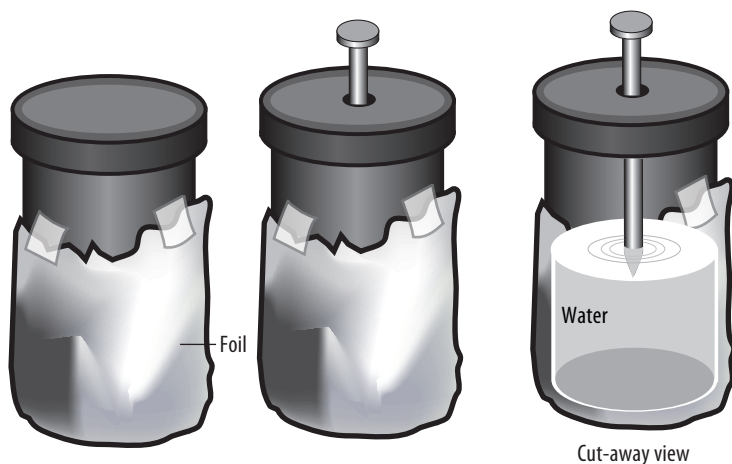
Materials



- 35mm film canister
- A 2-inch nail or a paper clip with one leg straightened
- Aluminum foil
- Adhesive tape
- Tap water
- Electrophorus or other static electricity source

Making the Leyden Jar

1. Cut a 4-cm x 12-cm piece of aluminum foil and smooth it out with your fingers.
2. Neatly wrap the bottom two thirds of the film canister in the foil and tape it in place securely.
3. Push the nail (or paper clip) through the top of the canister, so that the tip of the nail points toward the inside of the canister. The head of the nail should stick out a few centimeters.
4. Fill up the canister most of the way with tap water and snap the lid in place. The point of the nail should be immersed in water.



Using the Leyden Jar

- A. Charge the electrophorus as in Extension 1, but do not discharge it.
- B. Lift the pie pan off the Styrofoam plate. Hold the Leyden jar by the foil and drag the top of the the nail along the edge of the pie pan. Note that the aluminum foil charge tester on the electrophorus flips down as the pie pan touches the nail.
- C. Charge the pan again and repeat step 2. Do this several times.
- D. Discharge the Leyden jar by touching the nail and the foil on the jar at the same time (you will get a shock, but it is not large enough to be dangerous).

Discussion questions

- Is there a maximum charge that your jar can hold? How might you test this?
- Can you discharge the Leyden jar into other objects? Try discharging it into a fluorescent tube or light emitting diode (LEDs) in a dark room. Do this by touching one lead to the nail and one lead to the foil.
- Can you discharge the Leyden jar without touching it? Sparks should be able to jump between your fingers and the charged object if you hold your fingers close enough. How far you can make the sparks jump?

FOR THE TEACHER

(Level 2)

The Leyden Jar

Materials

- 35mm film canister

Usually a camera store will give you empty film canisters

- A 2-inch nail or a paper clip with one leg straightened
- Aluminum foil
- Adhesive tape
- Tap water

Not purified or distilled

- Electrophorus or other static electricity source such as a PVC pipe rubbed with wool

Discussion

The pan has a positive charge on it when it leaves the Styrofoam plate. When you drag the nail along the pan, electrons in the neutral nail are attracted to the positively charged pie pan. These electrons go from the nail to the pan, neutralizing the pan and leaving the inside of the Leyden jar positively charged. Repeating the process increases the charge inside the jar.

As the inside of the jar becomes positively charged, the charges in foil on the outside of the jar are also affected. The electrons in the foil move to the inside-facing side of the foil because they are attracted to the positively charged interior of the jar. This leaves the outside-facing side of the foil positively charged. Since you are holding the can by the foil, negative charges in your hand are attracted to the positively charged foil, and they flow into the foil. This leaves the foil with an overall negative charge.

When you touch the aluminum foil and the nail at the same time, electrons flow through your hand from the foil to the water, neutralizing the charge inside the jar and giving you a shock.

If you are working with a more advanced class, you may wish to challenge your students to write an explanation of how the charges are moving throughout the process of charging and discharging the Leyden jar. This exercise will be most effective when groups discuss their explanations and use pictures to visualize how the charges flow.

Suggested resources

"Charge and Carry: Store up an electric charge, then make sparks." Exploratorium Snacks.

http://www.exploratorium.org/snacks/charge_carry.html

Another form of the electrophorus and Leyden jar activities with a good explanation.

Katz, Eugenii. *"Leyden Jars."* http://chem.ch.huji.ac.il/~eugeniik/instruments/archaic/leyden_jars.htm
History of the Leyden jar and pictures of various types of jars.

Bibliography

"Charge and Carry: Store up an electric charge, then make sparks." Exploratorium Snacks.

http://www.exploratorium.org/snacks/charge_carry.html

FOR THE TEACHER

(Level 2)

Franklin's Bells

This is a simple device for detecting static electricity that works with a television or CRT (non-flatscreen) computer monitor. Franklin used a similar device in his house to let him know when static electricity was in the air, like during a thunderstorm.

It is recommended that Franklin's Bells be done as a demonstration because there are safety concerns about having students work with the static charges on TV / computer screens. Construction is simple enough that inspecting the finished product enables students to understand how the bells are made.

Safety

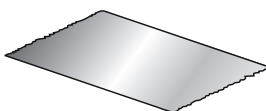
An uncomfortable and possibly dangerous shock can result from discharging the electric charge of a TV screen or computer monitor through your body. Be sure to connect the second can to a ground (such as the metal on the back of a computer or the metal leg of a table or chair). Only touch the bells and screen when the screen is turned off and the bells have stopped ringing.

Materials

■ Two empty soda cans, at least one with a pull tab



■ Sewing thread or thin string



■ Aluminum foil



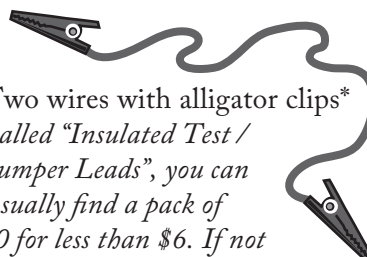
■ Plastic pen



■ Adhesive tape

■ Two wires with alligator clips*
Called "Insulated Test / Jumper Leads", you can usually find a pack of 10 for less than \$6. If not available at a local hardware store or RadioShack, you can purchase them from

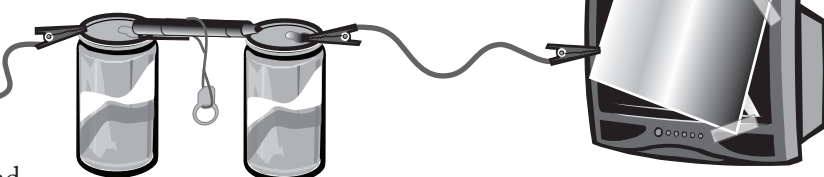
RadioShack.com, model 278-1156.



■ TV or CRT computer monitor (some newer screens are "non-static" – these won't work. If you are having trouble making the bells ring, try another screen)

Making Franklin's Bells

1. Break the tab off of one can and tie it to one end of the thread.
2. Tie or tape the other end of the thread around the center of the pen so that when hanging from can level, the tab does not touch the table.



3. Place the cans about three centimeters apart, and lay the pen on top of them so that the tab is suspended between the cans. Make sure the tab is not touching either can.

Graphics by Kerry G. Johnson



Graphics by Kerry G. Johnson

4. Connect one can to a ground, such as the metal part of a computer frame, using one of the alligator clip wires.
5. Use the other wire to connect the other can to a sheet of aluminum foil about the size of the TV or computer screen.
6. Turn the screen off, and tape the foil directly to the screen.
7. Turn the screen on – the tab should swing back and forth hitting the cans and creating a bell-like sound until the charge on the screen is dissipated. You can make the tab continue moving by turning the screen on and off repeatedly.

Note that the screen becomes charged when it is switched off as well.

Discussion questions

- What causes the bells to ring?
- What would happen if you used a metal pen instead of a plastic one?
- What do you need to connect the second can to ground?
- How else could you detect static electricity?

If you have access to a source of constant static electricity, such as a Van de Graaff Generator or Wimshurst Machine, try connecting the bells to it after using the TV. The bells should ring constantly as long as the machine is turned on.

Discussion

The tab moves because it is made of conducting metal and therefore attracted to charged objects. When the screen is turned on, a static charge accumulates on it (students may have noticed that they can get small shocks from TV screens). The aluminum foil / wire set-up transfers most of this charge to the first soda can. The hanging tab is uncharged, and therefore attracted to the charged can by induction.

When the tab strikes the can, some of the can's charge is transferred to the tab, and the tab is then repelled from the first can. The charged tab is then attracted to the neutral second can by induction. When it strikes this can, it transfers its charge to the second can and into the ground through the second wire. After the tab touches the second can, both the tab and second can are neutral, as at the start of the experiment, and the tab is attracted to the first can once again. This cycle repeats until all of the charge from the screen has been moved to the ground by the tab.

Suggested resources

"Franklin Bells." The Bakken Library and Museum, 2004
<http://www.thebakken.org/artifacts/Franklin-Bells.htm>
History of Franklin bells and explanation of their use detecting thunderstorms.

Bibliography

Field, Simon Quellen. "Electromagnetism: A High Voltage Motor in 5 Minutes."
 Science toys you can make with your kids.
<http://www.scitoys.com/scitoys/scitoys/electro/electro4.html>

ACTIVITY 2

Traveling Charges

(Insulators and conductors)

Table of contents

Page 2: Human Circuit: Use a static charge to test whether people conduct electricity (level 1).

Page 4: SOS: Investigate switches and use them to send messages in Morse Code (level 2).

Page 7: Types of Circuits: Explore how the type of wiring affects the brightness of a set of light bulbs (level 2).

Page 11: Electromagnets: Make a simple electromagnet and test its strength (level 2).

Page 15: Homemade Light Bulb: Demonstrate how a light bulb filament works using thin wire (level 2 demonstration).

Safety

Please note that while following the precautions in this guide can help teachers foster inquiry in a safe way, no guide could ever predict all of the problems that might occur. Good supervision and common sense are always needed.

FOR THE TEACHER

Human Circuit

(Level 2)

This activity is a quick and memorable way to show that people are conductors. Each individual in a connected circle of people will feel a shock as it is discharged around the loop.

We recommend using a Leyden Jar (like the one made on Page 6 in the *Opposites Attract* section) as the static electricity source, but other sources work as well. One alternative is the *Light and Sound Ball*** that lights up when a circuit is completed.

**Available from the ABoyd Company: <http://www.aboyd.com/prodinfo.asp?number=SAF%206521-18>

Safety

Everyone that participates in this activity will get a small shock. Although the shock is not dangerous, students should be told what to expect and given the option not to participate.

This experiment should only be done with small amounts of static electricity, so use only the Leyden Jar from Page 6 in the *Opposites Attract* section or another safe source such as the *Light and Sound Ball*.

Materials

- Static electricity source (charged Leyden Jar)
- People

Instructions

1. Charge the Leyden jar (or other static source, if necessary).
2. Have students stand in a circle holding hands.
3. Enter the human circuit holding the Leyden jar by the aluminum foil only in your right hand, and join hands with the student on your left.
4. On your signal, the student on your right side should touch the nail, completing the circuit. If all students are all holding hands as instructed, everyone will feel the shock as it travels around the circle.
5. Repeat the experiment at least once more to show that the results are consistent.

Discussion questions

- Are people conductors? How do you know from our experiment? Did the results agree with your prediction?
- Why is it important that everyone hold hands? What would happen if one person was wearing mittens?
- What are other safe ways you can test whether people are conductors or insulators?
- What part of your body did you feel the shock in as it traveled around the circle?

Discussion

Salt water is a decent conductor of electricity, and since the human body is about 70% water and contains lots of salt, the human body is also a conductor. People usually feel the shock most strongly in their wrists because the electricity travels from one hand to the other primarily through the blood.

Suggested resources

Zavisa, John. "How Lightning Works." How Stuff Works.

<http://science.howstuffworks.com/lightning.htm>

Information on lightning and safety. Use the table of contents at the bottom of the page to find more information.

