PS 1360 Activities --- Fall Semester 2007

1. The Nature of Science

Ask the class for examples of something they find amazing --- how a telephone works, the weather, the human body ... anything at all. Point out that a lot of amazing things are found in the mundane world. We are surrounded by miracles if we take the time to observe.

Bring a flask partially filled with water to class. During the class, light a bunsen burner and heat the water to boiling. *Do not identify the liquid as water for the class.* Ask the class to observe what is happening, and to write down 5 observations. After a few minutes, list several (5 -- 10) of their observations on the board. Ask questions about the observations:

- Which of the observations were more pure, and which involved some interpretation? (Words such as "water" or "molecules" involve interpretation.)

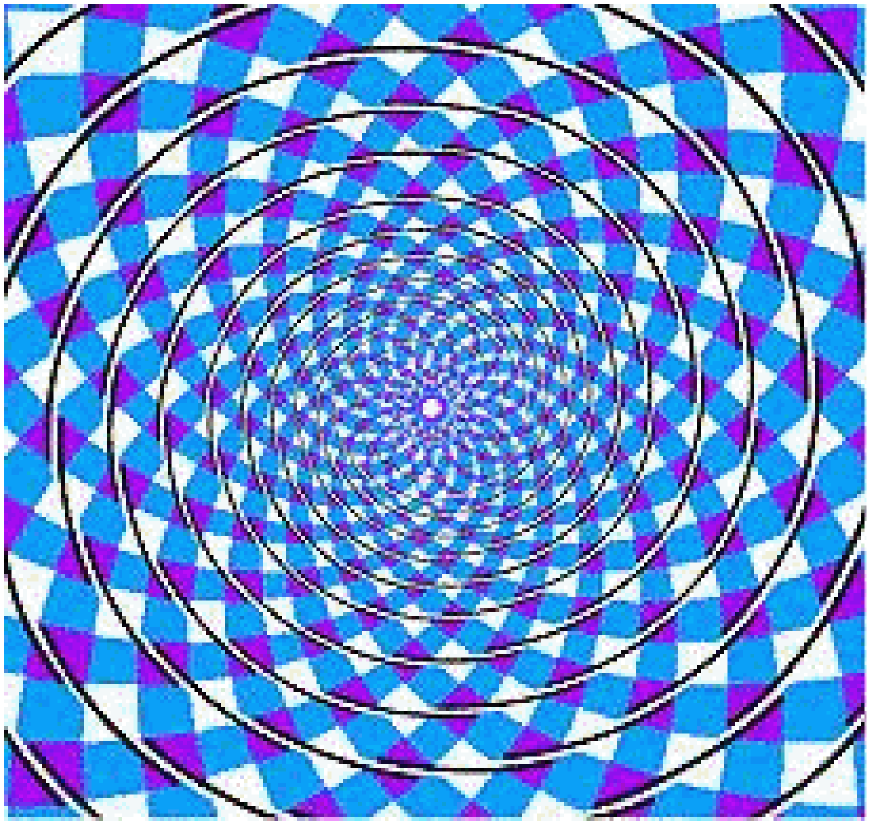
- If observation is perception by means of the senses, which senses were used to make the observations? Sight? Hearing? Touch (sensation of heat)?

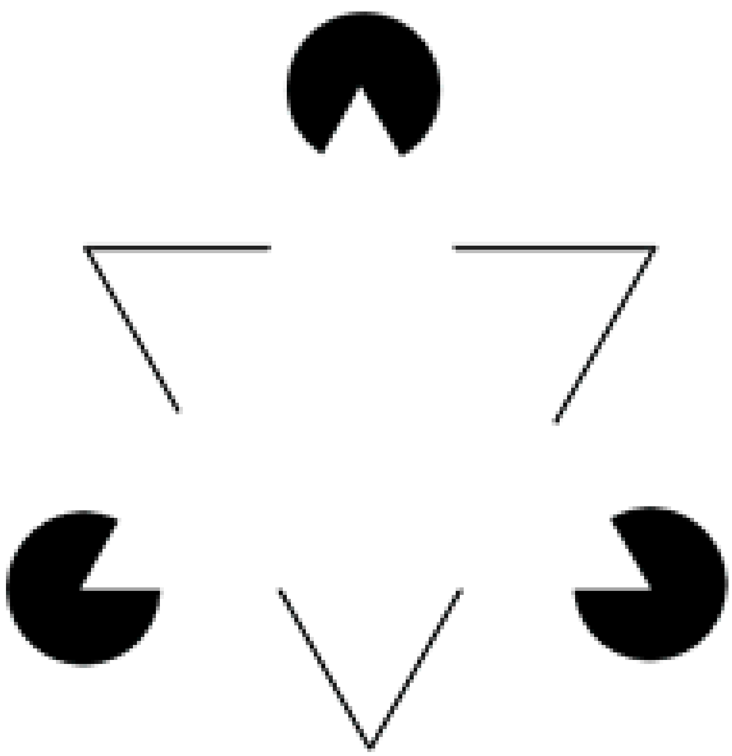
As an alternative, the class could blow some bubbles and be asked to observe and describe their appearance and behavior.

Bring a magnet to class (I used a cow magnet) suspended from a string, so it can swing freely back and forth. Place a small disk magnet directly under the cow magnet when it is hanging at rest; the disk magnet should repel the cow magnet. Allow the cow magnet to swing back and forth, and ask the class to observe what is happening, and to write down 5 observations. Then ask the class questions as in the previous activity.

Is there such a thing as an observation that is completely free from interpretation? No. Hand out examples of optical illusions --- next page --- to demonstrate that the brain makes interpretations we may not be aware of. Our very choice of words also may involve some interpretation.

Ask the students to draw a picture of "A Scientist Doing Science," with their names on the back of the picture. The next day, display all of the pictures, and ask the class to identify any stereotypes they notice. (Are the scientists predominantly white males?)





Provide each pair of students with two paper cups, and ask them to make a clock that can be used to measure a one-minute interval. No instructions provided. Give students about 10 minutes to construct their clocks, and have a contest. Use a stopwatch to measure a one-minute interval, and have students raise their hands when they think one minute has elapsed according to their clocks. (Don't say anything at the one-minute mark --- let the suspense build). Give a paper award to the winners. A certificate is a fine award because it can be taken home by children and displayed on the refrigerator door.

Ask for examples of various water clock designs. Point out that there is no "best design," and that sometimes you just have to jump in and get involved rather than wait for detailed instructions.

Pass around some kilogram masses, and ask the students to hold them and form a “muscle memory” about the weight. Pass around a liter bottle of spring water (i.e., Evian), and point out that a liter of water has a mass of one kilogram. (By definition, one cubic centimeter has a mass of one gram, and one liter = 1000 cubic centimeters.) Then later, pass around a fruit (i.e., Sharlyn melon) with a mass of nearly 1 kg, and ask the class to judge if it’s mass is greater than or less than one kilogram. Have a class vote on the answer.

Pass out meter sticks, and have the students measure the distance from the tip of their nose to the tip of their middle fingers. Point out that this is the human origin of the distance unit of a “yard,” when in 1160 AD the King of England proclaimed one yard to be the distance from the tip of his nose to the tip of his finger.

Classification exercise. Use a multistage binary classification scheme to classify 8 or 16 shoes donated by students. At each stage, the shoes should be divided nearly equally according to the answer to a "yes/no" question. For each question suggest by the class, determine if the question is both clear and effective at separating the shoes. Point out that classification schemes are human inventions, and more than one design is possible. In some cases (e.g., biology), a good classification scheme will have objects that branch off later in the scheme more closely related than object that branch off earlier. Not for shoes, though. When each shoe has been uniquely identified, it can be given a name. The naming is usually done going backward through the stages of yes/no questions. (Warning: this can be done for other objects than shoes, but not for children. Some of the suggested classification questions could be unintentionally cruel.)

Big Drip Award

to

on

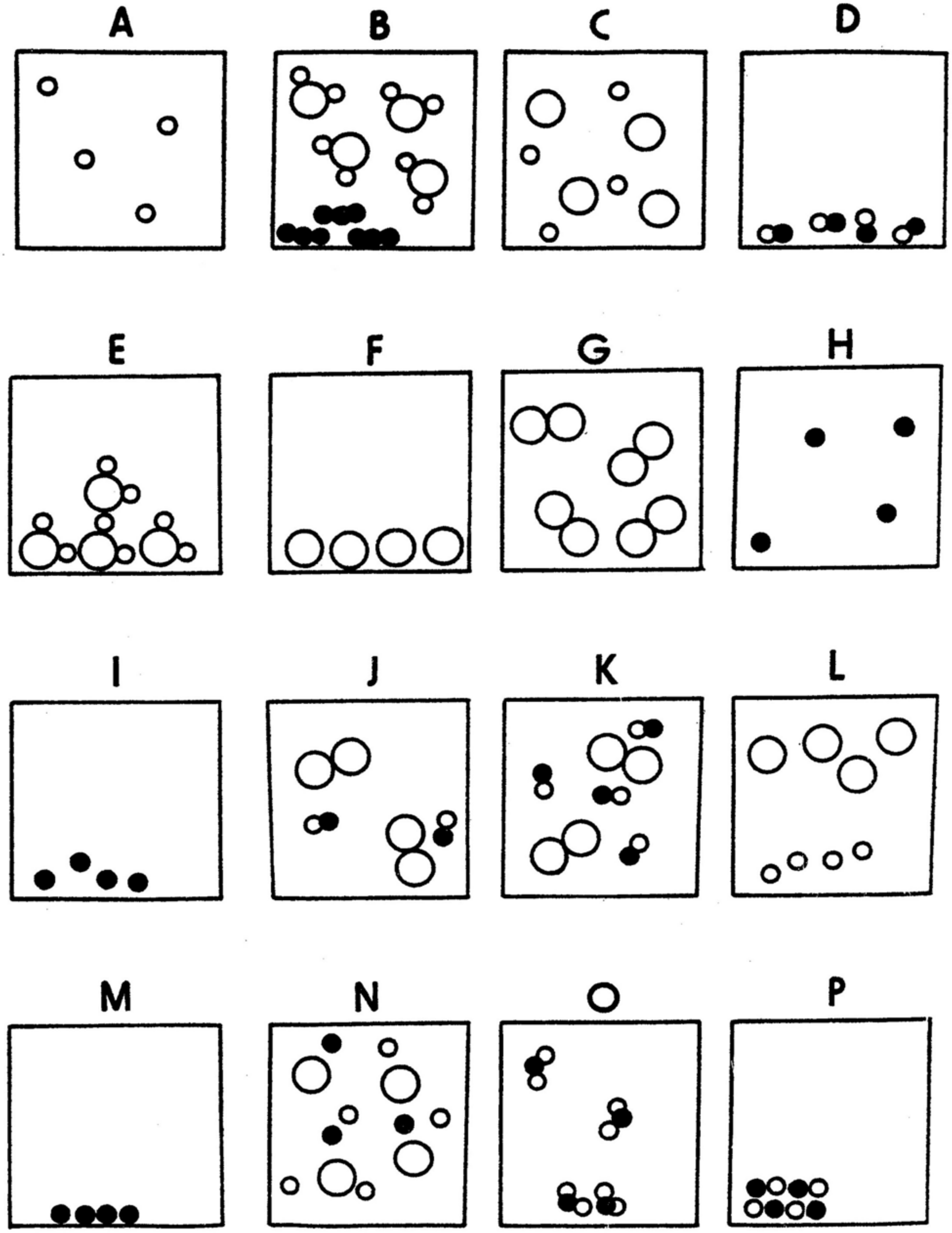
for a Most Excellent Water Clock!

Hand out a classification diagram (next page) for a homework exercise in classifying 16 boxes containing circles. The next class day, have the students trade their classifications with one another and see if they can use the scheme designed by another. Ask if any questions were found to be unclear.

Ask the class for examples of limits to their ability to observe the world. (Too large, too small, too fast, too slow, too far away or inaccessible, not visible ...) Then ask the class for examples of instruments that extend our human senses. This can lead to a discussion of the range of distances and times encountered in science.

Go outside and step off a scale model of the solar system, using a 2.25" diameter billiard ball for the Sun. Explain that students could have previously cut out or drawn a picture of each planet on a notecard in preparation for this activity. Point out the vast emptiness of space in this scale model. The nearest star (another billiard ball) would be 1040 miles from the billiard-ball Sun. In fact, if two grains of sand were placed in a football stadium, the stadium would be more packed with sand than space is packed with stars! Also point out that if the billiard ball represents the central nucleus of a hydrogen atom, then on average the electron would be 4,140 feet away --- about five times as far as the location of Pluto in the model solar system. An atom is also a vast emptiness! (The solar system exercise is a few pages ahead.)

Here is another way of showing distances in the solar system. Get a roll of white paper. (Mine was 2 1/4 inches wide and 130 meters long.) At one end draw a circle about 9.4 millimeters in diameter and color it yellow to represent the Sun. Then 27.9 cm from the end draw a line across the roll to represent the orbit of Mercury. Draw the next line 39 cm from the end to represent the orbit of Venus. Draw lines for the rest of the planets: 3 m 30.7 cm from the end for Earth's orbit; 5 m 1 cm from the end for Mars' orbit; 17 m 19.1 cm from the end for Jupiter's orbit; 31 m 60 cm from the end for Saturn's orbit; 63 m 36.2 cm from the end for Uranus' orbit; 99 m 54.7 cm from the end for Neptune's orbit; and 130 m from the end for Pluto's orbit. Students can either work in teams to make their own rolls, or you could show the class a roll that you have made. Having a student take one end of the roll and walk away with it as the roll unwinds makes an effective demonstration of the huge distances between planets.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MODEL SOLAR SYSTEM

Planet	Equatorial Diameter	Ave. Distance from Sun
Sun	1.39 million km	- - - - - - - - - - -
Mercury	4,870 km	57.9 million km
Venus	12,100 km	108 million km
Earth	12,800 km	150 million km
Mars	6,800 km	227 million km
Jupiter	143,000 km	778 million km
Saturn	121,000 km	1.43 billion km
Uranus	52,300 km	2.87 billion km
Neptune	49,500 km	4.50 billion km
Pluto	about 3,100 km	5.89 billion km
Nearest Star (Proxima Centauri)		40,700 billion km

Measure the model Sun's diameter in inches: **2.25 in**. **(The examples in boldface are for a billiard ball.**)

Mercury:

Divide the model Sun's diameter in inches by 285 to get the diameter of model Mercury in inches: **7.89×10^{-3} = 1/128** inches. Multiply the model Sun's diameter in inches by 3.47 to get the distance to model Mercury in feet: **7.81** feet.

Venus:

Divide the model Sun's diameter in inches by 115 to get the diameter of model Venus in inches: **1.96×10^{-2} = 1/64** inches. Multiply the model Sun's diameter in inches by 6.47 to get the distance to model Venus in feet: **14.6** feet.

Earth:

Divide the model Sun's diameter in inches by 109 to get the diameter of model Earth in inches: **2.06×10^{-2} = 1/64** inches. Multiply the model Sun's diameter in inches by 8.99 to get the distance to model Earth in feet: **20.2** feet.

Mars:

Divide the model Sun's diameter in inches by 204 to get the diameter of model Mars in inches: **1.10×10^{-2} = 1/128** inches. Multiply the model Sun's diameter in inches by 13.6 to get the distance to model Mars in feet: **30.6** feet.

Jupiter:

Divide the model Sun's diameter in inches by 9.72 to get the diameter of model Jupiter in inches: **0.231 = 1/4** inches. Multiply the model Sun's diameter in inches by 46.6 to get the distance to model Jupiter in feet: **105** feet.

Saturn:

Divide the model Sun's diameter in inches by 11.5 to get the diameter of model Saturn in inches: **0.196 = 1/5** inches. Multiply the model Sun's diameter in inches by 85.7 to get the distance to model Saturn in feet: **193** feet.

Uranus:

Divide the model Sun's diameter in inches by 26.6 to get the diameter of model Uranus in inches: **8.46×10^{-2} = 1/16** inches. Multiply the model Sun's diameter in inches by 172 to get the distance to model Uranus in feet: **387** feet.

Neptune:

Divide the model Sun's diameter in inches by 28.1 to get the diameter of model Neptune in inches: **8.01×10^{-2} = 1/16** inches. Multiply the model Sun's diameter in inches by 270 to get the distance to model Neptune in feet: **608** feet.

Pluto:

Divide the model Sun's diameter in inches by 448 to get the diameter of model Pluto in inches: **5.02×10^{-3} = 1/256** inches. Multiply the model Sun's diameter in inches by 353 to get the distance to model Pluto in feet: **794** feet.

Multiply the model Sun's diameter in inches by 462 to get the distance to the model nearest star in miles: **1040** miles.

Yo-yo prediction exercise. Place a partially wound yo-yo with the string going under the top and laying on the table. Perhaps pull the string a bit while holding the yo-yo so the class can see which way the yo-yo turns. With the yo-yo on the table, ask the class to predict which way the yo-yo will move when pulled gently parallel to the table top. Most will give the wrong answer; pull the yo-yo so they can watch it move. They will ask for you to place the yo-yo on the table with the string going over the top. Place the yo-yo like this, ask for their predictions, and pull the string. Discuss the results, and let them come up with the general *hypothesis* that the pull and the motion are always in the same direction. Test this hypothesis with a new configuration: Lay the yo-yo on its side and pull the string. Finally, lead into a brief look ahead toward Newton's second law, F = ma, and talk a bit about how Newton's three laws and his law of gravity come together to form Newton's theory of mechanics (which describes how things move in the natural world).

As an example of the ideas of observation ☞ analysis ☞ hypothesis ☞ prediction ☞ experiment ☞ observation ..., ask for two volunteers to do an experiment. The will roll a large steel ball (about 2 cm diameter) down a “V”-shaped track that has a gentle slope. (A gentle slope is essential to give large time differences for the different balls.) Ask the class to use their watches to measure the amount of time for the ball to roll all the way down. Write down the time on the board. Now use a smaller steel ball and ask the class for its prediction of whether the rolling time will be greater or less. Do the experiment, and point out the importance of keeping some things the same (release with no speed, release from same spot). Write down the time on the board. Now use an even smaller steel ball, and ask the class for its prediction of whether the rolling time will be greater or less. Do the experiment, and let the class generate an hypothesis: “If the ball is smaller, then the rolling time will be greater.” Point out the independent variable (size of ball), the dependent variable (rolling time). Ask if a glass marble should be used (their answer should be “no”) and let them develop the idea of controlled variables: values that are kept the same to avoid confusion.. Ask the class to name some of the controlled variables in this experiment: same point of release, same release speed of zero, same ball material (steel)....

Ask the class to list some of the attributes of a good experimenter. They will probably list things such as creative, dedicated, honest, skeptical, honest, curious, open to new ideas. Point out that several of these describe children, and that all children are natural experimenters.

An example of an experiment involves letting water run out of a cup through a hole in the bottom. Each pair of students gets two 9 oz Dixie cups, a ruler, a pin, a pencil, and a plastic spoon. First motivate the experiment by discussing the water clock activity on page 3. Referring to the students who made a water clock by letting water drip out a small hole in the cup's bottom, wonder whether the drips come out at a constant rate, regardless of the amount of water in the cup. Generalize to the case of a larger hole that will produce a steady stream of water. They will probably guess that the water will run out more slowly as the cup empties. State the hypothesis: "If there is less water in the cup, then the water flows more slowly out of a hole in the cup’s bottom. (Also discuss what makes a good hypothesis: it must be able to be proven true or false.)

One cup is filled with water. Water is transferred to the empty cup one spoonful at a time, and water levels are marked with a pencil on the side of the cup at 5 spoonful intervals. Label the marks --- “0" for the bottom of the empty cup, “5" at the 5 spoonful mark, and so on. The top mark should be at 25 spoonfuls. Pour the water out of the marked cup, turn it over, and use the ruler and pin to punch two pinholes about 1/8" apart at the center of the cup's bottom. Use the pin to make a circle of holes 1/8" in diameter, and use the pencil to carefully remove the circle (pushing from the inside of the cup outward). The result is a cup with an 1/8" hole in its bottom. Ask the students to practice working in pairs, putting a finger over the hole, adding water to the top mark, and removing the finger to let the water run out. The students may notice that the stream of water breaks up before the cup is completely empty. Discuss how this will affect the timing of the water running out of the cup; you could decide to end the experiment at the first mark (5 spoonfuls from the bottom). Here is one way to do the experiment (others are also possible): The students will fill the cup to the "25" level and remove their finger when they start timing (at zero seconds). Then they will measure with their wristwatches the time when the water passes the “20" mark, the “15" mark, the “10" mark, and the “5" mark. (so they stop the flow by placing a finger over the hole when the water level falls to "25"). (The above specifications allow reasonable flow rates and time intervals.) Ask the students to repeat the experiment, so they have two sets of data.

After the experiment, Ask two groups for their results, and put them on the board. |Discuss the ideas of (1) the independent (manipulated) variable = the levels where the time measurements are made, such as“20"; (2) the dependent (responding) variable = the time when the water passes each level; and (3) the controlled variables = the same size of the hole, the same shape of the cup (don’t squeeze it), holding the cup level ... they will think of others as well. Ask the class, for the data on the board, was the hypothesis true or false? Point out that if water runs at a constant rate, then the same amount of time is need to drain each 5 spoonfuls. They will see that this is not the case, in the data on the board and in their own data. The hypothesis is true! Explicitly say that if there is less water in the cup, then the water flows more slowly out of a hole in the cup’s bottom.

Any experiment that reveals how Nature behaves, that gets a valid answer to a question asked of Nature, is a success. The students will immediately start conjecturing why the water flows faster when more water is in the cup. (Someone will guess the answer: more pressure at the bottom to force out the water.) Point out that a good experiment always raises new questions and hypotheses (which is what they are suggesting).

Hand out graph paper, and ask the students to graph their data. Ask them not to connect their data points yet. Stress that there is a great difference between graphing in a math class and in a science class. In a math class, the points are known exactly. In science, the data points are only approximate, and have some experimental error in them. Discuss how the best-fitting smooth curve through the data points is their interpretation of how Nature behaves. As a rule of thumb, as many points should lie above the line as below it, more or less. Also, their graphs should use most of the paper, and not be confined to a corner. Pass out fresh graph paper, and have the students turn in their revised graphs on Thursday.

The preceding activity can also be done based on the previous activity of rolling steel balls of different sizes down a "V"-shaped track. Or, let the end of the track extend over the edge of the table. Let the ball start at different distances up the track (10 cm, 20 cm, etc) and measure how far from the end of the track the ball hits the ground.

Pass out "The Astronomically Correct Signs of the Zodiac" the day before and ask students to check their horoscopes for the day. They will notice that their Sun Signs are one month off (in most cases); explain that Earth's orbit has changed so the Sun passes through the constellations of the zodiac at a different time of year than it did 2000 years ago when astrology was first invented by the Babylonians. This can lead to a discussion of science and pseudoscience.

2. Motion and Newton's Laws

Two students measure the distance across the room with a meter stick, and time the students as they walk across the room in opposite directions --- one walking normally, and the other jogging. Each member of the class can then calculate their walking speed. Then you can walk across the room *in the opposite direction* as the walking student, timing yourself to take the same amount of time. Point out that your speeds were the same, but your velocities were different, since you walked in the opposite direction as the walking student.