Bibliography

Goldberg, Jeanne. "Shocking Evidence!" WVIZ, Educational Services.

http://www.wviz.org/edsvcs/projects/NTTI/Lesson_Plans/01_Shocking_Evidence.asp

SOS

Wire a switch into a circuit – the kind of switch used in telegraphs.

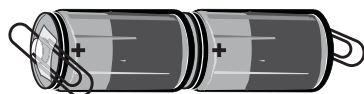
Safety

You will be working with wires and batteries in this activity. Use the materials only as described in the directions because the wires are sharp and electricity can be dangerous.

Materials

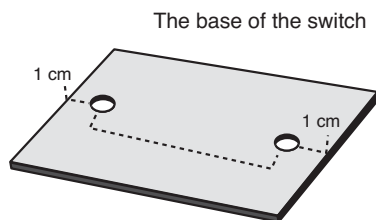
- Miniature, incandescent light bulb, around 4v
- Miniature light bulb holder
- 3 wires with alligator clip ends
- 2 metal paper fasteners
- Nail
- 2 D batteries
- 3 paperclips
- Piece of cardboard, 7-cm x 3-cm
- Tape

Instructions



1. Tape the two batteries together, positive end to negative end.

2. Tape a paperclip to each end of the battery system, as in the core activity.

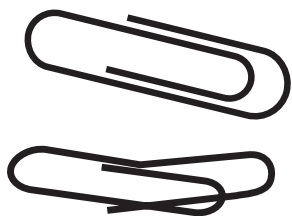


3. Cut a piece of cardboard 7-cm x 3-cm.

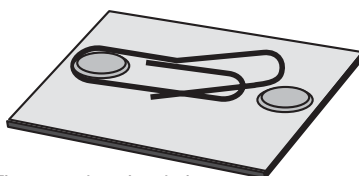
4. Use the nail to poke a hole in the cardboard, 1-cm from the edge of the cardboard

5. Poke a second hole a paperclip length away from the first hole.

6. Trim the cardboard so that the second hole is 1-cm from the end.



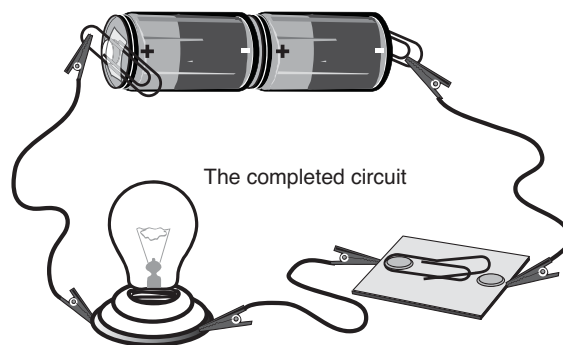
7. Bend a paperclip near the middle so that the longer loop sticks up slightly.



The completed switch

8. Place the fastener through the paperclip and then through the cardboard as shown in the picture, and secure it at the back by unfolding the legs of the fastener.

9. Push the other paper fastener through the second hole (do not put it through the paperclip) and secure it by unfolding the legs. Make sure that the legs of the two fasteners do not touch on the underside of the cardboard.



The completed circuit

10. Place the switch on top of an insulating surface (such as cardboard).

11. Connect the switch and bulb base to the batteries as shown.

12. Press down on the paperclip to make it connect with the free fastener. The light bulb should light up.

Troubleshooting

Some things to check if the bulb does not light up:

- Is there good contact at ALL connection points? (check between the batteries too)
- Are the batteries charged?
- Has the bulb burned out, or is it not screwed all the way into the base?

Discussion questions

- How does your switch take advantage of the different properties of insulators and conductors?
- What types of things run on switches? What are the main advantages of wiring something to a switch?
- If you wanted to send an auditory Morse code message instead of a visual one, what would change about your set-up?

FOR THE TEACHER

SOS

(Level 2)

Materials

- Miniature, incandescent light bulb, around 4v*
These are available from science supply stores, such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6221004. \$15.50/pack of 10.
- Miniature light bulb holder*
These are available from science supply stores, such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6004100. \$15.95/pack of 12.
- 3 wires with alligator clip ends
Called "Insulated Test / Jumper Leads", you can usually find a pack of 10 for less than \$6. If not available at a local hardware store or RadioShack, you can purchase them from RadioShack.com, model 278-1156.
- 2 metal paper fasteners
Available in the office section of retail stores such as Target and Wal-Mart, as well as office supply stores.
- 2 D batteries
- 3 paperclips
- Piece of cardboard, 7-cm x 3-cm
- Tape
- Scissors
- Nail

Notes on the activity

If you have time, you may want to hand out a Morse Code table (easily findable on the internet) and let students send messages to each other.

After completing this activity, you may want to challenge students to create different kinds of switches – such as switches that are on by default or that allow electricity to flow in different configurations. Additional materials will be needed for this.

Discussion

In this activity, students have created a simple switch that is off by default – the bulb only lights up when you press down on the paperclip so that it is touching both fasteners and completing the circuit.

Suggested resources

Bellis, Mary. "The History of the Telegraph and Telegraphy." About.com
<http://inventors.about.com/library/inventors/bltelegraph.htm>
Tells the history of the telegraph and Morse code.

Bibliography

Glover, David. Batteries, Bulbs, and Wires: Science Facts and Experiments.
New York: Kingfisher, 1993. Pages 17, 20

Types of Circuits

(Level 2)

Explore how wiring affects the brightness of the bulbs.

Safety

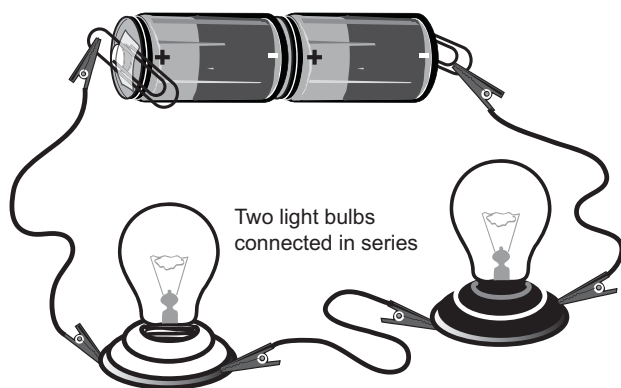
You will be working with wires and batteries in this activity. Use the materials only as described in the directions because the wires are sharp and electricity can be dangerous.

Materials

- 2 miniature light bulbs
- 2 miniature light bulb holders
- 4 wires with alligator clip ends
- 2 D batteries
- 2 paperclips
- Adhesive tape

Instructions

1. Tape the two batteries together, positive end to negative end.
2. Tape a paperclip to each end of the battery system, as in the core activity.
3. Create a single bulb circuit, by connecting the base of the bulb to the paperclips. Make sure the light bulb lights up.
4. Disconnect the wire from one end of the battery system, and clip it instead to the second light bulb.



5. Use another wire to clip the free screw on the base of the second light bulb to the free end of the battery system

6. Observe the brightness of the bulbs. Are they brighter, dimmer, or the same brightness as when there was only one bulb in the circuit?

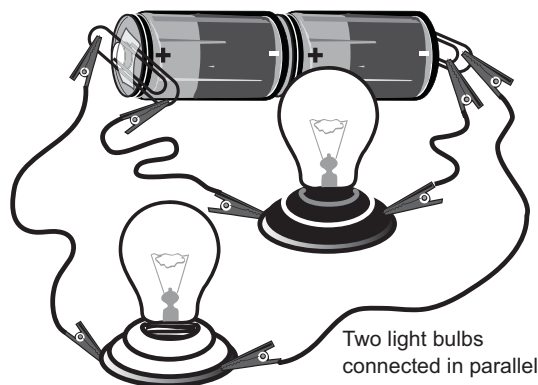
7. Unscrew one light bulb and record what happens.

8. Disconnect the second light bulb.

9. Connect the second bulb to the batteries again, this time in the same way that the first one is connected. You will need two additional wires for this.

10. Observe the brightness of the bulbs. Are they brighter, dimmer, or the same brightness as when there was only one bulb in the circuit?

11. Unscrew one bulb and record what happens.



Discussion questions

- If you wanted to create a row of bright light bulbs, how would you wire them?
- Which kind of wiring would cause the batteries to run out sooner? Why?
- What happened in each case when you unscrewed one of the bulbs? Why?
- What kind of wiring do you think the circuits in your classroom use? How could you find out?

FOR THE TEACHER

Types of Circuits

(Level 2)

Explore how wiring affects the brightness of the bulbs.

Materials

- 2 miniature, incandescent light bulbs, around 4v

These are available from science supply stores, such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6221004. \$15.50/pack of 10.

- 2 miniature light bulb holders

These are available from science supply stores, such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6004100. \$15.95/pack of 12.

- 4 wires with alligator clip ends

Called "Insulated Test / Jumper Leads", you can usually find a pack of 10 for less than \$6. If not available at a local hardware store or RadioShack, you can purchase them from RadioShack.com, model 278-1156.

- 2 D batteries
- 2 paperclips
- Adhesive tape

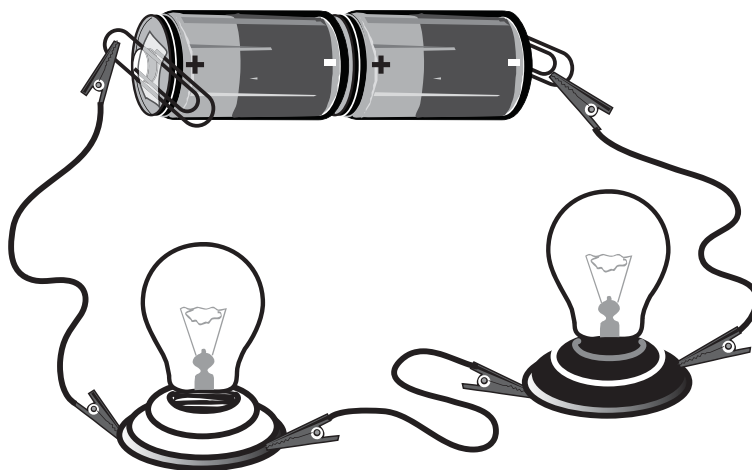
Discussion

The brightness of two otherwise identical light bulbs in a circuit is determined by the amount of current flowing through them. The amount of current flowing through a circuit depends on the resistance and voltage of the circuit. A light bulb is a source of resistance in a circuit.

- **Current:** The number of electrons that pass a certain point per second; a high current means that many electrons pass a given point each second.
- **Resistance:** How easy it is for the electrons to travel; a higher resistance means that it is harder for electrons to travel through the circuit.
- **Voltage:** The force motivating electrons to flow; a high voltage means electrons are very motivated to move.

When a light bulb is added to a series circuit:

- **Current:** The current decreases. Think of current as a flow rate (electrons passing per second) – if you imagine the electrons being slowed down by the first light bulb and then being slowed down again by the second light bulb, you can see how it would create a "traffic jam" effect and slow down the flow.
- **Resistance:** The electrons have to travel through two light bulbs, so the resistance increases from a one light bulb circuit.
- **Voltage:** The total voltage of the circuit is constant since the battery system is always at 3volts.

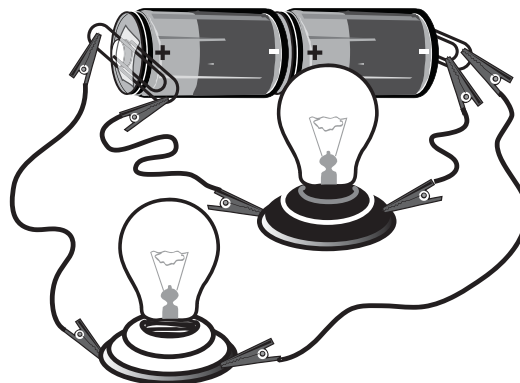


This means that less current flows through a series circuit with two bulbs than a single bulb circuit, so the light bulbs are dimmer.

When you unscrew one of the light bulbs in a series circuit, you break the circuit and the other light bulb goes out.

When a light bulb is added to a parallel circuit:

- **Current:** As you add more branches to a circuit, you increase the overall flow rate – thereby increasing the current. This is like a new lane being opened up to ease traffic.
- **Resistance:** Since you have these alternate branches, or “routes”, it is easier for “traffic” to flow through the circuit, meaning that resistance has gone down.
- **Voltage:** The total voltage of the circuit is constant since the battery system is always at 3volts.