The instructor sits on a small cart, and asks a student to push and pull the instructor back and forth across the room. Note that if the student stops pushing, the instructor quickly comes to rest. Two purposes: (1) to illustrate the idea that a force is just a push or a pull; and (2) to bring out the FALSE but common belief that a force is required to keep something moving. Emphasize that this "common-sense" belief, which is reinforced daily with shopping carts, etc., is INCORRECT. Be certain that the class does not leave without hearing the correct version, that a force is necessary to *change* the way something moves (speed it up, slow it down, or change its direction). Roll a billiard ball down a level metal “V”-track, and ask the class to describe its motion. They should say that the ball moved in a straight line at a constant speed. Push a book across the table, and ask the class to describe its motion. They should say that the book slowed down as it moved in a straight line. Toss a ball through the air, and ask the class to describe its motion. They should say that its direction of motion was not straight (“an arc”) and that its speed changed. Ask which of these was being affected by an unbalanced force, and what the force was. (Answers: no unbalanced force for the rolling ball, the unbalanced force of friction opposed the motion of the book, and the unbalanced force of gravity pulled down on the ball.)

Bring a toy car to class loaded with weights so it squeaks as it rolls. Tie a string to the front of the toy car and pull it at a constant speed (emphasize the squeaks). Then let the string go slack as the car quickly slows to a stop. Ask the class when the car’s velocity was constant (answer: while you were pulling) and when the car’s velocity was changing (when the string was slack and the car was slowing down). Ask the class to identify the horizontal forces acting on the car, and ask whether or not the forces were in balance. (Answer: While pulling, the forces were your pull forward and friction pushing backward. These forces were in balance while you were pulling the car at a constant speed. When the string was slack, the unbalanced force of friction slowed down the car.)

Have each member of the class attach a string about 30 cm long to a small ball (tennis ball, etc.) The students hold the ball motionless in front of them, and note that because the ball remains at rest, the upward pull of the string must balance the downward pull of gravity on the ball --- there is no unbalanced force. Now ask them to move the ball to the right and watch the string. They will see that the top of the string is slanted so it pulls the ball to the right. This pull to the right is the unbalanced force that causes the ball to start moving from rest. The slanting string provides the unbalanced force to the right that starts the ball moving.

The class sits in a circle on the floor, and the students roll a billiard ball across the floor to another student (at random). Ask them to watch how the balls move. After a few minutes, add a second ball, and let both balls pass back and forth across the floor. Sometimes they will collide — point out that both balls change their motion. After a while, ask the students to describe the motion of the balls. Draw out that the balls move in a straight line at a constant speed unless the balls hit something (a student's hand, another ball, etc.) That is, unless an unbalanced force acts on the ball, it will travel in a straight line at a constant speed.

Have the students (still sitting in a circle on the floor) pass a ball from neighbor to neighbor so it goes in a circle. They should just nudge the ball with their hands if they can. Point out that they are continuously pushing the ball inward toward the center of the circle Explain that they are supplying a *centripetal force* (means "center seeking") to keep the ball moving in a circle.

The students can walk in a single-file line up and down the hall, noting that the string does not hang straight down when they speed up, slow down, or change direction. This shows that an unbalanced force (produced by the pull of the string) is needed to produce a change in motion, and that the direction the string pulls (the direction of the slant) is the same as the direction of the change in the motion. Also, have the students hold the ball with their arm straight out from your body while they spin at a steady rate in a circle. The inward lean of the string shows there is an inward force on the ball toward the center of the circle, called a centripetal (center-seeking) force. A homework activity (next page) follows this up by asking the student to observe the pull of the string while they perform certain activities.

The class pairs off in teams of two, with each team taking an embroidery hoop and a marble. Each team sits in the hallway, with the two team members about 1 m apart. The floor is marked with straight black lines that run from one team member to the other. One member of the team lays the hoop on the floor, and rolls a marble around and around inside the hoop. That person's challenge is suddenly to lift the hoop straight up (no "shoveling"!) at the right time and place so the marble rolls along the line to the other team member (the "catcher" of the marble). By trial and error, the students should come to realize that the marble goes in a straight line, tangent to the hoop, as soon as the hoop is lifted. Point out that the force of the hoop was supplying the unbalanced force that kept the marble rolling in a circle, always changing direction. (Mention that this is the same thing they were doing to keep a billiard ball moving around in a circle.) But as soon as the hoop was lifted, that unbalanced force disappeared, and the marble moved in a straight line at constant speed. The hoop should be lifted when the marble is rolling directly toward the "catcher."

OBSERVING A BALL ON A STRING

Attach a ball to a string about 30 cm long. Before you begin, hold the ball motionless, so it is hanging vertically straight down in front of you. The upward pull of the string exactly balances the downward force of gravity, so the ball remains at rest. In the exercises below (except #2), you will change the motion of the ball. As the ball's motion changes, the string's pull is no longer balanced by gravity. *The direction that the top of the string leans is the same as the direction of the unbalanced pull that is changing the ball's motion.* For each exercise, circle the direction that the top of the string leans. (Note: when riding in the car, keep the ball inside!)

1. Starting at rest, begin moving forward. (You could start walking, or be a passenger in a car.) Which way does the top of the string lean as you begin moving forward?

toward you   away from you   to the right   to the left   vertical

2. Move forward with a steady speed. (In this case, the ball's motion is not changing, so there is no unbalanced force.) Which way does the string pull the ball?

toward you   away from you   to the right   to the left   vertical

3. Slow down from a steady forward speed. Which way does the top of the string lean as you slow down?

toward you   away from you   to the right   to the left   vertical

4. Go into an elevator. Which way does the top of the string lean as you begin to move upward?

toward you   away from you   to the right   to the left   vertical

5. Go into an elevator. Which way does the top of the string lean as you begin to move downward?

toward you   away from you   to the right   to the left   vertical

6. Hold the ball with your arm straight out from your body while you spin at a steady rate clockwise (left-to-right) in a circle. Which way does the top of the string lean?

toward you   away from you   to the right   to the left   vertical

7. Hold the ball with your arm straight out from your body while you spin at a steady rate counterclockwise (right-to-left) in a circle. Which way does the top of the string lean?

toward you   away from you   to the right   to the left   vertical

8. When you are a passenger in a car, which way does the top of the string lean as you turn right?

toward you   away from you   to the right   to the left   vertical

9. When you are a passenger in a car, which way does the top of the string lean as you turn left?

toward you   away from you   to the right   to the left   vertical

"I don't know what I may seem to the world, but, as to myself, I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

— Isaac Newton
(1642 — 1727)

“The Big Isaac”

Newtonburger

The Quarter-Pounder

1 pound = 4.45 newtons

Place a large empty can on the floor, and put some padding (crumpled paper towel) inside the can. Give each student a marble (or a jack) line them up in a row. Ask each student to hold their arm in a steady position (no pivoting!) as they walk past the can with a constant speed and drop the marble in the can. Afterward, as the students when they released the marble. They will say before the marble was over the can. Point out that before the marble was released, it was moving forward at a constant speed as a student carried it. The downward force of gravity on the marble and the upward force of the student's fingers were in balance. There was no horizontal force acting on the marble. But when the student released the marble, there was an unbalanced vertical force — gravity. As a result, the marble's vertical motion changed as it fell downward. However, there was still no horizontal force on the marble after it was released, so it continued to move forward with a constant horizontal speed.

Give each student a plastic cup and a marble (or a jack). Have them put a tissue into the cup for padding. While they stand still, have them hold the marble up at eye level, and the cup at waist level directly below the cup. Ask them to drop the marble into the cup a few times for practice while standing still. Then line the students up in the hall, and tell them that, while they are walking forward in a straight line at a constant speed, they will drop the marble into the cup as before. Ask where they should hold the marble --- directly over the cup, or ...? They will discover that the marble should be held directly over the cup since both will continue to move forward at a constant speed and direction after the marble is released. Point out that Aristotle argued that the Earth could not be rotating because, if it were, when you jumped into the air, the Earth would rotate away beneath your feet and you would land some distance from where you started. (At the equator, the Earth rotates at about 460 meters per second as it spins. In Ogden, it is closer to 350 meters per second.) Ask how dropping the marble in the cup shows that Aristotle was wrong. Lead them to the conclusion that both the Earth and you are moving as the Earth spins, so you will keep moving along with the Earth while you are in the air and come down in the same place you started.

A simple demonstration of inertia involves a quarter (25 cents), a 3"x 5" notecard (or postcard), and a flask or bottle whose top (opening) is only slightly wider than the quarter. Lay the center of the card over the top of the flask, and place the quarter on top of the card directly over the opening. Hold the flask with one hand to steady it, and flick the card with your finger. The card will fly off the flask, but the coin's inertia will keep it over the opening so it falls down into the flask.

A fancier demonstration of inertia involves balancing an embroidery hoop on the mouth of a bottle. A bottle with a narrow neck and mouth work best. A small stubby pencil with a flat end (as used for keeping score in golf or bowling) is balanced on top of the hoop. When so balanced, the pencil should be directly over the mouth of the bottle. Put your hand inside the hoop, and suddenly yank the hoop horizontally out from under the pencil. The pencil's inertial will keep it over the mouth of the bottle, and it should fall straight down into the bottle.

A third demonstration of inertia. Give every student a plastic (not paper) cup with a smooth bottom, and ask them to fill their cups until they are about 2/3 full. Give every student a piece of legal-size paper (8.5" x 14") and instruct them to place the cup on the paper about 6" from the edge of a table that has a smooth surface. The end of the paper should hang over the edge of the table. Tell each student to grip the paper firmly, and pull the paper sharply *downward* over the edge of the table. The inertia of the cup will keep it in place on the table as the paper slides out from beneath.

A fourth demonstration of inertia. Each student brings a small empty plastic water bottle (i.e., Evian) or pop bottle *with a screw-on cap*. Give each student a small piece of cork and a piece of thread. One end of the thread is tied to the cork, and the cork is placed into the bottle. The bottle is filled absolutely full of water, and screwing on the cap anchors the other end of the thread. The result is that when the bottle is held upside down, the cork floats in the middle of the bottle. If the bottle is held at rest, the cork floats in the middle of the bottle. If the bottle starts to move to the right, the cork moves to the right side of the bottle. If the bottle is moving to the right at a steady speed (say), the cork floats in the middle of the bottle; but is the bottle then slows down, the cork moves to the left side of the bottle. Point out that all this behavior occurs because the water has more mass --- more inertia --- than the same amount (volume) of cork. Thus the water resists having its motion changed more than the cork. For example, if the bottle starts to move to the right, the water's inertia causes it to lag back, and so the water pushes the cork forward to the right side of the bottle. The result is that the cork always moves in the same direction as the change in the bottle's motion. In other words, *the cork always moves in the direction of the bottle's acceleration*. Explain to the students that they have made an acceleration detector.

Describe Galileo's experiment with freely falling objects at the Leaning Tower of Pisa. Simultaneously drop two balls, one heavy and one light, from the same height. The class will see that the balls fall side-by-side and hit the ground at the same time. Explain that although the balls speed up (accelerate) as they fall, all freely falling objects speed up at the same rate. Explain that freely falling means that gravity is the only force pulling on the objects --- no air resistance, propellers, etc. To drive this point home, say you are going to drop a ball and a paper towel, and ask the students to watch as they fall side-by-side. Before you drop them, somebody will object that the ball will hit the ground first. Someone will advance the idea that the air will keep the towel from falling as fast as the ball. In response, wad up the paper towel into a tight ball, explaining that you are removing the effect of the air resistance. Drop the ball and the wadded-up towel, and the class will see that they do indeed fall side-by-side with the same acceleration.

To give an class an example of acceleration, ask a student to move across the room, beginning with a slow walk and ending with a slow jog. Time the student with a stopwatch, and calculate the student's acceleration. Point out the unit of acceleration, and its meaning (m/s^2 = m/s of speed increase each second). Finally, say that Galileo showed that all freely falling objects fall with the *same acceleration* ($g = 9.8\ m/s^2$).