This means that overall more current flows through a parallel circuit of two bulbs than a single bulb circuit. However, the current is split between the two different paths, so each bulb gets about the same amount of current it would have if it were the only bulb in the circuit.

When you unscrew one of the light bulbs, you break the circuit, but only along one branch. This means that you now have a one bulb circuit, with some extra wires hanging off of it.

Suggested resources

“Electric Circuits” School Science.

<http://www.schoolscience.co.uk/content/3/physics/circuits/circh2pg1.html>

Contains more information on series and parallel circuits (click “next” for information on parallel circuits). Also check out the “circuit challenges.”

Bibliography

“Light Bulb Circuits.” Family Science Physics

www.science.tamu.edu/CMSE/fmsn/LightBulbs.doc

Pelak, Kelly. “Electricity Unit: Circuits”, 1997

http://www.ed.uiuc.edu/YLP/96-97/96-97_curriculum_units/Electricity_KPelak/circuits.html

Electromagnets

(Level 2)

Create a temporary magnet using electricity – and then investigate how to change the strength of the magnet.

Safety

This activity requires you to work with wire and nails (or other sharp objects) that could be dangerous. Be careful when holding the electromagnets and only turn on the electromagnet for short periods of time. Disconnect the electromagnet if you feel it getting warm.

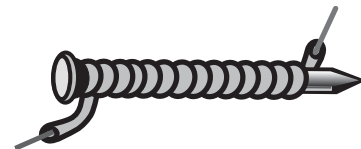
Materials

- 6-cm long bolt
- 1-m of 20 gauge insulated copper wire
- Wire strippers or strong scissors
- 2 wires with alligator clip ends*
- 2 D batteries
- Paper clips (several)
- Adhesive tape

Instructions

1. Tape the two batteries together, positive end to negative end.
2. Tape a paperclip to each end of the battery system, as in the core activity.
3. Strip away 1-cm of insulation from each end of the wire.

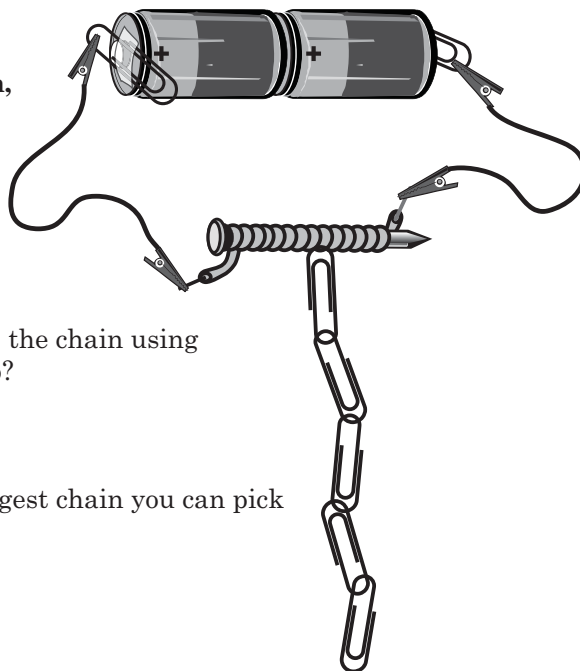
4. Neatly and tightly wrap the wire around the nail 30 times, leaving at least 3-cm of wire sticking out at both ends. Wrap the wire in only one direction, as shown in the picture.



5. Connect an alligator clip wire from the end of the wire coming off of the nail to the battery system.
6. Connect the other alligator clip wire from the nail to the free end of the battery system - this creates a complete circuit.

WARNING: If you feel the electromagnet getting warm, turn it off immediately. Only keep the electromagnet on for short periods of time, otherwise you will drain the battery quickly.

7. Bring the nail near the pile of paper clips and observe what happens.
8. Link some of the paperclips into a chain and try to pick up the chain using the electromagnet. What is the longest chain you can pick up?
9. Disconnect the battery system and take off 5 loops.
10. Reconnect the nail to the battery system. What is the longest chain you can pick up now? Record this information.
11. Repeat Steps 9-10 a few times.
12. Graph your data.



Discussion questions

- How does decreasing the number of wire loops around the nail affect the strength of the magnet?
- Is there a limit to how strong you can make your electromagnet? If so, how many loops does it take to reach this limit?
- Can you still pick up paperclips after disconnecting the battery system? Why or why not?
- Besides changing the number of loops, how else could you change the strength of the magnet?

FOR THE TEACHER

Electromagnets

(Level 2)

Create a temporary magnet using electricity – and then investigate how to change the strength of the magnet.

Materials

- 6-cm long bolt
- 1-m of 20 gauge insulated copper wire
This wire is also called “Bell Wire” and can be found in the doorbell section of hardware stores. It costs about \$5.00 for 65’ (20-m).
- Wire strippers or strong scissors
- 2 wires with alligator clip ends*
Called “Insulated Test / Jumper Leads”, you can usually find a pack of 10 for less than \$6. If not available at a local hardware store or RadioShack, you can purchase them from RadioShack.com, model 278-1156.
- 2 D batteries ■ Adhesive tape ■ Paper clips (several)

Discussion

When current flows through a tightly coiled wire it creates a strong magnetic field in the space inside the loops. The strength of this magnetic field is proportional to the number of loops – for example an electromagnet with twice as many loops has a magnetic field twice as strong.

If you coil this wire around an iron core, such as a nail, the magnetic field is intensified. This is because the nail becomes a temporary magnet under the influence of the magnetic field from the coiled wire. When the current is disconnected, the magnetic field created by the coiled wire disappears and the nail quickly loses its magnetization.

The strength of the magnet also depends on the amount of current passing through the wire (you can investigate this by changing the number of batteries). The strength of the magnetic field is also proportional to the current – an electromagnet with twice as much current has a magnetic field twice as strong.

Electromagnets are useful because you can control the strength of the magnet by controlling the current. This means that you can easily turn them on and off.

Electromagnets are used in junkyard cranes to lift and then drop cars, in particle accelerators where magnetic fields are used to direct beams of particles, and in magnetic levitation trains such as those in Germany and China.

Suggested resources

Kurtus, Ron. “Electromagnetism.” School for Champions, 2005.
<http://www.school-for-champions.com/science/electromagnetism.htm>
A detailed explanation of electromagnetism.
“Maglev Train.” Wikipedia. http://en.wikipedia.org/wiki/Maglev_train

Go here to find out more about levitating trains and where they are used.

Bibliography

Glover, David. Batteries, Bulbs, and Wires: Science Facts and Experiments.
New York: Kingfisher, 1993. Page 25

Kurtus, Ron. "Electromagnetism." School for Champions, 2005.
<http://www.school-for-champions.com/science/electromagnetism.htm>

FOR THE TEACHER

Homemade Light Bulb

(Level 2 *demonstration*)

This activity uses household items to create a simple light bulb. **This extension is best done as a demonstration, as safety is a significant concern.**

Please test this demonstration before performing it for your class, as results can vary depending on the type of wire used, battery strength, and filament length. Also be aware that the batteries will drain quickly from repeated demonstrations of this effect.

Safety

- The filament in this demonstration gets VERY HOT. Do not touch it for at least a full minute after power has been disconnected. The connecting wires may also become hot. Be very careful when handling the wire at all times.
- The filament may smoke – avoid inhaling this smoke.
- Wash your hands after handling picture hanging wire.

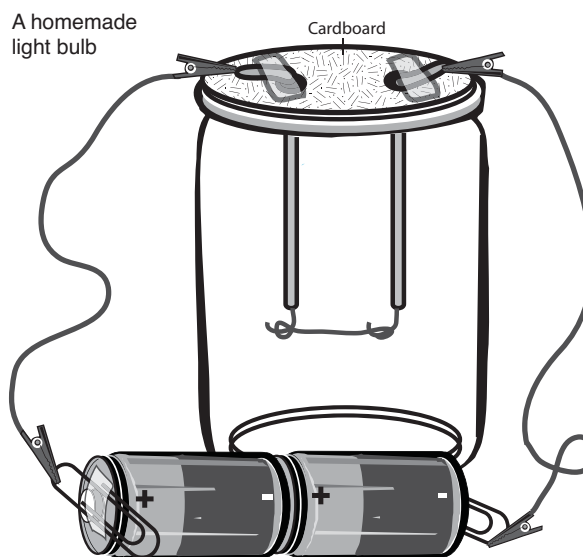
Materials

- Large glass jar
Available in the baking aisle of many grocery stores and the house wares section of retail stores such as Target and Wal-Mart.
- Picture hanging wire and/or 32 gauge nichrome wire
Picture hanging wire is available at hardware stores. Although harder to find, nichrome wire makes a great demonstration because it glows significantly longer than picture hanging wire before burning out. You can purchase nichrome wire at PnJ Resources, LLC, http://www.pnjresources.com/Nichrome_page.htm, for about \$2/10' spool.
- 2 Wires with alligator clip ends*
Called "Insulated Test / Jumper Leads", you can usually find a pack of 10 for less than \$6. If not available at a local hardware store or RadioShack, you can purchase them from RadioShack.com, model 278-1156.
- Insulated wire (about 25-cm)
- Cardboard (at least as large as the jar opening)
- 3 brand new D batteries
- Wire cutters and strippers
- 2 Paper clips
- Nail (slightly thicker than the insulated wire)
- Adhesive tape

Instructions

1. Cut a piece of cardboard to just fit over the top of the jar.
2. Use the nail to punch 2 holes in the cardboard, about 1.5-cm apart and near the center.
3. Cut two pieces of insulated wire, 12.5-cm long.
4. Strip 2.5-cm of insulation from each end of both wires.

5. Bend one end of each wire into a small hook and push the other end of each wire through one of the holes in the cardboard lid, so that the hook ends hang about halfway into the jar.
6. Bend the wires on top of the lid and tape them down, making sure they don't touch each other or any other conducting surface.
7. Cut a 5-cm piece of picture hanging wire and separate it into individual thin wires (or cut a 5-cm piece of nichrome wire).
8. Twist 2 or 3 of the thin wires from the picture hanging wire together to form a filament, and bend it around the hooks that will hang inside the jar (or bend a single strand of nichrome wire around the hooks).
9. Replace the lid and tape it onto the jar.
10. Tape the three D batteries together, positive end to negative end.
11. Tape a paper clip to each end of the battery system.
12. Connect an alligator clip wire from one of the paper clips to the end of one of the wires coming out of the jar.
13. Connect the other alligator clip wire from the free paperclip to the free wire coming out of the jar.
14. The filament should glow for a few seconds (or longer, if using nichrome wire) and then break.



Troubleshooting

If the wire burns out too quickly, add another strand of picture hanging wire to the filament or use one less battery in your circuit. If you have trouble getting the wire to glow, check the connections between the batteries and between the filament and the insulated wires.

Discussion questions

- What makes the wire glow?
- Why do wires in electric circuits get warm? What kinds of precautions do we take to make sure this is not dangerous?
- How are light bulbs you buy in a store different from this homemade one?
- How do you think changing the thickness of wire might affect the light produced?

Discussion

The filament glows because the thin wire has a high electrical resistance, meaning that it is difficult for electrons to travel through it. Because there is a high current flowing through the wire and the wire has high resistance, the energy is released as light and heat. Filaments glow and burn while thicker wire only heats up slightly because thin wire has this higher resistance (traffic flows faster, or meets with less resistance, on a wider road with more lanes).

When the wire burns out the circuit is broken and the filament no longer glows. If you look carefully at the filament of a burned out light bulb you can sometimes find the break; you can also shake the bulb and hear the broken pieces rattling.

Commercial light bulbs give off brighter light than the homemade bulb because their filaments are made of tungsten instead of the iron (or nichrome) wire we used. Tungsten's high melting temperature makes it an ideal filament, since other metals melt before getting hot enough to give off the white light we use to light our homes. They are able to stay lit for many hours because the glass bulbs either have no air in them, or are filled with a dilute gas other than oxygen, since oxygen speeds up the burning process.