Galileo also discovered the formula for the distance, d, an object falls in t seconds, $d = \frac{1}{2} gt^2$. Explain the t^2 means that the object falls four times as far in two seconds than it does in one second ($2^2 = 4$), and nine times as far in three seconds than it does in one second ($3^2 = 9$). Students may wonder how Galileo managed this measurement with the crude clock available to him. Explain how Galileo "slowed down time" by investigating how a ball rolled down a ramp under the influence of gravity. Set up a ramp tilted at a slight angle (or better yet, use a metal track with a V-shape to guide the ball's motion). Have a student use a water clock or time his or her pulse to provide a time count (out loud, so the class can hear). Release the ball from rest, and stop it after one time count. Mark where you stopped the ball with masking tape. Again release the ball from rest (same starting point), but this time stop it after two time counts. Show that the ball rolled four times as far as it did in one time count. Repeat, but this time stop the ball after three time counts. Show that the ball rolled nine times as far as it did in one time count. This is how Galileo slowed down the falling motion to get his formula.

Ask the students to bring an unopened can of soup and an opened (and washed) soup can to the next class. Two water bottles, one empty and one full, will also work.

Ask the students to hold an empty soup can in their hand. Tell the class you will time them for 15 seconds as they shake the empty can back and forth as many times as they can (have them count). Do the same thing with the full can. Point out that the full can has more inertia (mass), and that it therefore resists being accelerated --- shaken --- more.

Newton's second law, force = mass x acceleration, says that twice the force acting on the same mass produces twice the acceleration, but that twice the force acting on twice the mass produces the same acceleration. You can demonstrate this using a very light plastic toy car that carries one or more rolls of pennies. A long string connects the car to a plastic sandwich bag that contains other rolls of pennies. The string passes over the edge of the tabletop, and the weight of the pennies in the falling bag provides the force that pulls the car across the tabletop. 1) Two identical cars. Each car carries one penny roll, and is pulled forward by the weight of one penny roll in the falling bag. When released from rest at the same time, the cars should accelerate side-by-side across the tabletop. 2) Add one roll of pennies to one of the bags. Now one of the cars is pulled by a greater force (the weight of two penny rolls instead of one), but each car still carries one penny roll. When released from rest at the same time, the car attached to the bag containing two rolls of pennies should accelerate much faster than the car attached to the bag containing just one roll of pennies. Explain: increasing the force acting on the same mass increases the acceleration by the same factor. (For example, twice the force acting on the same mass produces twice the acceleration.) 3) Add another roll of pennies to the car that is attached to the bag containing two rolls of pennies. Now one of the cars is pulled by twice as much force (the weight of two penny rolls instead of one), but that car carries two penny rolls. When released from rest at the same time, the cars should accelerate side-by-side across the tabletop. Explain: twice the force acting on twice the mass produces the same acceleration. A table like this may help:

force (# penny rolls in bag or # of rubber band chains)	mass (# penny rolls on car)	acceleration (a = F / m)
1	1	a = 1 / 1 = 1
2	1	a = 2 / 1 = 2
2	2	a = 2 / 2 = 1
1	1/2	a = 1 / (1/2) = 2

Ask the students if there is any way to have a car with an acceleration of 2 with just one penny roll in the falling bag. They may come (with your help) to the idea that the car could carry half of a roll of pennies while it is being pulled by the bag with one roll of pennies in it. Break a penny roll in half and try it. (The result is shown in the last line of the table.)

This experiments can also be done using chains of rubber bands instead of hanging pennies to provide the force that pulls the cars. Use two rubber band chains to pull a car with twice the force.

Explain that this experiment shows that twice the force acting on twice the mass produces the same acceleration. Explain that this result shows the reason why every freely falling object falls with the same acceleration. Suppose ball A has twice the mass of ball B. Therefore gravity is pulling on ball A with twice for force as on ball B. But we have just found, with the cars, that twice the force acting on twice the mass produces the same acceleration. As a result, gravity will cause ball A and ball B to fall with the same acceleration, side by side.

Have the students repeat the previous homework activity using the bottle acceleration detector instead of the force on the string. They should conclude that the string (attached to the ball) and the cork (floating in the bottle) always lean in the same direction. This shows that the unbalanced force and the acceleration are always in the same direction --- in agreement with Newton's second law of force = mass x acceleration.

If they hold the bottle out away from their body and spin in a circle, they will see that the cork moves toward them, toward the center of the circle. This shows that, for an object moving in a circle, the object's acceleration is toward the center of the circle. The unbalanced force producing the circular motion must also be toward the center of the circle. (This unbalanced force is provided by the student's arms as he or she pulls inward on the bottle.) You might point out that the technical name for such a center-seeking force is a *centripetal force*.

The students can also pair off, facing each other and holding each others hand as they spin around in a circle. Ask them what they feel in their arms, and they will say that they are pulling the other person toward them. Explain that this pulling is the unbalanced force toward the center of the circle that produces the students' circular motion. Again, point out that the technical name for such a center-seeking force is a *centripetal force*.

A centripetal force can be demonstrated on an overhead projector using a small embroidery hoop. Project the hoop on the blackboard, draw a circle over the hoop's shadow on the board, and roll the ball around the hoop. Ask the class to identify the force that keeps the ball moving in a circle, and lead them to the answer that the hoop is continually nudging the ball inward, toward the center of the circle. Ask the class to predict what will happen if the centripetal force is removed by lifting the hoop. If they say it will move in a straight them, ask them when to lift the hoop so the ball travels straight to the right. Draw the path of the ball on the board, and show that it is always tangent to the hoop.

Yet another way of demonstrating a centripetal force is to take a metal coathanger and stretch it out by pulling on the hook and the middle of the straight wire at the bottom. Hang the coathanger on your index finger with the hook at the bottom, and balance a penny on the end of the hook. (There is a dimple in Lincoln's cheek that makes this easy; bend the hook slightly if you have trouble balancing the penny.) Ask the class to identify the direction of the hook's force on the penny. They should reply, "Toward your finger." With a little bit of practice you can spin the coathanger on your finger with the penny kept in place at the end of the hook. While spinning the coathanger, again ask the class to identify the direction of the hook's force on the penny. Again, the answer should be, "Toward your finger." That is, the force on the penny is toward the center of the circular path of the penny. If you are *very* lucky, you can stop the coathanger with the penny still balanced on the hook!

There are several ways to demonstrate Newton's third law. Ask a student to put his or her hands against yours, and lean toward each other as you press against one another's hands. Ask the class if the students can push you without you pushing back. You will get various answers, so ask the class what would happen if the student pushed without you pushing back. Suddenly relax your arms slightly (so the student lunges forward slightly without falling), and point out that you can't push if there is nothing to push against. Lead the students to Newton's third law in the form, "If I push you, you push back just as hard.

Pass out rubber bands to the class, so each student gets one. Have each student stretch their rubber band between their thumbs, and ask if they can pull with one hand without the other pulling back. Regardless of how they move their hands about, they should always feel the same pressure on each of their thumbs, illustrating that each hand is pulling on the other hand with the same size force.

Have two students hold two identical kitchen scales with their weighing pans pointed toward each other, and with the scales pointed toward the class so the class can see the readings on the scales. (Use scales with a dial, and not an electronic scale with numbers.) When the two students press their scales together, the class can see that the dials read the same. If one student pushes the other across the room with their scales in contact, the class can see that the dials read the same. If one student runs into the other student (gently) so their scales collide, the class can see that the dials read the same. This last demo works best if the students are different sizes.

Newton's third law allows us to move. Explain to the class that as you start or stop walking, your foot pushes backward (starting) or forward (stopping) on the floor. That is a force on the floor, and can't change your motion. But the floor exerts an equal but opposite force on your foot. If your foot pushes backward on the floor, the floor pushes you forward and you start walking. If your foot pushes forward on the floor, the floor pushes your foot backward and you stop walking. To demonstrate this, play a game of "Simon Says" and have the class start and stop walking. Ask them to pay attention to the how their feet are pushing the floor as they stop and start. Finally, ask the class to identify the type of force they were using to push on the floor. Answer: friction. Point out that friction makes all sorts of acceleration possible: feet pushing on the floor, car tires pushing on the road, etc. Also point out that previously, when the instructor sat on a small cart and asked someone to push the cart back and forth across the room, the student had to keep pushing to balance the force of friction. When the student's force and friction were in balance, the cart moved at a constant speed. When the student stopped pushing, the unbalanced force of friction brought the cart to a stop.

Pass balloons out to the class, so everyone gets a balloon. Have the students blow up their balloons, and then have them let the air out while still holding onto the balloon. Ask them what has happened, and they will say that the balloon has forced the air back out. Again, have the students blow up their balloons, and ask what will happen if the balloons are released. The answers will bring out the point that the balloon will accelerate forward: as the balloon pushes back on the air, Newton's 3rd law says that the air will push forward on the balloon. Point out that this is how rockets work: the rocket pushes back on the burning fuel, and the burning fuel pushes the rocket forward. Have the students release their balloons all at once, and watch as the balloons go everywhere. Ask, "why do rockets have fins?" (Answer: to stabilize the flight of the rocket.) A toy water-filled rocket can be used outside to demonstrate Newton's 3rd law. The rocket pushes back on the water, and the water pushes forward on the rocket.

Another way of stabilizing the flight of a balloon is to stretch a light string across the room. Thread the string through a long straw (not a short piece of a straw), and tape the straw to a blown-up balloon that you are holding closed. Holding the string taut, release the balloon and watch it fly along the string. (Here, the string stabilizes the flight of the balloon.) If the students are going to do this, use different size balloons, and ask them to predict which one will go farthest, and which one will go fastest. This can be a good exercise in making hypotheses, since the students will come up with many different ideas about what will happen and why. Their hypotheses will be tested by experiment when they release their balloons.

Repeat the demonstration of Newton's third law using the kitchen scales and rubber bands. Now connect the front ends of two cars with a chain of rubber bands --- one a light plastic car, and the other a heavy metal car. Hold the cars apart so the rubber bands are stretched, and ask the students which car is feeling the larger force, and confirm that the forces are the same, according to Newton's third law. You can then make the point that if a large car collides with a small car, the forces will be the same on the two cars. Ask the class how the cars will move when you release them. After they have made various guesses, release the cars so they can see the answer for themselves. Because the plastic car has less mass, it will have a greater acceleration (a greater change in its motion), and it will therefore suffer more damage in a collision. On the other hand, the metal car has more mass, so it will suffer a lesser acceleration (less change in its motion), and therefore suffer more damage. In summary:

same force = (small mass) x (large acceleration) = (large mass) x (small acceleration)

3. Work and Simple Machines

Have students push a book across their desk. Explain that they are doing work because they are using a force to move their book a certain distance across their desk: work = (force) x (distance moved). Now have the students hold their book motionless with their arm stretched straight out, parallel to the floor. When their arms are getting tired, ask if they are doing any work. They will say "yes," but explain that the answer according to the definition of work is "no," because the book has not moved any distance.

A lever can be made with a meter stick balanced at the 50 cm mark on a the thin edge of a "pink pearl" eraser. Put 12 pennies at the 40 cm mark, so the lever is unbalanced. Now put 12 pennies at the 60 cm mark, which will raise the lever back to a balanced position. Note how far (vertically) the 12 pennies at the 60 cm mark moved. Now remove the 12 pennies at the 60 cm mark, and let the other side fall back down out of balance. Now ask how many pennies you should put at the 70 cm mark to balance the lever. They should reply, "6 pennies." Put 6 pennies at the 70 cm mark, which will raise the lever back to a balanced position. Explain that half the force (6 pennies) was used to raise the 12 pennies at the 40 cm mark, but that the 6 pennies had to move twice as far. Remove the 6 pennies from the 70 cm mark, and ask how many pennies you should put at the 80 cm mark to balance the lever. They should reply, "4 pennies." (If not, try it and show their answer is wrong.) Put 4 pennies at the 80 cm mark, which will raise the lever back to a balanced position. Explain that now 1/3 the force (4 pennies) was used to raise the 12 pennies at the 40 cm mark, but that the 4 pennies had to move three times as far. Remove the 4 pennies from the 80 cm mark, and ask how many pennies you should put at the 90 cm mark to balance the lever. They should reply, "3 pennies." Put 3 pennies at the 90 cm mark, which will raise the lever back to a balanced position. Explain that now 1/4 the force (3 pennies) was used to raise the 12 pennies at the 40 cm mark, but that the 3 pennies had to move four times as far. The conclusion is that you always have to do the same amount of work when you use the lever to lift the 12 pennies. If the force is divided by a certain number, the distance moved is multiplied by the same number, so the work = (force) x (distance moved) stays the same. Explain that simple machines do not save you from having to do work. They only make the work easier to do by decreasing the applied force, while increasing the distance moved by the same factor. **CAUTION:** Be sure that all of your pennies are dated after 1982. Pennies minted prior to 1982 are composed of an alloy of copper and zinc, whereas those minted after 1982 contain a core of nearly pure zinc covered with a layer of pure copper. The pre- and post-1982 pennies have different weights, and mixing them will affect the balance of the meter stick.

This will illustrate that the work done when you roll a bowling ball up an inclined plane is the same as the work done when you lift the ball straight up to the same height. Weigh a bowling ball on a kitchen scale. Explain that when you lift it up a vertical height h, the force you have to lift with is the weight of the ball. The work that you do in lifting the ball straight up is therefore work = (force) x (distance moved) = (weight) x h. [If you want to get a value for the work, multiply the ball's weight in pounds by 4.45 to get its weight in newtons, and then multiply the weight in newtons by the height h in meters. The result will be the work in units of joules.] Now use a board to make an inclined plane. Tilt the scale on its side (you may have to reset the zero reading of the scale), and use the scale to push the scale up the inclined plane, so at the top of the inclined plane the ball will have reached the same height h as before. You should discover that work you do in rolling the ball up the inclined plane, the reading of the scale multiplied times the length of the inclined plane, is the same as when you lifted the ball straight up. This is another example of how simple machines do not save you from having to do work. They only make the work easier to do by decreasing the applied force, while increasing the distance moved by the same factor.

Here is way to demonstrate a first-class lever. Have a student stand in front of the class and hold a bowling ball at waist level. After a while, ask if the student's arms are getting tired, and again reinforce the idea that the student is not doing any work because the ball is not moving.

Put the bowling ball in a sturdy bag, and hang the bag from one end of a long thin pipe. Use the back of a chair as a fulcrum, with the chair near the bag. Ask the same student to lift the bowling ball by pushing down on the other end of the pipe, and ask the student how hard the ball is to lift this way ("Easy!") Demonstrate how easy it is by hanging a can of soup (or something weighing about 1 lb) in a plastic bag about where the student's hand was to balance the bowling ball. Point out that the ball moved a smaller distance than the student's hand as the ball was lifted, so the work would be the same whether the student lifted the ball directly, or used a lever.

The bag can be placed between the fulcrum (chair) and the student's hand to form a second-class lever. Demonstrate this, and ask the class if they have ever used anything that works like this. (Answer: a wheelbarrow!)

Another way of demonstrating a second class lever is to place two kitchen scales one meter apart. Put a meter stick between the scales, and hang a 1 kg mass from the center of the meter stick. The scales will read the same. Now move the mass toward one end of the scale, and ask the class which scale now reads more. They will answer, "the scale nearest the hanging mass." Pick up the other end of the meter stick, and explain how you are lifting up the kilogram mass with less than a kilogram's worth of effort.

Review the idea of work by asking a student to lift a bowling ball (weight = mg = 16 lb = 71.1 N) up from the floor to the desk top (a height h = 1 m). Remind the class the student is lifting with a force equal to the weight of the ball, and that work = (force) x (distance traveled). Thus the student did (71.1 N) x (1 m) = 71.1 Joules of work. Point out that the formula you used for work was work = (weight) x (vertical height traveled) = mgh. Repeat the experiment, and time the student's lift with a stopwatch. Divide the student's work by the elapsed time to get the power (work done per second) in units of watts. Mention that another unit of power is also familiar, and that one horsepower = 746 watts.

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4. Energy

The concept of the conservation of energy can be illustrated with two glasses, one labeled "kinetic energy," and the other labeled "potential energy." For example, show the class a ball that is held at rest at the top of a “V”-shaped track or an inclined plane. Pour some water into the potential energy glass (dyed with food coloring to make it easy to see), and explain that at the top of the hill, all of the ball's energy is in the form of gravitational potential energy. Let the ball roll down the track (slowly, not a steep slope), and as it does, pour the colored water from the potential energy glass into the kinetic energy glass so all the water is in the kinetic energy glass when the ball reaches the bottom of the track. Explain that as the ball rolled down the track, more and more of its energy was converted from potential energy into kinetic energy, until at the bottom of the track, *all* of the ball's potential energy had been converted into kinetic energy. The ball is moving fastest where it has the most kinetic energy --- at the bottom of the track.

Repeat this demonstration by drawing a more realistic hill (not a straight slope) on the chalkboard, and draw the ball at several locations on the hill. Ask where the ball is moving fastest. Some students will incorrectly answer that the ball is moving fastest somewhere in the middle, where the slope is the steepest. To lead them to the realization that this is incorrect, again pour the water from the potential energy glass (ball at the top of the hill) into the kinetic energy glass (ball at the bottom of the hill), and rephrase the question as "where does the ball have the most kinetic energy?" The students will realize that the ball is actually moving fastest at the bottom of the hill, where is has the most kinetic energy.

Hand out a thick rubber band (like that used when you buy asparagus or celery). Set up a ball swinging on a string (a simple pendulum). Ask the students to shoot their rubber bands at the ball (in an orderly fashion so nobody gets hurt!). The ball should be hit and start swinging. On the board, draw the different stages of this process, and identify the energy at each stage: the rubber band stretched on a finger (all elastic PE); the rubber band flying through the air (almost all KE, maybe a little gravitational PE for an arced flight); the rubber band pushing the ball upward (doing work); the ball at its highest point (rubber band’s work stored as gravitational PE).

Now watch the ball swing, and ask: Where the KE is zero? (Answer: when the swing is widest, where the motion stops for an instant.) Where is the gravitational PE is zero? (Answer: at the lowest point of the swing.) Note that again, the ball is moving fastest where it has the most KE — at the lowest point of the swing, where all of the energy is potential energy.

Ask the class to bring in a ball to prelab, and bring some rubber bands to class. Ask them to attach 8 linked rubber bands to the ball using some tape --- call it a bungee ball. Have everyone stand up and hold the end of the rubber band cord in one hand and the ball in the other hand, motionless at about eye level. Have them drop the ball and catch it when it comes back up (without jerking with the hand holding the cord). Repeat this a few times, and ask them to describe the several stages of this motion. Put these on the board, and identify the energy at each stage on the way down: 1) ball motionless at the top (KE = 0, elastic PE = 0, grav PE = maximum); 2) ball falling and speeding up, rubber band slack (KE increasing, elastic PE = 0, grav PE decreasing); 3) ball falling and slowing down as rubber band stretches (KE decreasing, elastic PE increasing, grav PE decreasing); 4) ball motionless at the bottom (KE = 0, elastic PE = maximum, grav PE = 0). The description of the stages on the way up are similar to those on the way down. Ask, "Where is the ball moving fastest?" This is a bit tricky, but ask them to let the ball hang without moving. Call this the equilibrium point. Then they should experiment a bit, and notice that if the ball is pulled down just a bit from this equilibrium point, the rubber band cord will pull it back up, but if the ball is lifted up just a bit from this equilibrium point, gravity will pull it back down. The class should reason that this equilibrium point is where the ball is moving fastest.

Someone in the class will notice that the ball does not come all the way back up, and wonder if there is some energy that is disappearing or being lost. The answer is yes, some energy is being converted into thermal energy by the stretching of the rubber bands. In this case, the law of conservation of energy says that the sum of (kinetic energy) + (potential energy) + (thermal energy) remains the same throughout the bungee ball's bounce. You might try repeating the demonstration with the labeled glasses ("kinetic energy" and "potential energy," as described above), but this time adding a third glass labeled "thermal energy." As the students describe --- step by step --- the ball falling down and back up, ask them to tell you how to pour the water, starting with all the water in the potential energy glass when the ball is motionless at the top, about to be released. At the equilibrium point, about half of the water will have been poured from the potential energy glass into the kinetic energy glass (because the ball has lost about half of its height, so half of its gravitational potential energy has been converted into kinetic energy). But now the increasing stretch of the rubber band means that water is poured back into the potential energy glass. At the bottom all of the water is again in the potential energy glass, this time in the form of elastic potential energy. The process is reversed on the way back up. But point out that in the stretch of the rubber band, some of the energy has been converted into thermal energy --- pour a little water into the thermal energy glass. After several bounces, the bungee ball will come to rest at the equilibrium point. When this happens, about half of the water will have been poured from the potential energy glass into the thermal energy glass, with the kinetic energy glass empty (the ball still has about half of its height, so half of its gravitational potential energy is still present). Again, stress that the total energy --- kinetic + potential + thermal --- is conserved.

Students may wonder whether the stretching of the rubber band really produces thermal energy. Pass out some THICK rubber bands to the students, and have them hold it unstretched between their thumbs pressed gently against their upper lip, just under their nose. Now have them suddenly stretch the rubber band. They should feel a definite warming sensation. Have the students hold the stretched rubber band against their lip until the warm feeling is gone, and have them suddenly relax the rubber band to its unstretched length. Now they should feel a definite cooling sensation. [This isn't due to friction, which would produce a heating effect whether the rubber band was being stretched or relaxed. It turns out that stretching the rubber band aligns the rubber molecules, which in turn releases heat. Relaxing the rubber band causes the rubber molecules to become more jumbled, which in turn absorbs heat.]

To demonstrate what happens when a system is not closed, so thermal energy can "leak out," have students 1) drop a rubber ball, and watch it bounce until it comes to rest; 2) drop their bungee balls, and watch as it comes to rest; and 3) release a marble in a mixing bowl with a round bottom (or in an embroidery hoop held in a slanted position against a book), and watch as it comes to rest. Point out that as friction --- and sound --- remove energy from the system, two things happen:

- the kinetic energy tends to zero, and
- the potential energy tends toward its smallest possible (minimum) value.

(When the bungee ball comes to rest, note that it is not at its lowest point, and that the rubber bands are stretched just a bit. Although some gravitational potential energy and elastic potential energy still remain, this equilibrium position of the ball is where it has the least total potential energy. If the ball is pulled down just a bit from this equilibrium point, the rubber band cord will stretch to increase the elastic potential energy, and if the ball is lifted up just a bit from this equilibrium point, the greater height will increase the gravitational potential energy. The equilibrium position is where the sum of the gravitational potential energy and the elastic potential energy is a minimum.)

Repeat the lab experiment showing the class two glasses of water — one hot, one cold. Let the glasses sit still for a few minutes (to allow any currents to die down). Add a drop of blue food coloring to each, and ask the class to describe the difference in behaviors of the two glasses. The class will observe that the color spreads rapidly in the hot water, but very slowly in the cold water. Ask why this happens, and lead the class to the idea that the water molecules in the hot glass have more random kinetic energy than the molecules in the cold glass. That is, the molecules in the hot water are moving much faster --- in random directions --- than the molecules in the cold water, and so the molecules of the hot water do a faster job of spreading around the food coloring. Tell them that thermal energy is the kinetic energy of randomly moving molecules.