Suggested resources

"Fluorescent Lamp." Wikipedia. http://en.wikipedia.org/wiki/Fluorescent_light
This site explains how a fluorescent bulb works.

Harris, Tom. "How Light Bulbs Work." How Stuff Works.
<http://home.howstuffworks.com/light-bulb2.htm>
This site has a detailed explanation of the parts of a light bulb and how they work together to produce light. After clicking "Next" a couple of times, there are links to more information on light bulbs.

"Incandescent Light Bulb." Wikipedia. http://en.wikipedia.org/wiki/Incandescent_light_bulb
This site has more information on incandescent and halogen bulbs.

Bibliography

"Edison Invents: Make a Light Bulb." Smithsonian's Lemelson Center.
http://invention.smithsonian.org/centerpieces/edison/000_lightbulb_01.asp

Reuben, Gabriel. *Electricity Experiments for Children*. New York: Dover Publications, Inc, 1960. Page 42.

"Short Circuit: What Happens When You Blow a Fuse?" Exploratorium Snacks.
http://www.exploratorium.edu/snacks/short_circuit.html

ACTIVITY 3

Soak up the Sun

(Heat absorption)

Table of contents

Page 2: A Day at the Beach: Investigate how the temperatures of water and sand change throughout the day (level 1).

Page 6: Cold Floors: Compare how different materials feel to the touch with their actual temperatures (level 1).

Page 9: Colored Filters: Observe how colored filters change what we see (level 1).

Page 11: Color Coded Secret Messages: Use colored filters to make and read secret messages (level 2).

Page 14: Soak up the Sun II: Suggestions for expanding on the PhysicsQuest “Soak up the Sun” activity (level 2).

Page 17: Solar Ovens: Build solar ovens using your knowledge of how materials absorb and reflect heat (level 2).

Safety

Please note that while following the precautions in this guide can help teachers foster inquiry in a safe way, no guide could ever predict all of the problems that might occur. Good supervision and common sense are always needed.

A Day at the Beach

Investigate how the temperatures of water and sand change throughout the day.

Safety

Spilled water or sand can make the floor slippery, so be sure to clean up immediately after any spills. Be careful when working with light bulbs. Some bulbs get very hot, so do not touch them.

Materials

- 2 identical containers ■ 2 thermometers ■ Water at room temperature
- 2 lamps ■ Sand at room temperature ■ Timer or stopwatch

Setting up the experiment

1. Fill one container with sand (at room temperature) to a depth of about 1-cm.
2. Fill the other container to an equal depth with water (at room temperature).
3. Lay a thermometer in the bottom of each container. The bulbs should be covered by the sand / water.
4. Position a lamp 15-cm directly above each thermometer bulb. Make sure that you can read the thermometers without disturbing the setup. You may need to use a stack of books to prop up the containers so they are the correct distance from the lamps.
5. Make a table for recording time and temperature, like the one shown.
6. Write down which container you think will heat the fastest, and why.

Time (minutes)	Water Temperature (°C)	Sand Temperature (°C)
0		
2		
4		
6		
8		
10		
12		
14		
16		
18		
20		

← Turn off lamps

Collecting Data

Two data collectors should record the temperatures of the sand and water. A third should keep track of the time and tell the data collectors when to measure the temperature.

1. Start the stopwatch and turn on the lamps.
2. Record the temperature of the sand and water every two minutes.
3. After 10 minutes, turn off the lamps.
4. Record the temperature of the sand and water every two minutes for the next 10 minutes. While data for the last 10 minutes is being recorded, predict which pan will cool faster. The first 10 minutes of data could be helpful in making a hypothesis.
5. Graph the data for the water and sand on the same graph.

Discussion Questions

- Did the water or sand heat faster? Did this match your prediction?
- Did the water or sand cool faster? Did this match your prediction?
- Using your results, can you explain why pools often feel warm long after the sun has gone down?
- Why is the sand at the beach so hot in the afternoon, while the water remains cool?
- How might having a large lake or an ocean nearby change the climate of an area? Think about spring and fall.
- Do you think your results would have been different if the sand and water were heated with a Bunsen burner or a hot plate? Why or why not?
- How does a real beach differ from our set-up?

FOR THE TEACHER

A Day at the Beach

(Level 1)

Investigate how the temperatures of water and sand change throughout the day.

Materials

- 2 identical wide and shallow containers
Disposable pans, like those in the baking aisle of the grocery store, work well
- Sand at room temperature (enough to cover the bottom of your container to a depth of 1-cm)
Small bags of sand are available at most craft stores.
- Water at room temperature (enough to cover the bottom of your container to a depth of 1-cm)
- 2 identical lamps with 60w bulbs
Desk lamps from retail stores such as Target or Wal-Mart work well and are available for around \$10 each.
- 2 thermometers*
"Metal Back Student thermometers" such as those included in the kit range from 20 to 230°F/-30 to 110°C and are available at science supply stores such as Science Kit & Boreal Labs (Item # WW6644400) for about \$3.50 each.
- Timer or stopwatch

Discussion

Data collection for this activity takes 20 minutes, so you might want to have three students collect data while the rest of the class works on another assignment. Creating more than one setup of this experiment requires a lot of extra materials, so we recommended performing it as a class experiment.

If you have extra containers and lamps, your students can study other materials – such as playground gravel, wet sand, or potting soil.

The sand should both heat and cool faster than the water. This is because water has a higher specific heat capacity than sand – meaning that it takes a lot of heat, or energy, to raise the temperature of water one degree, whereas it takes comparatively little energy to change the temperature of sand by one degree.

The high specific heat capacity of water also explains why it cools slower. More heat must be removed from the water to lower the temperature by one degree than must be removed by the sand to lower its temperature by one degree. The materials also absorb different amounts of heat due to their colors, but the main factor at play is heat capacity, so changing the heating method should not change the qualitative results.

This activity provides an excellent opportunity to discuss error analysis. Encourage students to make a list of things that could make a scientist doubt their results, and have them discuss how the results might change if the set-up was changed. They might consider things like:

- Whether the water circulated during the test and how this would affect the comparison.
- Whether the lamps had the same heat output.
- What would happen if the containers had equal masses of sand and water.

Suggested resources

“Costal Versus Inland Temperatures.” Bigelow Laboratory for Ocean Sciences.

<http://www.bigelow.org/virtual/handson/coastvsinland.html>

A similar activity with more emphasis on coastal versus inland climate.

“Specific Heat Capacity.” Wikipedia.

http://en.wikipedia.org/wiki/Specific_heat_capacity

Includes background on specific heat capacity and a table of values for common materials.

Cold Floors

Explore the way a material feels to the touch and compare this to its actual temperature.

Materials

1. Put your hand on each of the materials. Write down which feel cool and which feel warm.
Rank the materials in order from coldest to warmest.
2. Flip over the sheets one by one and record the temperatures.

Discussion questions

- Were you surprised by the temperature readings? If so, how were they different than you expected?
- Why do the temperatures not match how the surfaces feel?
- If you were re-doing a room in your house, would these results affect the type of floor you put in? If so, how?

FOR THE TEACHER

Cold Floors

(Level 1)

Explore the way a material feels to the touch and compare this to its actual temperature.

Materials

- Self adhesive liquid crystal thermometers, or an infrared thermometer
Liquid crystal thermometers are commonly used for measuring the temperature of terrariums and are available at an aquarium or pet store for a few dollars.
Infrared thermometers are available for \$35+ from science supply stores such as Science Kit & Boreal Labs (www.sciencekit.com) and Edmund Scientific (www.scientificsonline.com).
- Pieces of several of the following (pieces should all be larger than your hand)
 - Steel • Floor tile • Carpet • Wood • Plastic • Cardboard
- Ice cubes (optional)

Notes on the activity

- Metal sheets can warm up rather quickly from repeated touching, so you may want to have several on hand.
- Not all liquid crystal thermometers are well calibrated. Be sure that they all have the same reading at room temperature before attempting this activity. A more expensive but effective alternative is an infrared thermometer, which can quickly and easily measure surface temperature.

Required preparation

1. Stick one liquid crystal thermometer to the back of each piece of material.
2. Place all materials, thermometer-side down, on a large piece of insulating material, such as cardboard. Allow them to come to room temperature.

Discussion

All of the thermometers should be at room temperature, despite some of materials feeling warmer to the touch than others. The way a material feels depends on its ability to conduct heat. Heat travels quickly through metals, for example, and slower through materials like carpet and wood.

When two objects with different temperatures come in contact with one another the heat will flow from the warmer object to the colder object. This is why your coffee cools off to room temperature if you don't drink it fast enough. In this activity, when your hand comes in contact with the piece of flooring, heat flows from your hand to the object since your skin is the warmer object.

Touching metal will cause it to heat up, but that heat is quickly spread out through the metal. This takes heat away from the contact surface between your hand and the metal, thereby carrying away body heat and leaving the surface of the metal feeling cold. Touching carpet will also cause it to heat up, but since carpet doesn't conduct heat as well as metal, the heat from your hand will remain on the surface of the carpet and it will soon reach the same temperature as your hand.

The direction of heat flow is always from the warmer object to the cooler object. This idea can be emphasized by comparing the results of touching metal with your hand (your hand is the warmer object) and touching metal to a piece of ice (the metal is now the warmer object – see addition)

Discussion (continued)

You may wish to have students rank the heat conductivities of the materials. They can check their answers by looking up the heat conductivity of the materials on the internet.

This is a good way to introduce the idea that all materials in a given environment eventually come to the same temperature. Also notable is that hot metals are more dangerous than other materials at the same temperature because they will transfer heat to your hand more quickly.

The results of this activity can also motivate a discussion of why scientists prefer to use numerical measurements, rather than their senses alone, to make scientific observations.

Optional addition

1. Place all materials on a large piece of insulating material, such as cardboard.
2. Have students predict which material will melt an ice cube the fastest based on what they felt when touching each material and the results of the thermometer readings.
3. Have them verify by touch that all the ice cubes are really ice and have similar mass.
4. Place one ice cube at the center of each material. Allow the ice cubes to melt without touching or moving them and observe differences in melting time.

Discussion Question

■ Why does a piece of metal melt an ice cube faster than a piece of wood, even though the metal felt colder originally?

Discussion

In the original activity your hand was the warmer object. In this variation, the piece of flooring is the warmer object. The metal melts the ice cube faster than the wood because the heat in the metal travels through it to the surface in contact with the ice faster than it can in the other materials.

Suggested resources

Elert, Glenn. "Conduction." The Physics Hypertextbook, 2006.

<http://hypertextbook.com/physics/thermal/conduction/>

Background on thermal conductivity and table of common materials' conductivities.

Taylor, Stuart, Paul Walorski, and Tom Young. "Ask the Experts." Physicslink.com. <http://www.physicslink.com/Education/AskExperts/ae680.cfm>

Explanations of conductivity and other factors influencing how "hot" or "cold" an object feels.

Bibliography

"Cold Metal." Exploratorium Snacks. http://www.exploratorium.edu/snacks/cold_metal.html

Colored Filters

Explore how looking through colored filters changes what you see.

Safety

1. Never look directly at the sun or other bright light sources.
2. Flip over the sheets one by one and record the temperatures.

Materials

- Red, blue and green primary color filters
- Additional color filters
- This page, printed in color

Instructions / discussion questions

- Look at an object with lots of different colors, such as a painting, through each filter. How do the colors change when you look at them through a filter?
- Find objects that look the same as white objects through each filter. What color are they without the filter?
- Look at the colors below through each filter and describe what you see. What causes these changes in appearance?



Image courtesy NASA

FOR THE TEACHER

Colored Filters

(Level 1)

Materials

- Red, blue and green primary color filters
Theatre supply stores sell large sheets of lighting gels for a few dollars that work very well. You can also get these from science supply stores.
- Additional color filters
Such as a book of gel samples from a theater supply store.
- Previous page, printed in color

Instructions

Divide students into groups. Give each group three filters, one of each color. Have students look around the room through the filters and pay attention to how objects' appearance change depending on which filter is used.

Discussion

We see because objects reflect light into our eyes. Objects have color because they reflect some colors more than others. For example, a red apple reflects red light but absorbs most blue and green light, so it looks red. A blue object reflects blue and absorbs green and red.