The idea that thermal energy is just randomly directed kinetic energy can be demonstrated by placing a clear baking dish on an overhead projector. Put several marbles --- representing the molecules of a substance --- into the dish. Shake the dish gently and explain that in a colder substance, the molecules move more slowly and collide less often. Now shake the dish harder and explain that in a hotter substance, the molecules move more rapidly and collide more often. Ask the class which marbles are hitting the side of the dish hard, and they will answer the faster (i.e., hotter) marbles. Explain that if the sides of the dish could move, the faster moving marbles would push out the sides slightly. This would tend to make the faster (i.e., hotter) marbles less tightly packed. In other words, the more vigorous collisions between the molecules of a hot substance cause it to expand and be less dense ("lighter").

5. Temperature and Heat

Everything with a temperature above absolute zero loses thermal energy by radiation (light). To demonstrate that the human body loses energy by giving off infrared light (nonvisible light that our eyes cannot detect), turn off the lights in the room, and have the students hold their hand flat in front of their forehead. As they bring their hand close to their forehead, they will feel a sensation of heat. That is the infrared radiation that they are emitting. Explain that, on average, each person "shines" with about 200 watts of infrared light.

To show the transfer of thermal energy by conduction, give the class a cup of hot water, and have them hold a penny halfway into the water. After a few seconds, the penny will become noticeably warm. *(Do not hold a penny in a flame — burns may result!*)

Convection (energy carried upward by hotter, and therefore less dense, liquid or gas) can be demonstrated in several ways. Hold a light plastic trash can liner bag open over a bunsen burner or several candles. When the hot air has filled the bag, it can be released to float upward. Students should be told to watch as the bag finally tips over and lets the warm air "spill out."

Another method of demonstrating convection is to cut a round circle out of a piece of paper (6" or so in diameter), and then cut a 1"-wide spiral pattern so it goes around about three times. Tape a long piece of thread to the center of the spiral, and hold the spiral safely above a candle flame. The rising hot air will cause the spiral to rotate. (First, have the class hold their spirals over their heads and gently blow upward, so they will see which way the spiral rotates with the rising air.) "Angel chimes" that are used for Christmas decorations work on the same principle, and can be shown to the class.

To show that convection also works with liquids, use a "tornado tube" (available from many science stores or teaching supply stores) to connect two clear 2-liter pop bottles and stand them end-on-end. The bottom bottle should be filled with hot water that is colored a deep blue with food coloring. The top bottle should be filled with cold clear water. Streams of hot blue water will rise into the top bottle, carried upward by convection.

A thermometer can be made from a plastic soda straw (preferably a thin one that is somewhat transparent). Fold one end of the straw over three times to close it off, and hold it closed with a paper clip. Get a cup of room-temperature water that has been dyed a dark blue with food coloring, and hold the open end of the straw below the surface. Squeeze some air out of the straw, lift the straw out of the water, and turn it over so the open end is at the top. There should be a column of water visible at the top of the straw. Gently pinch the straw below the water column to squeeze out about half of this water. This should leave a plug of water a bit below the top of the straw. Hold the straw by the paper clip for a few moments to be sure that the straw is at room temperature, and use a pen or pencil to draw a mark at the bottom of the water plug. Next get two cups, one filled with ice water, and one with hot water. Place the straw into the cold water (the more of the air column below the mark that is in the water, the better), and watch the water plug fall. Now place the straw into the hot water, and watch the water plug rise. Explain that in the cold water, heat is being transferred from the air column to the cold water. The thermal energy of the air is being reduced, so the air molecules are moving more slowly and don't strike the bottom of the plug as hard — so the water plug falls to a lower level. In the hot water, heat is being transferred from the hot water to the air column. The thermal energy of the air is being increased, so the air molecules are moving more rapidly and hit the bottom of the plug harder. This pushes the water plug to a higher level.

6. Static Electricity

Ask the students to bring sweaters from home, while the instructor brings balloons to class, along with some string, pieces of styrofoam packing, and puffed rice. Hand these out to the class. Have the students blow up their balloon and tie it off, and tie a string to the end of the balloon. Ask them to rub the balloon against their sweaters, and hold the balloons near other balloons and near the objects supplied. Have a thin stream of water running so the students can hold their balloons near the water. Ask for observations, and draw conclusions that 1) two effects --- attraction and repulsion --- imply two types of charge, positive and negative; 2) the originally "uncharged" balloon and sweater don't attract or repel before they are rubbed, but attract each other after rubbing. Some charge has therefore been transferred from the sweater to the balloon, so the balloon has a negative charge (negative by definition), and the sweater has a positive charge. They attract, so opposite charges attract; 3) two rubbed (and therefore negatively charged) balloons repel, and so like charges repel.

Is water charged? Hold the negatively charged balloon near the stream of water, and watch as the water is attracted to the balloon. Explain that water (H_2O) consists of two hydrogen atoms attached to one side of an oxygen atom (so it looks like Mickey Mouse's head):

positive end

H H

O

negative end

The hydrogen end (top of Mickey's head) is slightly positive, while the oxygen end is slightly negative. (The technical term is that water is a *polar molecule*.) Bringing the negatively charged balloon close to a water molecule attracts the positive end and repels the negative end, so the molecule rotates so the positive end is closer to the negatively charged balloon.

H

negative end O positive end BALLOON (negative)

H

Since the positive end of the water molecule is closer to the balloon, there is an overall attraction. (This is because the electric force becomes stronger when the charges are closer together.) To see if the class understands, ask them to predict what will happen when a positively charged sweater is brought close to the stream of water. Answer: it will also attract the water, since the water molecule will rotate the other way so its negative end is closer to the positively charged sweater.

H

positive end O negative end SWEATER (positive)

H

You may want to model this by asking a student to portray a water molecule. The student's head can be the negative oxygen atom, and the student's outstretched hands can be the positive hydrogen atoms. (Mark the student's forehead and hands with a sticker dot, with a "+" or "-" on it.) The student can then rotate toward the balloon, or rotate away from the sweater.

Another way of demonstrating the polar nature of water molecules is to blow a large bubble and hold it in place (attached to the bubble blower). Slowly bring a negatively charged balloon close to the bubble. The bubble will be attracted to the balloon and distorted (stretched out) from its round shape. Point out that the distortion is because the electric force between charges gets weaker with distance, so the near side of the bubble is attracted more strongly that the far side of the bubble. Repeat the demonstration with a positively charged sweater.

Students may think that when a negatively charged balloon attracts something, the other object must have a positive charge. (For instance, they may think that the puffed rice that was attracted to their balloon had a positive charge.) To show that this is not the case, hang a piece of uncharged styrofoam from a piece of string, and bring the styrofoam close to the negatively charged balloon. Although the styrofoam does not have any electric charge, the styrofoam will be attracted to the balloon. As the styrofoam approaches the balloon, the negative charge on the balloon will attract the positive parts of the molecules that make up the styrofoam, and repel the negative parts. This is similar to what happened to the polar water molecules (described above). The positive ends of the molecules will be closer to the balloon than the negative ends, and the result is an overall attraction of the styrofoam to the balloon.

Let the styrofoam cling to the balloon for a bit, and then pull the styrofoam away from the balloon. Again, bring the hanging piece of styrofoam close to the balloon, and now the styrofoam will repelled from the balloon! When the styrofoam *touches and clings* to the negatively charged balloon, some of the negative charge is rubbed off onto the styrofoam. (Sometimes the styrofoam may actually jump off of the balloon.) Now, when the styrofoam is pulled away from the balloon, some of the balloon's negative charges comes off with the styrofoam. When the hanging piece of styrofoam is again brought close to the balloon, both the styrofoam and the balloon have a negative charge, so the styrofoam is repelled from the balloon.

Wood molecules act like styrofoam molecules when an electrically charged object is brought near, and can be attracted by a charged object. To demonstrate this, balance a long heavy piece of wood (say, 4" x 4" x 6 ‘) on an overturned watchglass or something else rounded so it is easy to balance. Rub a balloon against a sweater, and hold the negatively charged balloon near one end and to the side of the wood. The wood will begin to spin, and by moving the balloon so it is just ahead of the wood, it can be made to spin faster and faster.

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 ____________________________________________
|____________________________________________|   O balloon
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Introduce the class to the idea of an electric (force) field by using an electric field detector made of a long wooden dowel with a string (about 15 cm long) hanging from one end . Rub an inflated balloon against a sweater so the balloon is negatively charged. Hold the end of a long string above the balloon, and the end of the string will be attracted straight toward the balloon (just like the hanging piece of styrofoam was earlier). Move the thread all around the balloon so the class can see that the thread always points straight toward the balloon. Explain to the class that the string is lining up with the electric field that surrounds the charged balloon. Draw a balloon on the board, and ask the class how you should draw the lines of electric force (electric field) around the balloon. It should always line up with the thread, and the class should understand that the electric field always points directly away from the balloon. [Technical note: By convention, the electric field points directly away from a positive charge, and directly toward a negative charge. Don't bother the class with this fine distinction.] Explain that electric fields are how electrically charged objects can react to each other at a distance. Each charged objects “feels” the electric field produced by other charged objects.

A "cush ball" makes a good model of the lines of electric force around a charged object. The strands of plastic are all pointing away from the center where the charge would be.

7. Phase Changes

The three phases of H_2O (ice, water, steam) can be demonstrated by giving each student in the class three plain color coding labels (round stickers), with two the same color (say, one blue and two red). Have each student put a plus sign (“+”) on the red stickers, and place one on the back of each of their hands. Have each student put two minus signs on the blue sticker (“--”), and place it on their forehead. Instruct the students to hold their right arm horizontally out in front of them, and their left arm horizontally to the left. Explain to the students that they are now water molecules, with their hands representing the two positively charged hydrogen ends, and their head the negatively charged oxygen end.

First, ask the students to stand up, and have each student place his or her right hand on the shoulder of the student in front of them, and his or her left hand on the shoulder of the student to their left. While keeping their arms rigid, point out to the class that they do not have much freedom to move around. They are locked in a rigid pattern of H_2O molecules. Ask what phase of water they think they are demonstrating, and they should respond “ice.” Point out that the class has a definite shape and volume.

Second, ask the students to imagine that your are adding energy (heat) to the class, and allow the students to move around while always keeping their hands on the shoulders of other students. (Point out that they can move their hands from one shoulder to another, since their positive hands are attracted to their negative heads, but hands shouldn’t touch hands, since they are both positive and would repel each other.) The class may want to move away from their chairs so they have more freedom; this is fine, since water can flow. Explain that the class still has a definite volume (it take up the same amount of space), but now the H_2O molecules are free to move and flow while staying together. Ask what phase of water they think they are demonstrating, and they should respond “water.” Point out that water has a definite volume, but not a definite shape.

Third, ask the students to imagine that your are adding more energy (heat) to the class, and allow the students to remove their hands the shoulders of other students. Instruct the students to walk in a straight line until they reach a wall or a desk, and they change direction and walk in a straight line in some other direction. (They should walk slowly so things don’t get out of control!) After a while, the students should be spread all over the classroom. Ask everyone to stand still, and point out that the class no longer has a definite volume, and that the H_2O molecules have filled the classroom so their shape is the shape of the classroom. Ask what phase of water they think they are demonstrating, and they should respond “steam.” Point out that steam does not have a definite volume, and that it takes the shape of its container (just like the liquid water does).

The idea of a phase transition from solid to liquid to gas can be demonstrated with a clear plastic dish that is divided into several (about six) sections by radial ridges. (The dishes used to contain the water from plant pots work well.) Place the dish on the overhead, and place one marble into each section. Shake the dish gently, so each marble remains in its section. Explain that this represents the atoms that make up a solid, with each atom attracted to its neighbors and held in a more-or-less fixed position relative to the other atoms. That is why a solid occupies a definite volume and has a definite shape. Now shake the dish harder, so the marbles are not confined to their own sections but still stay in the dish. Say that you are increasing the thermal energy of the atoms Explain that the result represents the atoms that make up a liquid, with the atoms still attracted to each other but with each atom moving freely among the other atoms. That is why a liquid occupies a definite volume but does not have a definite shape. Now shake the disk vigorously, so the marbles eventually escape from the dish and fall to floor, rolling to the side of the room. Again tell the class that you are increasing the thermal energy of the atoms. Explain that the result represents the atoms that make up a gas, with the atoms no longer attracted to each other and with each atom moving out along its own path. That is why a gas expands to occupy the volume of its container. A gas does not have a definite volume or a definite shape.