Color filters absorb all of the light that goes through them except for one color – the color that they reflect. For example, the green filter absorbs red and blue light, but reflects and transmits (lets through) green light. This is why when you look through it you see the world in shades of green: objects reflecting a lot of green light (green objects) look brighter than those reflecting less green light (red or blue objects).

Red and blue objects look dark through a green filter because the filter absorbs most of the light that they are reflecting. Yellow and cyan objects appear as different shades of green because they reflect some green light and some red (yellow objects) or blue (cyan objects), but the filter blocks every color except green. White light is a mixture of all colors, so when viewed through a filter, a white object will appear a light shade of the color of the filter.

Suggested resources

Crump, Lorraine I. "I Can See a Rainbow!" SMILE Program.

<http://www.iit.edu/~smile/ph9203.html>

Another color mixing activity which includes several activities related to why the sky is blue and rainbows.

"RGB World: Understanding Color." RGB World, Inc., 2006.

<http://www.rgbworld.com/color.html>

Background on the two types of color mixing as well as reflection and absorption.

Bibliography

"Colored Shadows." Exploratorium Snacks.

http://www.exploratorium.edu/snacks/colored_shadows.html

Colored Secret Messages

Explore how colored filters can be used to create and decode secret messages.

Materials

- Red, blue and green primary color filters
- Secret messages printed in color
- Additional color filters
- Computers with Microsoft Word (optional)

Instructions

1. Look at the secret messages below.
2. Predict which filter will make each message clear.
3. Go through your filters and find one that lets you read each message.

Discussion questions

- Why is it difficult to read the messages?
- How is the color of the filter that lets you to read the message related to the colors in the message?

Camouflaged secret messages

People often have red eyes in pictures because light from the camera's flash reflects off of the blood vessels in the back of the eye.

Oceans and lakes look blue because they reflect the blue of the sky.

Plants look green because they reflect green light. They use red light to make their food, so a green filter will make them grow very slowly.

Overlapping Secret Messages

Can you see this red message?
A blue message goes crazy!

Make your own camouflaged secret messages

1. Open Microsoft word.
2. Create a text box and type your message.
3. Right click on the edge of the text box and select the “format” option.
4. Under “colors and lines” select “fill” and go to “fill effects” to see the pattern choices (option titles may vary with Microsoft version).
5. Look through the filter you want to be the key to your message and choose a pattern and color that is hard to see through without the filter but nearly invisible with the filter.
6. Change the color of the text to a color other than the filter color.
7. Test that your message is only visible when using the filter.

Make your own overlapping secret messages

1. Open Microsoft word
2. Use word art (on the “Drawing” toolbar) to write your secret message (choose a bold style without a shadow).
3. Use word art to create a different message, we’ll call this message 2
4. Right click on message 2 and choose “format”
5. Under “colors and lines” select “line” and choose “no line”
6. In the same menu, select “fill” and then choose “fill effects” to see the pattern choices.
7. Look through the filter you want to be the key to your message and choose a pattern and color that is hard to see through without the filter, but nearly invisible with the filter.
8. Using the same procedure, change the secret message so that it has no outline and is filled with a pattern that is easily visible through the filter.
9. Click and drag the secret message so that it is on top of message 2 (you may need to change the layout of the secret message to “behind text” under the “format” menu in order to do this.). The secret message should be difficult to read without the filter and easier using the correct color filter.

FOR THE TEACHER**Colored Secret Messages**

(Level 2)

Materials

- Red, blue and green primary color filters

Theatre supply stores sell large sheets of lighting gels for a few dollars that work very well.

- Additional color filters

Such as a book of gel samples from a theater supply store.

- Secret messages printed in color

- Computers with Microsoft Word (optional)

Discussion: Camouflaged messages

Each text message is covered by a pattern of a different color. To see through the pattern, you have to use the colored filter that matches the color of the pattern.

The pattern should “disappear” when viewed through the matching filter for the same reason that red objects and white objects look similar through a red filter. The red light from a white-colored object passes through the filter to your eyes, but the other colors are blocked. This makes the white object appear a light shade of red. Therefore, looking through a red filter at a red pattern on a white background lessens the contrast between the pattern and the background. This makes the hidden message appear dark and easy to read.

Games, such as Outburst (by Get Together Games), sometimes use this technique to keep the words on game cards hidden. They include a color filter so that at the appropriate time the players can read the words.

Discussion: Overlapping messages

Each of these messages is really two overlapping messages made from different colored dots. When viewed through a filter of one of the colors, the dots of that color disappear for the reasons given above, leaving the other message readable.

Suggested Resources

Crump, Lorraine I. “I Can See a Rainbow!” SMILE Program

<http://www.iit.edu/~smile/ph9203.html>

Another color mixing activity which includes several activities related to why the sky is blue and rainbows.

“RGB World: Understanding Color.” RGB World, Inc., 2006

<http://www.rgbworld.com/color.html>

Background on the two types of color mixing as well as reflection and absorption.

Bibliography

“Colored Shadows.” Exploratorium Snacks.

http://www.exploratorium.edu/snacks/colored_shadows.html

FOR THE TEACHER

Soak up the Sun

(Level 2)

This extension lists variations/additions on the “Soak up the Sun” PhysicsQuest activity (pages 29-37 in the PhysicsQuest manual). Instead of trying all of the variations suggested below; you may wish to focus your students on one factor for a more in-depth discussion

Safety

Students should be careful when working with light bulbs. Certain bulbs, especially halogen bulbs, get very hot when running, so students should not touch any light bulbs during testing or for few minutes after testing. Incandescent bulbs are also very easy to break, so students should be advised to handle them with care and ask for help if one breaks. Students should be careful with the glass used in the Windows activity, as it may have sharp edges and can easily break.

Materials needed for all variations

■ Core activity materials from Activity 3

■ Thermometers (2)*

“Metal Back Student thermometers” such as those included in the kit range from 20 to 230°F/−30 to 110°C and are available at science supply stores such as Science Kit & Boreal Labs (item # WW6644400) for about \$3.50 each.

- Desk lamp with 60w light bulb
- Plain white paper
- Graph paper
- Colored pencils / markers
- Stop watch or clock with second hand
- Scissors
- Metric ruler

Cooling Rates

Have students complete the core activity as instructed in the PhysicsQuest Student Guide, but instead of setting the thermometers aside when the five minutes of data collection has passed, two group members should collect data on the rate of cooling for each color for an additional 5 minutes. They should graph all of the data together.

Additional materials

- Another stopwatch

Discussion questions

- Which color cooled the fastest? The slowest?
- Were you surprised by the result?
- How did the cooling rate compare to the heating rate for each color?

Discussion

Students should find no clear relationship between the cooling and heating rates of the different colors. This is because although materials absorb light in the visible range of light (this is why color makes a difference), they emit heat primarily in the infrared range. The color of a material has little effect on the rate of infrared emission.

Beyond Felt

Students should create pockets from the paper, foil, and wrap, as in the core activity. They should then follow the same instructions for collecting data as in the core activity.

Additional materials

- Aluminum foil
- Construction paper of various colors
- Plastic wrap

Discussion questions

- Which pockets got the hottest? Why do you think this is?
- What factors besides color affect how well an object absorbs heat?
- If you could create an ideal light-absorbing pocket, what would it be like?

Discussion

This variation is more of an exploration than an experiment because it introduces many different variables to the original color-based experiment – such as reflectivity, type of material, material thickness, etc. This activity is included because it is a good starting point for discussing how well different materials absorb light. This is also a good opportunity to talk with students about the importance of changing only one variable at a time in an experiment?

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Comparing Light Sources

Have students place a thermometer under each of the following types of lamps and record the temperature every minute for 5 minutes (as in the core activity). Make sure that the distance from the bulb to the thermometer is the same for all trials.

Additional materials

- Incandescent desk lamp
- Fluorescent desk lamp
- Halogen desk lamp

Discussion questions

- Which light source heated the felt the fastest? The slowest?
- How does the brightness of the lamp compare to its ability to heat the felt? Does the brightest lamp give off the most heat?
- If a lamp was not very bright, but the felt heated quickly, what would that tell you about its efficiency? In other words, is a large or small part of the lamp's energy going into producing light? Into producing heat?
- Is this a good test of how much heat different types of light bulbs give off? What other factors might have influenced your results.

Discussion

■ Incandescent light bulb

Probably the most common type of light bulb used in homes, incandescent light bulbs light up when an electric current travels through a thin wire filament (see Activity 2, Extension 5). This causes the filament to radiate light, much of which is infrared light, or heat. Incandescent bulbs are the least efficient type of bulb in terms of energy need per amount of visible light produced.

■ Halogen light bulb

Halogen light bulbs use a chemical process involving halogen gas to increase the lifetime of the filaments, but this only works if the bulb is allowed to get very hot. Although this increases the efficiency of the light bulb it also produces a lot of heat.

■ Fluorescent light bulb

Fluorescent lights, which are inexpensive and more efficient than incandescent light bulbs, emit light when a chemical reaction in the bulb turns UV light into visible light. This process doesn't give off much infrared light so the bulb only becomes warm instead of hot.

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Windows

In this activity students investigate how light shining through a window in a closed room affects the temperature of a room.

Have students place a thermometer in a box, cover the top of the box with the glass, and put the box in the sunlight (or directly below a desk lamp with an incandescent bulb). Then have them record the temperature on the thermometer every two minutes for a total of 10 minutes. After this, have students move the box/glass aside and put only an at-room temperature thermometer in its place. Again, have students collect data every two minutes for 10 minutes.

Additional materials

- Empty box (large enough to hold the thermometer)
- Glass or acrylic sheet (large enough to cover the box)

Discussion questions

- Were you surprised at the temperature difference between the two situations? Why or why not?
- Think about what you learned in this experiment – why do parked cars get so hot in the summer? On sunny winter days?
- In what other ways do windows affect the temperature of a room?

Discussion

When light from the sun enters a room through the window it is absorbed by the surfaces in the room and radiated as heat. The glass in the window doesn't allow the heat to escape by convection (rising of hot air), so the hot air stays in the room.

In addition, infrared light can pass through windows (although you can purchase windows with a special coating to reduce this). When infrared light enters a closed room it is also trapped in the room – which causes the room to heat up.

Solar Ovens*

Design and build a solar oven using your knowledge of heat absorption.

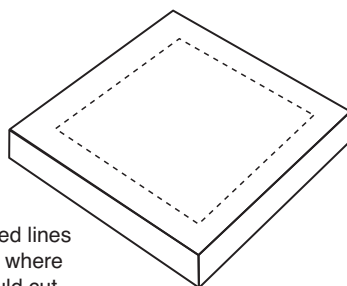
Materials

- Carboard box
- Scissors
- Aluminum foil
- Plastic wrap
- Black construction paper
- Adhesive tape
- Markers
- Thermometer
- Straw or stick
- Something to melt or cook

Make a solar oven

1. Draw a one inch border on all four sides of the top of the pizza box. Cut along three sides leaving the line along the back of the box uncut.

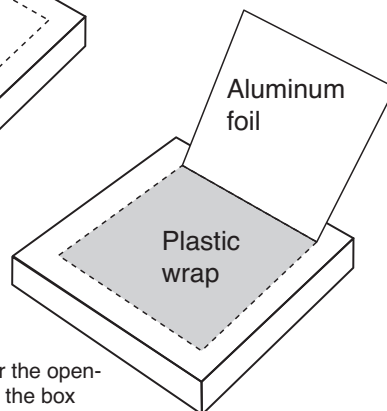
The dotted lines illustrate where you should cut.



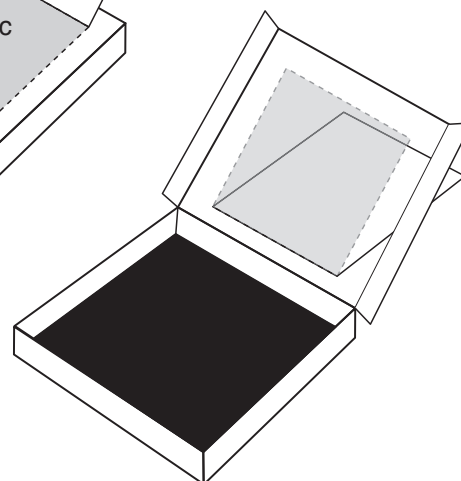
2. Form a flap by gently folding back along the uncut line to form a crease.