8. Electric Circuits

The idea of a complete circuit can be demonstrated by giving each student (or each pair of students) a lightbulb (flashlight size), a D-cell battery, and a narrow strip of aluminum foil, about 2 cm wide. Have them fold the strip of foil twice lengthwise to make a long flat wire, and ask them to get the bulb to light up. (After a minute or two, warn then not to directly connect the two ends of the battery with the foil wire because they will drain the battery.) Eventually they will find that they can light the bulb by holding the end of the lightbulb to one end of the battery, and connecting the other end of the battery to the threaded side of the bulb. Explain that there are electrons flowing from the negative end of the battery to the positive end of the battery --- the battery acts like a "pump" to push the electrons through the light bulb. Let's say that the negative end of the battery is connected to the threaded side of the bulb, and the positive end of the battery is touching the bottom of the bulb . The electrons move from the negative end of the battery through the foil wire to the side of the light bulb. Inside the bulb, a wire from the threaded side carries the electrons to the filament of the bulb, a short piece of tungsten wire that resists the flow of electrons. The electrical friction of the electrons moving through the filament causes the wire to become hot and glow brightly. Then the electrons leave the filament and travel through a wire to the bottom of the bulb, where they arrive at the positive end of the battery. Emphasize that there must be a complete path, a *complete circuit*, so the electrons can get from one end of the battery to the other. Otherwise the electron flow will be cut off, and the bulb will not light up.

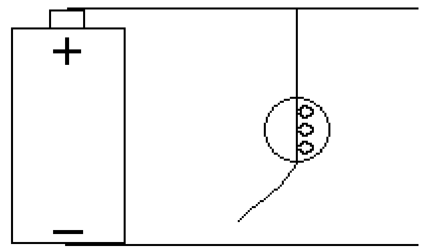
Give each team of students a household lightbulb (for a lamp, etc) and some newspaper. Ask the students to wrap the bulb up in newspaper and then break it with a hard object. After the glass from the bulb has been removed, ask the class to describe the wire connecting the filament with the bottom and threaded side of the bulb. Also, ask what the purpose of the black ring that separated the bottom of the bulb from the threaded side. (Answer: the ring is an insulator that separates the bottom of the bulb from the threaded side, so the current will flow through the filament instead of being short-circuited.)

A penny circuit can be made by having the class line up in the form of a loop. Have one person be the battery (perhaps wear a "battery" sign) and have another person be a light bulb ("light bulb" sign). Tell the students that they are copper atoms in a wire, and give each of them a copper penny. Explain that this penny represents one of the electrons of the copper atom that will be donated to form the electric current, and each student can hold only one penny. The battery supplies the power, so have the battery person say "move" at regular intervals (once a second or so). On hearing the word "move" everyone passes their penny to their neighbor (in a direction so the penny leaves the negative end of the battery, according to the "battery" sign). When the person representing the light bulb receives a penny, that person should shake the penny (representing electrical friction) and announce "shining." Point out that the battery doesn't store electrons — the battery just supplies the energy to move the electrons around the circuit. Remove a person so there is a gap in the line. Ask if the students can pass their pennies (still only one penny per person). They will say "no;" explain that you have opened a switch to stop the current.

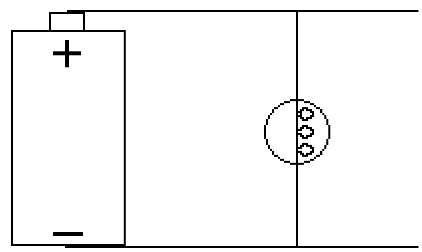
Another way to demonstrate how electrons move through the wires in a complete circuit uses a long rope (50' or so) with its ends tied together. Give every student in the class a twist-tie (for closing plastic bags) and ask the class to form a circle with each student holding part of the rope in front of them. Tell the class the each student represents a copper atom inside a copper wire, and explain that each copper atom donates one of its electrons to the current. The students should attach the twist tie (the donated electron) to the rope. With the students holding the rope *loosely* in their hands, explain that you are the battery as you pump the donated electrons around the circuit by (gently) pulling on the rope. (You could even make and wear a battery sign.) As the twist-ties pass through the hands of the students, explain that the donated electrons that make up the current travel from copper atom to copper atom in the wire, and that you (as the battery) are doing all of the work in keeping the current going. If you wish, you can select one student to be a light bulb (supply the student with a light bulb sign) and ask that student to grip the rope more tightly. The student should feel the heat from the rope's friction with their hands. This represents the resistance in the filament of a light bulb that causes it to heat and glow.

An inexpensive set of light bulbs (complete with holders) can be made from a string of clear miniature holiday decoration lights. Cut the wires connecting the bulbs about halfway between the bulbs, and remove the insulation from a short length of the ends of the wires. Take two aluminum foil wires, and hold one end of each wire (taped, rubber band, or by hand) at the terminal of a battery. Ask the class to *predict* what happens when:

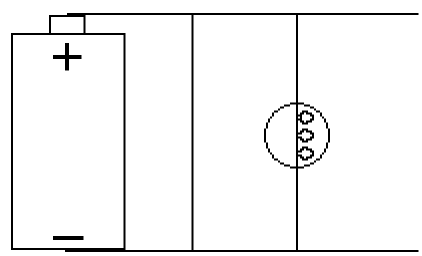
- The end of one bulb wire touches one of the wires attached to the battery. (The bulb does not light because there is not a complete circuit from one end of the battery to the other.



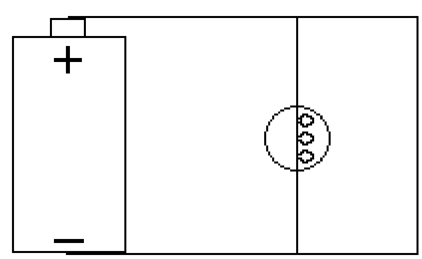
- One of the bulb wires touches one of the wires attached to the battery, and the other bulb wire touches the other wire attached to the battery. (The bulb lights because there is a complete path from one end of the battery to the other.)



- One of the bulb wires touches one of the wires attached to the battery, and the other bulb wire touches the other wire attached to the battery. The end of the wire attached to the bulb touches one of the wires, and the bottom of the bulb touches the other wire. A third aluminum wire is connected across the two battery wires in front of the bulb. The bulb does not light. Ask the class for a hypothesis about why the bulb does not light. They may guess that the electrons take the shorter route to the battery, and don't go through the lightbulb because it is part of the longer route.



- To test this idea, move the third wire in back of the bulb. The bulb does not light. (This shows that the hypothesis that the electrons take the shorter route is incorrect.) Ask again why the bulb shines, and review the idea of electrical friction resisting the flow of the electrons. Ask if there is any resistance to the flow of the electrons in the fourth wire that does not have the bulb. The students will probably come up with the phrase "the path of least resistance." Explain that the electrons prefer to take the easiest path from one end of the battery to the other, and that this path is through the wire with the least resistance.
  Warning: don't leave the third aluminum wire in place too long, or the battery will be drained!



9. Magnetism

Introduce magnets by placing a straight bar magnet or a "cow magnet" into a clear baking dish, and putting the dish on an overhead projector. Place a blank plastic transparency sheet over the magnet, and sprinkle some iron filings over the magnet. Tap the dish gently, and the iron filings will line up along the magnetic lines of force *(magnetic field*) of the magnet. (Be sure to use the baking dish because iron filings can damage an overhead projector if they get inside!) Point out that the iron filings are concentrated at the ends (*poles*) of the magnet.

Pass around some disk magnets with a hole in the middle (available from Radio Shack) and some paper clips, and have the students experiment with attracting things. They will find that some objects will be attracted by the paper clip and some won't, but nothing is repelled --- except another magnet. If they put a pencil through the central holes of two disk magnets, the two magnets may attract each other or repel each other. One may even "float" above the other, suspended as the magnetic force balances the force of gravity. Some students may magnetize their paper clip by stroking it in one direction on the disk magnet. Others will discover that the magnetic field penetrates paper or other material, so the clip will be attracted even when something comes between the clip and the magnet. Explain that the two types of effects between magnets --- attraction and repulsion --- implies that there are two types of poles, called north (N) and south (S).

Hang a bar magnet from a long piece of string so it is not close to anything made of steel or iron. After a while, the magnet will become oriented so it is parallel to Earth's magnetic field. Explain that the end of the magnet that points in the direction of north is called the north pole of the magnet, and the end of the magnet that points in the direction of south is called the south pole of the magnet.

Break or cut a bar magnet into two pieces. At the break, each piece will gain new pole that is opposite to the original pole:

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 ___________________________________________
|                                           |
|  N                                    S   |
|___________________________________________|
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becomes

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 _______________________           ___________________
|                       \          \                  |
|  N                S    /         /  N           S   |
|_______________________\          \__________________|
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after being broken.

This shows that *magnetic poles always come in pairs*. There is no such thing as an isolated north or south pole. On an overhead projector, bring the two broken ends close to each other. They will attract each other. This shows that unlike poles attract. Turn one piece around,

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 _______________________           ___________________
|                       \          |                  /
|  N                S    /         |  S           N   \
|_______________________\          |__________________/
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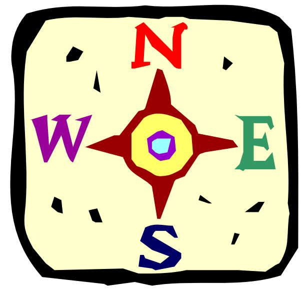
and now move one piece toward the other. The two pieces will repel; this shows that like poles repel.

Place a bar magnet on an overhead projector, and take several transparent compasses and place them along the side of the magnet. The compass needles will align themselves with the magnetic field. Explain that because each compass is just a small balanced magnet, the direction of the compass needles will trace out the direction of the bar magnet's field.

Give each team of students a compass, a paper clip, and a small yellow “Post-It” label. Ask the members of each team to write their names on the label, partially unwind the paper clip, and make a small yellow flag that shows their names. Go outside and have each team place their flag in the grass (so it wont be visible seen from a distance). Give each team a meter stick, and have them point toward north, south, east, and west (according to the compass) just to be sure that they are oriented. Give each team a sheet of paper with these “How to Get Back Home” directions: 1) Go 3 meters west; 2) Go 4 meters south; 3) Go 12 meters 53^{o} east of south; 4) Go 13 meters 30.5^{o} west of north. Have all of the teams complete one step before proceeding onto the next. At the end of step 4), have them lay their meter sticks on the lawn in their final positions. Make a “Homing Pigeon” award to the team that comes closest to their yellow flag.

How to Get Back Home



1. Go 3 meters west
2. Go 4 meters south
3. Go 12 meters 53° east of south
4. Go 13 meters 30.5° west of north

Homing Pigeon Award

presented to

for an outstanding use of

Magnetism

Give each team a 3½" floppy disk, and ask the class to take their disks apart, examining each piece and trying to deduce its function. Give each team a disk magnet, and ask them to discover which parts are attracted by the magnet. After a few minutes, ask if the floppy disk is attracted by the magnet. They will say that the central metallic spindle is attracted, but not the disk. Tell them remove the central spindle and test the floppy disk with a magnet. If they still are unable to attract the disk with their magnet, tell them to hang the disk on a horizontal pencil and slowly bring the magnet close to the disk. Then they should see that the magnet attracts the disk. Make the point that this 1.44 Mb disk has over 11 million bits (1 byte = 8 bits) of iron, in the form of iron oxide, and that as the disk spins the computer can recognize the orientation of each of those 11 million bits of iron, and change them when the computer writes to the disk.