3. Cut a piece of aluminum foil to fit on the inside of the flap. Smooth out any wrinkles and glue into place.

Cover the opening in the box with a piece of plastic wrap and the inside of the flap with foil



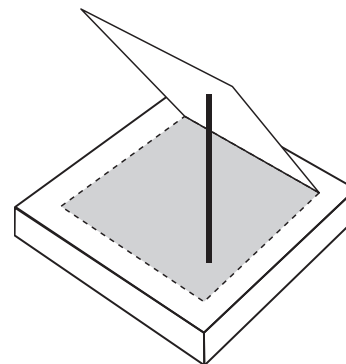
4. Measure a piece of plastic to fit over the opening you created by forming the flap in your pizza box. The plastic should be cut larger than the opening so that it can be taped to the underside of the box top. Be sure the plastic becomes a tightly sealed window so that the air cannot escape from the oven interior.



5. Cut another piece of aluminum foil to line the bottom of the pizza box and carefully glue into place.

6. Cover the aluminum foil with a piece of black construction paper and tape into place.

7. Close the pizza box top (window), and prop open the flap of the box with a wooden dowel, straw, or other device and face towards the sun. Adjust until the aluminum reflects the maximum sunlight through the window into the oven interior.



Your oven is ready! Test how hot your oven can get using a simple oven thermometer, and try melting or cooking something tasty!

*Text and illustrations shown with this activity are based on information from "Make a Pizza Box Solar Oven" by Solar Now, Inc. The original document can be found at <http://www.solarnow.org/pizzabx.htm>. Text has been adapted for use as a PhysicsQuest extension

Solar Ovens*

Discussion questions

- How could you make your solar oven heat up faster?
- What is the purpose of the clear plastic? The aluminum foil?
- What are the benefits and drawbacks of using a solar oven to cook food?

FOR THE TEACHER

Solar Ovens

(Level 2)

Text and illustrations shown with this activity are based on information from “Make a Pizza Box Solar Oven” by Solar Now, Inc. The original document can be found at <http://www.solarnow.org/pizzabx.htm>. Text has been adapted for use as a PhysicsQuest extension.

Materials

- Shallow cardboard box
A pizza box works well
- Scissors or box cutter
- Aluminum foil
- Plastic wrap
- Black construction paper
- Tape
- Markers
- Other miscellaneous materials such as newspaper, colored construction paper, or felt
- Thermometer*
“Metal Back Student thermometers” such as those included in the kit range from 20 to 230°F/–30 to 110°C and are available at science supply stores such as Science Kit & Boreal Labs (item # WW6644400) for about \$3.50 each.
- Straw, stick, or other object to prop up a flap of cardboard
- Something to melt or cook (marshmallows, chocolate chips, mini hotdogs etc.)

Notes on the activity

Step-by-step instructions are provided, as well as more open-ended inquiry-based instructions for more advanced classes.

Inquiry-based Solar Ovens Activity (step-by-step instructions on previous page)

Step-by-step instructions are provided, as well as more open-ended inquiry-based instructions for more advanced classes.

Divide students into small groups. Give each group a cardboard box and place the rest of the materials on a front table. Make sure there is enough of everything to go around. Tell the class that they will have 30 minutes to make a solar oven. They should spend 5-10 minutes planning and the rest of the time building. The group whose oven reaches the highest temperature after 10 minutes in the sun will be the winner.

Remind your class to use what they learned about how different materials respond to light in the core activity (and other extensions if you have performed them). Outside knowledge of other materials’ properties will be helpful as well. Depending on how advanced your class is, you may want to go over some of the concepts below before the contest. You might also considering building a sample oven as an example.

- Dark colors absorb more heat than light colors
- Shiny materials reflect light (and thus heat) and can be used to “aim” light
- Transparent materials allow light in, but do not let air out
- Warm air rises

Discussion

The sun's rays come into the box through the clear plastic. Once inside the rays are absorbed by the black construction paper and are radiated as heat. The heat is then trapped inside the oven in two different ways:

1. Cardboard is a good thermal insulator so very little heat escapes through radiation
2. The clear plastic does not allow much air to escape so little heat is lost to the raising of hot air (convection).

The aluminum foil flap lets the user direct the maximum amount of sunlight into the oven to keep it hot, since aluminum is a good reflector of light.

Suggested resources

D'Alto, Nick. "S'more Energy Please!" Education Place: Experience Science.
<http://www.eduplace.com/science/hmxs/ps/modd2/cricket/sect5cc.shtml>
Explanation of how a solar oven works and alternate design for an oven.

Field, Simon Quellen. "Light and Optics: Make a Solar Powered Marshmallow Roaster."
Science toys you can make with your kids.
http://sci-toys.com/scitoys/scitoys/light/marshmallows/solar_roaster.html
Instructions for another type of solar cooker, this one uses a Fresnel lens.

References

"Make a Pizza Box Solar Oven." Solar Now, Inc., 2003
<http://www.solarnow.org/pizzabx.htm>

ACTIVITY 4

Bring it into Focus

(Lenses and optics)

Table of contents

Page 2: Disappearing Test Tube: Make clear objects visible – or invisible – using what you know about how light bends (level 1 demonstration)

Page 5: TV Image Projection: Use your results from the core activity to project images from a TV screen (level 1, level 2)

Page 7: Total Internal Reflection: Explore how information travels through fiber optic cables with these experiments (level 1)

Page 11: Homemade Telescope: Make a simple refracting telescope and read messages from across the room (level 2)

Safety

Safety: Please note that while following the precautions in this guide can help teachers foster inquiry in a safe way, no guide could ever predict all of the problems that might occur. Good supervision and common sense are always needed.

FOR THE TEACHER

Disappearing Act (*demonstration*)

(Level 1)

This demonstration shows how you can make an object disappear based on its index of refraction. It is simple to complete, but the results can be difficult to understand without prior knowledge of how materials bend light. Two ways to carry out the demonstration are explained – as a magic trick or as a “show and discuss” demonstration.

Safety

If vegetable oil spills on the floor the floor will be very slippery. Be sure to clean up any spills immediately. Also, if you perform the magic trick be careful not to cut yourself when breaking the test tube and cleaning up the pieces.

Materials

■ Magic Trick

- Large beaker (*Must be big enough that you can completely submerge the Pyrex object in it*)
- 2 test tubes, or other small Pyrex objects (*stirring rods, small beakers, etc.*)
- Wessen brand vegetable oil (*enough to fill the beaker*)
- Rubber gloves (*optional*)
- Tongs
- Paper towels

■ Show and Discuss

- 2 large beakers (*Must be big enough that you can completely submerge the Pyrex objects in them*)
- 2 Test tubes, or other small Pyrex objects (*stirring rods, small beakers, etc.*)
- Wessen brand vegetable oil (*enough to fill one beaker*)
- Water (*enough to fill one beaker*)
- Rubber gloves (*optional*)
- Tongs (*optional*)
- Paper towels

Notes

- The small Pyrex objects should be cleaned before performing this demonstration.
- You may wish to wear rubber gloves to keep the oil off of your hands.

Magic Trick instructions

1. Before class begins submerge one test tube in a beaker filled with oil. The tube should be barely visible, if at all.
2. For the demonstration, take another test tube, break it carefully and then place the pieces in the “magic liquid.”
3. After some fancy magic words, pull out the unbroken test tube

Discussion questions

- There is science behind this magic trick, of course. How do you think the broken test tube was able to come out whole?
- Do you think this trick would work in a beaker full of water? Why or why not?
- How could you measure an object's index of refraction?
- Brainstorm other clear materials. Do you think they have higher or lower indices of refraction than oil? How could you test this?

Show and Discuss instructions

1. Fill one beaker with water and another with oil.
2. Place the test tube in the water-filled beaker and note its appearance.
3. Now submerge the beaker partway in the oil, but don't let the oil fill the test tube. The outside edges should be nearly invisible, but the inside edges should be easy to see.
4. Fully submerge the test tube, allowing oil to fill it completely. Now its edges should be very difficult to see.

Discussion questions

- What are some of the differences between oil and water?
- Why do you think you can see the test tube in the water but not in the oil?
- How could you measure an object's index of refraction?
- Brainstorm other clear materials. Do you think they have higher or lower indices of refraction than oil? How would you test this?

Discussion

We see the edges of objects because light is either reflected or refracted at their boundaries. In the case of clear objects, such as glass and some plastics, refraction allows us to discern their edges from the surroundings. For instance, water and glass have different indices of refraction, which makes the light bend at the boundary between the two materials. This makes the sides of a submerged test tube clearly visible when held underwater.

When a test tube is submerged in vegetable oil, however, the boundaries are invisible because the oil and Pyrex glass have the same index of refraction. This means that the light is not at all refracted when it crosses the boundary between the oil and glass.

This activity can also be performed as a laboratory session in small groups, though it can get very messy! Students may wish to test other liquids such as glycerin or other oils to see how the appearance of the test tube changes. You might also consider having students look up the index of refraction of the fluids they test on the Internet.

Another idea that can be introduced with this demonstration is that index of refraction changes with temperature. After students have observed the disappearing test tube, place the beaker containing the oil and the test tube on a hot plate. The edges of the test tube should gradually get easier to see as the temperature of the oil increases.

Suggested resources

“Index of Refraction.” HyperPhysics.

<http://hyperphysics.phy-astr.gsu.edu/hbase/tables/indrf.html>

Lists the indices of refraction table for common materials.

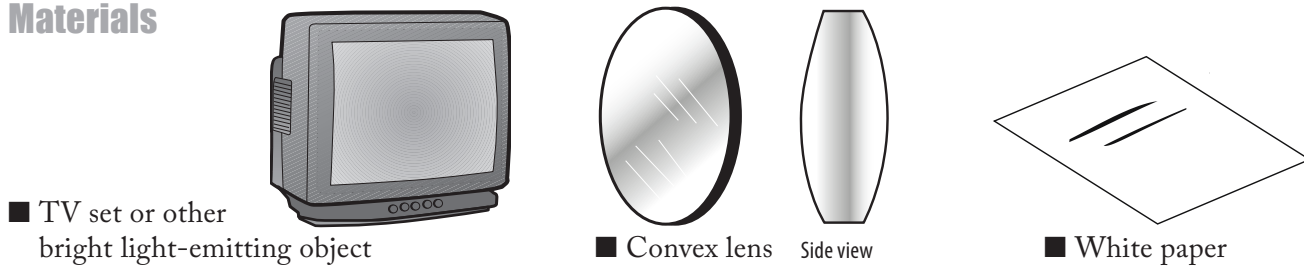
Television Projectors

Project an image of a television screen onto a piece of paper using a converging (convex) lens – and investigate how the distance between the TV and the lens affects the focal length of the lens.

Safety

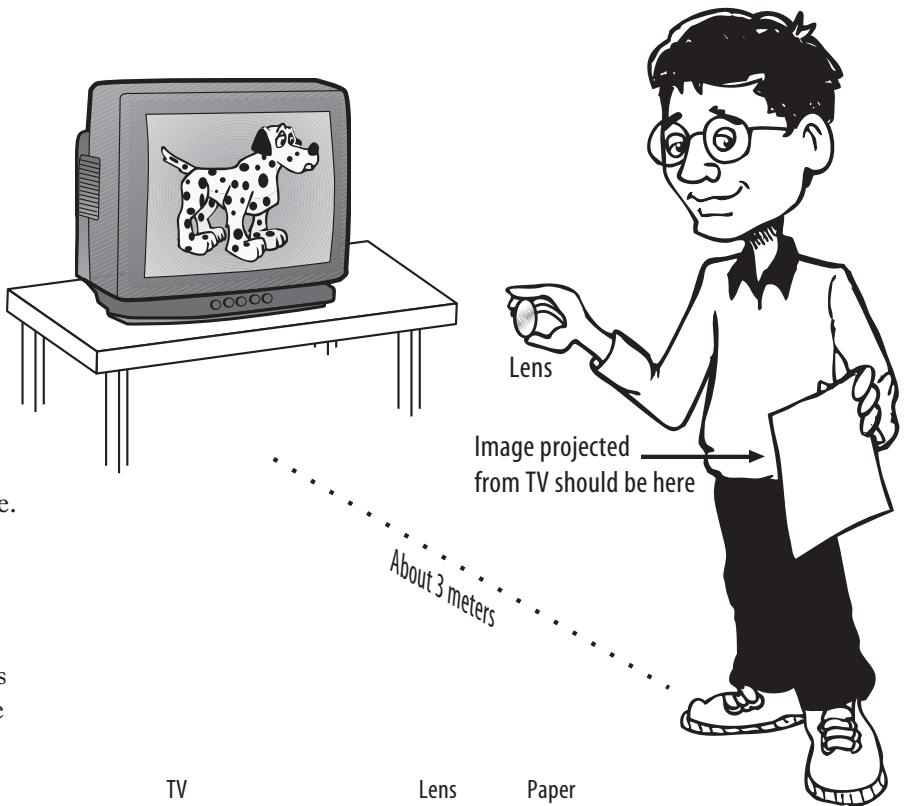
Never look directly at the sun or other bright light sources.

Materials



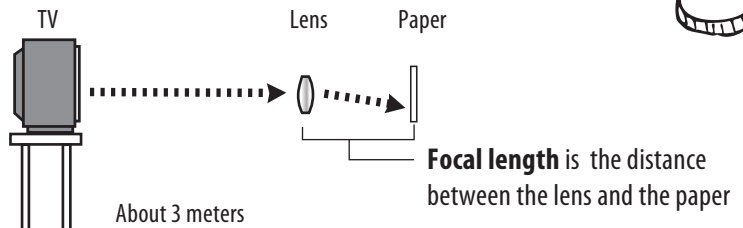
Instructions

1. Turn off the room lights.
2. Turn on the television and stand about 3-m from screen.
3. Face the screen and hold your lens parallel to the screen. Have a partner hold a sheet of white paper at the focal point of the lens.
4. Adjust the distance between the lens and paper until a clear image is visible.



Discussion questions

- Describe the image you see. How do its size and orientation compare to the image you see when you look at the TV screen?
- Is the distance between the paper and lens different from the focal length you measured earlier? If so, why do you think this is?
- When you bring the lens closer to the TV, do you need to change the distance between the lens and paper to get a clear image? If so, do you need to increase or decrease the distance?



NOTE: Diagram not to scale

FOR THE TEACHER

(Level 1, Level 2)

Television Projectors

Materials

- TV set or other bright light-emitting object

A television works well, but you can also use a computer monitor, bright window, or candle flame.

- Convex lens*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224520. \$3.95 each. Many places also offer classroom set specials.

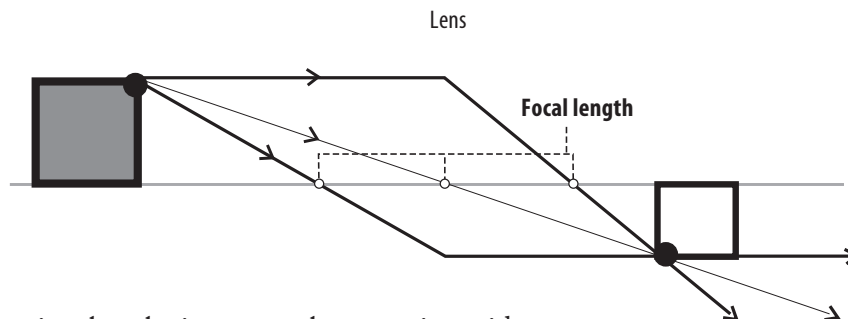
- White paper

- Dark room

Notes on the activity

If your class has geometry experience, you might have them use ray diagrams to explain the orientation of the image. They should use the following rules to draw the diagrams:

- Rays approaching a lens perpendicular to it pass through the focal point on the other side
- Rays passing through the center of the lens continue in a straight line
- Rays passing through the near focal point emerge perpendicular to the lens
- The image appears where all of the rays intersect



Discussion

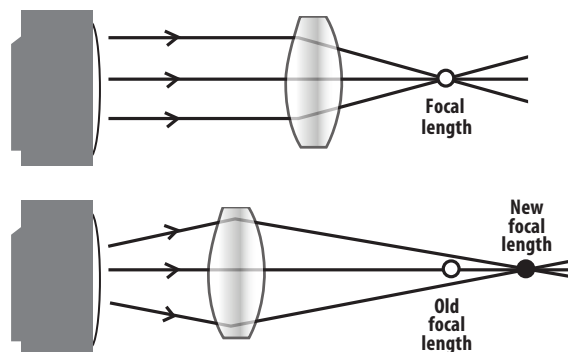
Students should notice that the image on the paper is upside down and backwards, as shown in the diagram. Students should also note that as they get closer to the TV the distance between the lens and the paper needs to increase to get a clear image. The technical focal length of a lens refers to the distance at which the lens focuses incoming parallel light rays (from far away objects). When the lens is close to the TV, the rays are no longer coming in parallel and so the focal length of the lens increases.

Suggested resources

Henderson, Tom. "Image Formation by Lenses." The Physics Classroom, 2004 <http://www.glenbrook.k12.il.us/GBSSCI/PHYS/CLASS/refrn/u14l5a.html>.
Information about how lenses bend light, ray diagrams, and links to more optics information.

Bibliography

Cobb, Vicki, Josh, and Theo. *Light Action: Amazing Experiments with Optics*. New York: Harper Collins Publishers, 1993. Pages 51-54.



- The focal length of a lens.
- If the same lens is moved closer to the TV, its focal length will increase.

FOR THE TEACHER

Total Internal Reflection

Several different ways to explore total internal reflection are explained here. Be sure to try these experiments before having your students try them in class.

Safety

Students should never look directly at bright light sources, even a flashlight. Warn students strongly about the dangers of looking directly into the laser beam. Shining the beam into their eyes or the eyes of their classmates may cause serious injury.

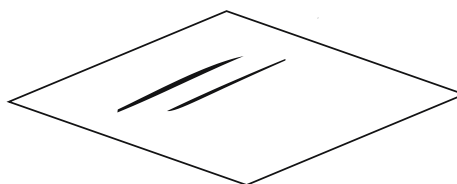
Trapped Underwater (*demonstration*)

Materials

■ Small fish bowl (or other clear container, such as a beaker or large drinking glass)



■ Water (enough to fill your container)



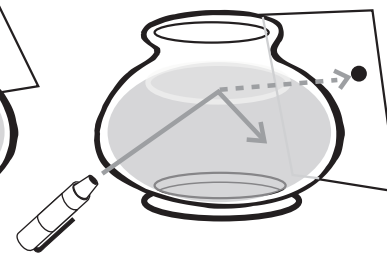
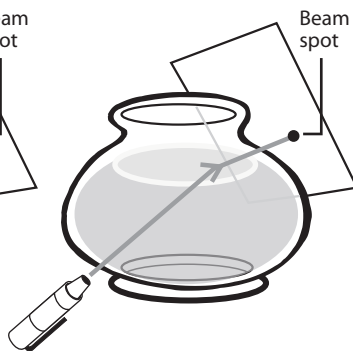
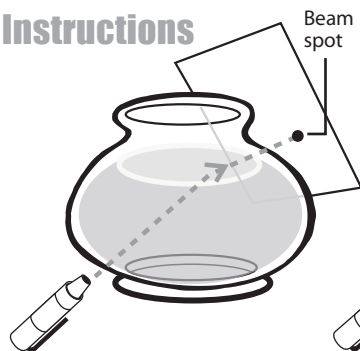
■ White paper



■ Milk

■ Laser pointer

Instructions



1. Fill the fish bowl with water and shine the laser through it. Find where the beam exits the bowl by moving a white piece of paper around the outside of the bowl until you see the spot from the laser.

2. Add a few drops of milk to the water and shine the laser through the bowl again. Continue adding milk until the beam is clearly visible inside the bowl.

3. Point the laser up through the water toward the liquid's surface, at a steep angle. Place a piece of paper on top of the container at an angle so you can see the exiting beam.

4. Slowly decrease the angle at which the beam hits the surface – you should see the exiting beam get closer and closer to the water's surface. Eventually, you will pass a critical angle beyond which all of the laser light is reflected by the water / air boundary.

Discussion questions

- Why do you have to add milk to the water for this demonstration?
- Why does the laser reflect off of the water?
- Does the laser reflect off the water at all angles?
- What would happen if you did this experiment in another clear liquid – like oil?

FOR THE TEACHER

Trapped Underwater *(continued)*

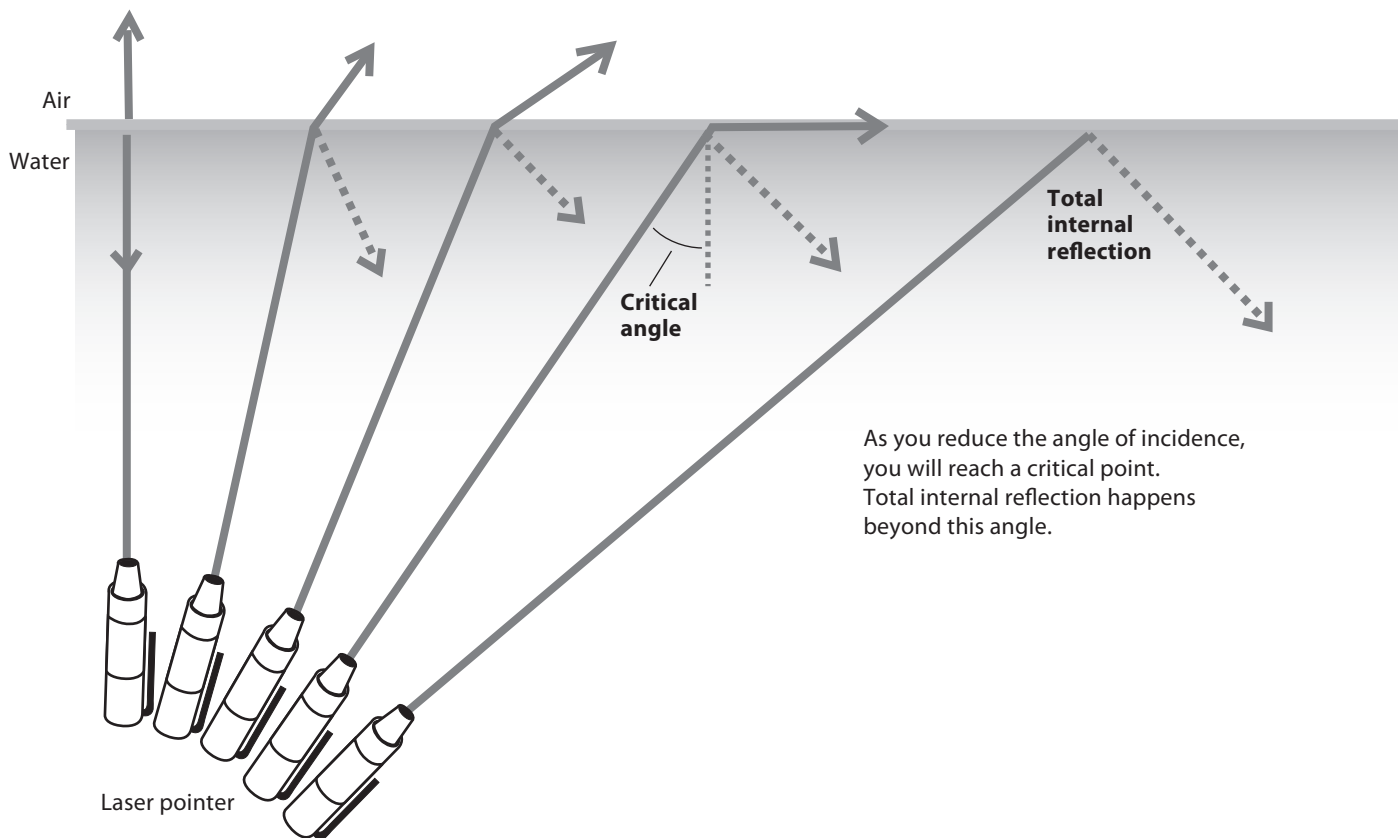
Discussion

The beam is visible when you add milk because of scattering – light bouncing in irregular directions off of impurities (our impurities are milk particles in the water). The laser light bounces off of the milk particles in random directions, so some light is reflected into your eyes. This reflected light allows you to see the beam.

When you point the light up at the water / air boundary, some of it is reflected by the boundary and some passes through into the air. The reflected light is reflected just as it would if the boundary was a mirror – the angle of reflection is the same as the angle of incidence. The light that passes through into the air is refracted, or bent, because water and air have different indices of refraction.

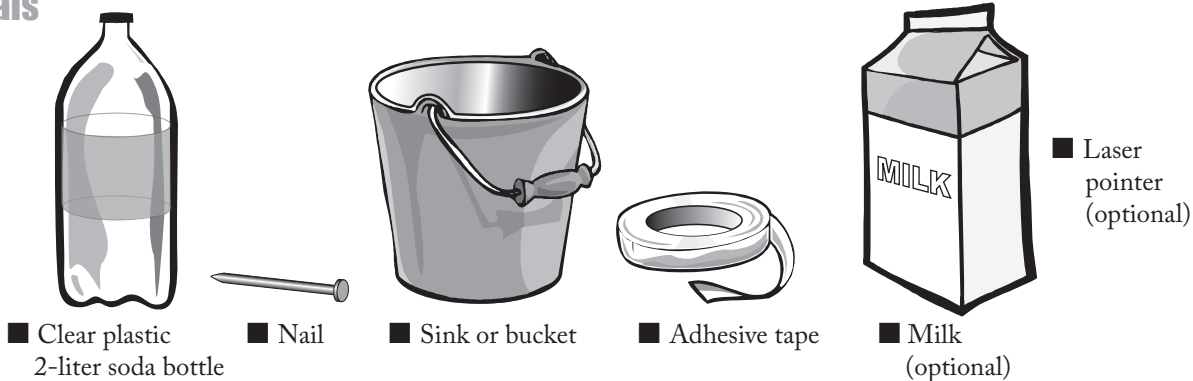
The percentage of light that is reflected and the percentage that is transmitted depends on the angle at which the light hits the boundary (see picture). If you keep increasing the angle, as in the demonstration, you eventually reach a critical angle where the light that passes through the boundary skims along the surface. This angle is determined by the indices of refraction of the two materials (at a water / air boundary, this angle is 48.6 degrees).

When the angle that the light hits the surface at is greater than the critical angle, all of the light is reflected within the water – this is total internal reflection.



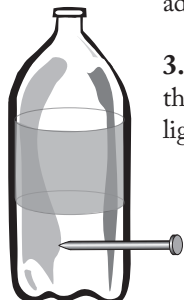
There's a hole in the bucket (*demonstration*)

Materials



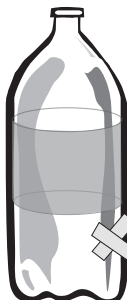
Instructions

1. Use the nail to carefully punch a small hole in the side of the plastic bottle, about 8-cm from the bottom. Smooth out the plastic edge around the hole as much as possible.



2. Cover the hole with adhesive tape.

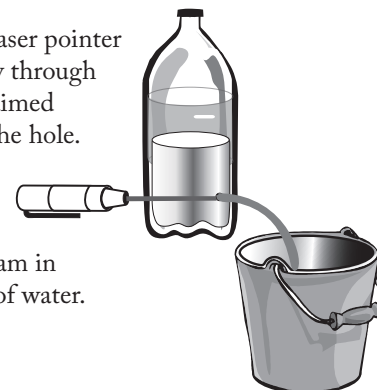
3. Turn off the room lights.



4. Fill the bottle 2/3 full of water, and add a small amount of milk.

5. Hold the bottle over a sink or an empty bucket and remove the tape.

6. Shine a laser pointer horizontally through the bottle, aimed directly at the hole. Add more milk if you cannot see the laser beam in the stream of water.



Discussion questions

- Are you surprised by what you see? Why or why not?
- Why does the light stay in the stream?
- Do you think the same thing would happen if you used another liquid instead of water?
- What was the purpose of adding the milk?
- Why did you need to point the laser beam directly at the hole?

Discussion

You should see light from the laser pointer travel with the stream of water as it flows out of the bucket. This is because the light is totally internally reflected within the water.

The laser beam has to be pointed directly at the hole because it does not spread out like a flashlight – if you pointed the laser down through the top of the bottle, not much of the light would make it out of the hole.

See discussion for Trapped Underwater for an explanation of total internal reflection and an explanation of how the milk makes laser light visible.

Fiber Optics

(Level 1)

Hand out sections (about 0.75-m) of fiber optic cable to small groups. Turn off the lights. Have students hold one end of their cable to the flashlight and observe what happens.

Materials

- Fiber optic cable
 - Flashlight
- Available at Arbor Scientific for \$0.75/m*
<http://www.arborsci.com/detail.aspx?ID=317>

Discussion questions

- When you shine a light in one end of the cable, where does the light come out? Is this what you expected? Why or why not?
- Why doesn't the light leak out of the side of the cable?
- Why would something like this be useful?
- What happens if you crack (or scratch) the cable? (If your teacher gives you permission)

Discussion

Students should see that although the cable is clear, no light escapes the sides and all is transmitted to the other end of the cable. This is because the light is totally internally reflected within the cable.

See discussion for *Trapped Underwater* for an explanation of total internal reflection

If you are not concerned with preserving the cable, you may wish to have some or all groups scratch their cables with scissors and report what happens. Light escapes from the cables when they have been scratched because the reflective coating is disrupted.

Fiber optic cables are used to send signals over long distances because all of the light stays in the cable. This means that the strength of the signal stays nearly the same even when transported over long distances. Fiber optic cables are also used in micro-surgeries so that doctors can see into patients' bodies without using large incisions.

Suggested resources

Goff, David. "A Brief History of Fiber Optic Technology." 2002.

<http://www.fiber-optics.info/fiber-history.htm>

History and applications of fiber optics and total internal reflection.

"Refraction, Snell's law, and total internal reflection." Boston University Physics Department, 1998.

<http://buphy.bu.edu/py106/notes/Refraction.html>

Total internal reflection explained using Snell's Law.

Bibliography

Gardner, Robert. *Experiments with Light and Mirrors*. Springfield, NJ: Enslow Publishers, Inc: 1995. Pages 72-73.

Homemade Telescope

(Level 2)

Use two lenses to make a simple refracting telescope. This telescope can be used to read a message posted across the room.

Safety

Never look directly at the sun or other bright light sources, especially through a telescope.

Materials

- Convex lens, focal length = 20-cm
- Concave lens, focal length = 5-cm
- Convex lens, focal length = 10-cm (optional)
- Ruler
- Modeling clay
- Cardboard (about 3-cm x 5-cm if using a standard-sized ruler)

Instructions

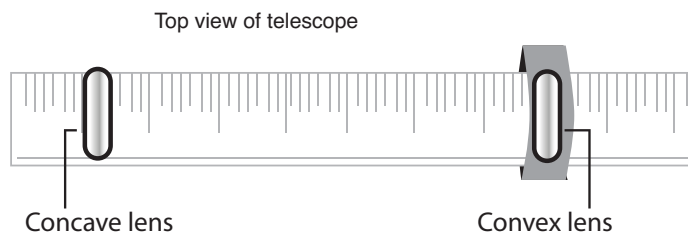
Cut two pieces of cardboard slightly wider than the ruler and tape them together with the ruler in the middle, as shown in the picture. You should be able to slide the cardboard sleeve up and down the ruler.

1. Stick the convex lens with the 20-cm focal length to this sleeve using a small blob of clay.

2. Attach the concave lens to the end of the ruler using another blob of clay.

3. Hold the end of the ruler with the concave lens up to your eye and look at a distant object out the window.

4. Move the convex lens toward or away from the concave lens until the image is in focus.



Discussion questions

- What are telescopes used for? What other instruments use lenses?
- What is the distance between the two lenses when you focus the telescope on a far away object? How does this relate to the focal lengths of the lenses?
- When you look at a nearby object with the telescope, do you need to change the distance between the two lenses? If so, do you need to increase or decrease the distance?
- How does the magnification of your telescope change if you replace the convex lens with one that has a shorter focal length? Can you explain why?

FOR THE TEACHER

Homemade Telescope

(Level 2)

Use two lenses to make a simple refracting telescope. This telescope can be used to read a message posted across the room.

Materials

- Convex lens with a focal length of 20-cm*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224520. \$3.95 each. Many places also offer classroom set specials.

- Concave lens with a focal length of 5-cm*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224510. \$3.95 each. Many places also offer classroom set specials.

- Convex lens with a focal length of 10-cm (optional)*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6223505. \$3.75 each. Many places also offer classroom set specials.

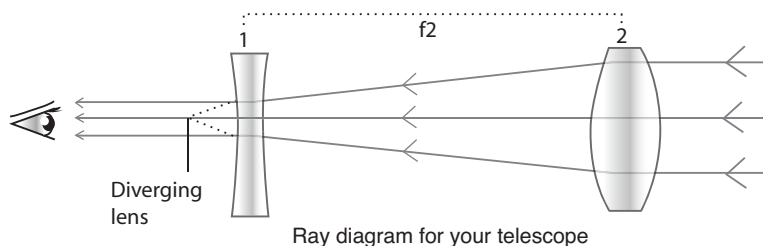
- Ruler
- Modeling clay (small amount)
- Cardboard (about 3-cm x 5-cm if using a standard-sized ruler)
- A message to post across the room that is not easily readable without the telescope

Discussion

Students should notice that the telescope makes distant objects appear larger and that the distance between the lenses when the telescope is focused is about the difference between the focal lengths of the lenses. Note that this distance also depends on how far away the object is that the students are looking at.

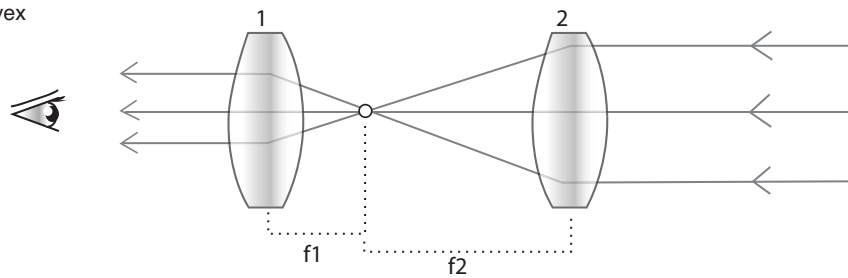
Below is a diagram of what happens to light rays in a refracting telescope like this one (some telescopes use mirrors instead of lenses, these are called reflecting telescopes). The parallel rays come in from distant objects and are bent by the two lenses. The rays then emerge from the second lens parallel again and the objects look bigger and clearer.

You may wish to have students replace the convex lens with another convex lens that has a different focal length and see how this affects the telescope. Since the distance between the lenses when the telescope is focused is about the difference in focal lengths, if students replace the convex lens with one that has a shorter focal length, they will have to move the lenses closer together to focus on an object. This will also change the magnification of the telescope, since the magnification power is equal to the focal length of the convex lens divided by the focal length of the concave lens.



The following diagram shows another type of refracting telescope. This one uses two converging lenses and the distance between the lenses is the sum of the two focal lengths. For an added challenge, have students make this kind of telescope as well. Note that the lens with the shorter focal length should be closer to the eye and that the image they see will be inverted. Keep in mind that it is much more difficult to read messages or locate small objects using this type of telescope because the inverted image can make adjusting the direction of the telescope confusing.

Ray diagram for a 2-convex lens telescope.



For more information

“Refracting and Reflecting Telescopes.” ThinkQuest, 2001.

http://library.thinkquest.org/J0112188/refracting_and_reflecting_telescopes.htm

Background on how telescopes work and information on the history of telescopes.

Bibliography

Pope, Tom and Jim Mosher. “Building a Galilean Telescope.” 2006.

http://www.pacifier.com/~tpope/Building_A_Galilean_Telescope.htm. 2006.

Trist, Bobbi. “Bouchet Outreach and Achievement in Science and Technology (BOAST): Building a Telescope.”

<http://www.life.uiuc.edu/boast1/sciencelessons/telescopes.htm>.