Place a shallow clear flat plate (or a casserole dish cover) on an overhead projector, and fill it with water. Cut out a small piece of styrofoam in the shape of a wide arrow

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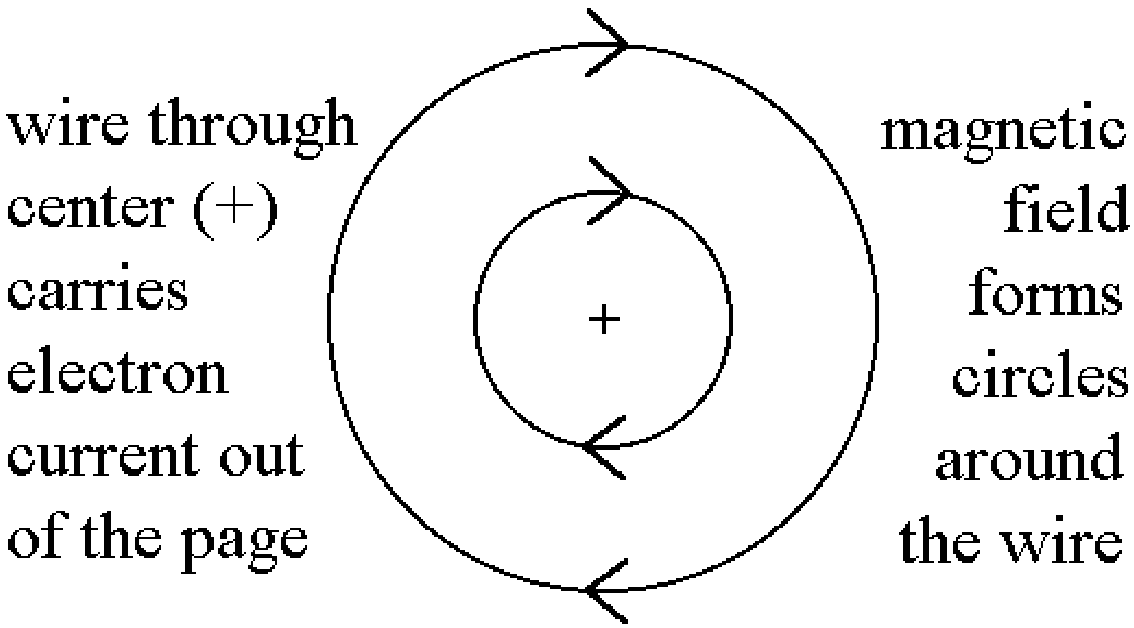
and float it on the water, where it will float about aimlessly. Stroke a paper clip (*in one direction*) with one end of a bar magnet many times until the paper clip is magnetized. Place the paper clip of the styrofoam arrow, and allow the class to watch as it aligns itself with the magnetic field that is in the classroom. Explain that you have made a compass by magnetizing a paper clip and allowing it to rotate freely.

On an overhead projector, float a magnetized paper clip on a styrofoam arrow in a dish of water to make a compass, as described above. Make an thin wire out of a strip of aluminum foil, and lay it over the arrow parallel to the direction it is pointing. Without moving the wire, connect a battery (I used a battery pack with two D-cell batteries) to the ends of the wire. The paper clip will rotate until it is nearly perpendicular to the wire. Explain that the floating magnetized paper clip is a compass that responds to the magnetic field in its surroundings. Before the battery was connected, the paper clip compass lined up with the magnetic field in the classroom. But after the battery was connected, the paperclip responded to a new magnetic field, a magnetic field that was created by the moving electric charges in the foil wire. Lead the class to the conclusion is that *magnetic fields are created by moving electric charges*. [Actually, when the battery is attached, the magnetized paper clip responds to both the magnetic field in the classroom and the magnetic field produced by the current (moving electrons) in the wire. The magnetic field produced by the moving electrons is much stronger than the classroom magnetic field, which is why the paper clip rotates so it is nearly perpendicular to the wire.]

To discover what the magnetic field around a current-carrying wire looks like, after the above demonstration disconnect the battery from foil wire and allow the paper clip to again line up with the magnetic field in the classroom. Now slide the wire *under* the dish, so it is lined up under the arrow parallel to the direction it is pointing. Without moving the wire, connect the battery to the ends of the wire. The paper clip will rotate *in the opposite direction* until it is nearly perpendicular to the wire. Ask what the magnetic field produced by the moving electrons in the wire must look like if it is always in opposite directions on opposite sides of the wire. Lead the class to the conclusion that the magnetic field must go in *circles* around the wire.



To help the class visualize what the magnetic field around a current-carrying wire looks like, hand out the diagram above, and ask the students to stick a pencil or pen through the cross (+) from behind the paper (so they are looking at the point of the pen or pencil when looking at the diagram). Explain that their pencil or pen represents the wire, and when the moving electrons of the current are flowing out of the tip of their pencil or pen, the magnetic field goes in the direction of the arrows on the circles. The arrows show the direction that the north end of a compass (and the floating magnetized paper clip) would point if it were placed near the wire.

Demonstrate how an electromagnet can be made by concentrating the magnetic field of a current-carrying wire by winding it around a nail or bolt. Take about thin insulated wire about a meter long, and wind it around one end of a nail or bolt. Secure the ends with tape or rubber bands so it won't unwind, and connect the ends to a battery. (I used a battery pack with two D-cell batteries.) Pick up some paper clips with the electromagnet to demonstrate that the nail or bolt now acts like a magnet. Repeat the demonstration on the overhead projector with the iron filings to show that the electromagnet's magnetic field looks like the magnetic field of a bar magnet.

To help students visualize what happens when an electromagnet is made by winding a wire around a nail or bolt, have them form groups of three and use their magnetic field diagrams with the pencil stuck through. Remind them that the pencil represents the wire that carries the electron current, and have each group of three use their pencils to form a horizontal triangular loop by touching their pencils so the point of one pencil touches the eraser of the next pencil. Ask the students which way the magnetic field goes in the center of the loop. If the students are holding their pencils so the point is on the left and the eraser is on the right, they will say that all of the magnetic fields are going upward at the center of the loop. New ask the students which way the magnetic field goes on the outside of the loop. If the students are holding their pencils so the point is on the left and the eraser is on the right, they will say that outside of the loop, all of the magnetic fields are going downward. On the blackboard, draw a vertical stack of loops (like a stack of bicycle tires), and draw a series of looping arrows. Each arrow makes a continuous loop as it goes upward through the center of the stack, goes through the top of the stack and then loops around to go downward outside the stack, where it loops back upward through the bottom of the stack to the loop's starting point. The students will see that this looks just like the pattern of magnetic field lines of a bar magnet.

At this point, somebody in the class may wonder where the moving electric charges are in a bar magnet. Remind them of the demonstration of breaking a magnet in two --- each piece gained a magnetic pole, so that the result was two smaller magnets. Now ask them to imagine breaking the smaller piece in two. What would be the result? Answer: two smaller magnets, each with a north and south pole. Imagine breaking one of these smaller magnets in two, and get two still smaller magnets. And again ... and again. Ask, "What the smallest possible piece of a magnet I could possibly end up with?" Someone will say, "an atom," which is correct. Explain that each atom acts like a tiny magnet, and has its own north and south pole. Now ask where there are electric charges moving in an atom. The answer is that the electrons move about the central nucleus of the atom, so *it is the motion of electrons in atoms that are responsible for the atom's magnetic field*. Explain that in some atoms, the electrons' motions make a very weak magnetic field that we don't notice under everyday conditions. That is why some materials can't be magnetized and aren't affected by magnets. But in some elements like iron and nickel, the motions of the atoms' electrons produce a strong magnetic field. So why isn't everything made of iron or nickel magnetic? Because in most substances, the individual atomic magnetic fields are pointed in random directions, so they cancel each other out. But in a magnetized object, the individual atomic magnetic fields are aligned; they tend to point in the same direction so they are lined up. (Remind the class that this is what happened when the paper clip was magnetized by stroking it with the magnet --- the magnetic fields of the atoms were being lined up.) The individual atomic magnetic fields in a magnetized object then add up to produce a strong magnetic field. Remind the class that when they wound their wire around a nail to make an electromagnet, the magnetic field produced by the current-carrying wire lined up the individual magnetic fields of the atoms in the nail. This magnetized the nail so its magnetic field added to the magnetic field produced by the current-carrying wire. [The nail was only magnetized temporarily, while the current was flowing. When the battery was disconnected from the wire, the nail's magnetization disappeared, although some students may have noticed that their nail remained slightly magnetized.]

To see what materials can be magnetized and attracted by a magnet, obtain samples of iron, cobalt, nickel and other elements. Hold a magnet near each sample; only the iron, cobalt, and nickel will be attracted. Point out that these substances are next to each other on the periodic table of the elements, a preview of the organizational power of the table.

Ask the class, “If a current moving through a wire creates a magnetic field, will a wire moving through a magnetic field create a current?” [Answer: Yes — as long as the wire is part of a complete loop (complete circuit).] Explain that this is how generators work. For a hydroelectric plant, for example, water turns a turbine that moves loops of wire through a magnetic field to generate electricity. Show the class a generator (from an old crank telephone, a bicycle light, etc) that can be cranked by hand to light up a bulb. Ask a student to turn the crank, and explain that the work they are doing is being converted into electricity. While they are turning the crank, unscrew the light bulb — the student will immediately remark how much easier it is to turn the crank. Explain that this is because the student no longer has to supply the work that lights the bulb.

10. Waves

Have the class perform a "wave," as done by the crowd at a sporting event. Have it go from one side of the room to the other. Ask the class how the wave traveled (answer: from one side to the other) and whether the students themselves crossed the room (answer: no). Explain that a wave is a disturbance that travels through a medium. For a water wave, the medium is water, and for a people wave, the medium is people. Explain that both water waves and people waves are transverse waves. The water moves up and down, perpendicular to the wave's direction of travel across the water. People's arms move up and down, perpendicular to the wave's direction of travel across the room. Repeat the wave from one side of the room to the other, and let the wave "bounce back" once it reaches the wall. Ask, "What that would represent for a sound wave?" Answer: an echo!

To show that the water just moves up and down as a water wave passes, put some water into a transparent baking dish, and put the dish on an overhead projector. With an eyedropper, drops a few drops into the water to demonstrate water waves spreading out from each drop. Now put a few small pieces of cork or styrofoam into the water, and repeat the drops. The waves will not push the pieces along, but move through them as the pieces bob up and down. (Ask if anyone in the class has gone swimming in a beach or gone boating as a waves passed by. They will say the wave lifted them up and down.)

Waves on a rope are also transverse waves. Have a volunteer hold one end of a long rope that is stretched across the room (not too tight). Move your end quickly up and down and a wave pulse will travel down the rope. Tie a piece of red yarn to the middle of the rope so the students can see that the rope moves up and down as the wave moves forward.

A slinky can be used to demonstrate a longitudinal wave on an overhead projector. Stretch the slinky across the projector, and quickly move one end forward and back again (in the same direction the slinky is stretched). A compression (where the coils are closer together) will move across the projector along the length of the slinky. Explain that for a longitudinal wave, the medium (in this case the slinky coils) moves in the same direction as the wave's direction of travels. If the waves are reflected from where you are holding it at the other end, ask the students if they see an echo.

A human longitudinal wave can be made by lining up about ten students in front of the room, standing side-by-side about half and arm's length apart. Have every student put their hands on their neighbors' shoulders. Now gently push one of the students on the end toward his or her neighbor, and that person will in turn push his or her neighbor, and so on as a compression moves down the line of students.

Sound waves are longitudinal waves, and can be demonstrated with a slinky. Let a student hold one end of the slinky by his or her ear, and hold the other end to your mouth. Explain that the coils of the slinky represent air molecule, and as you speak the air molecules moves back and forth, pushing on the air molecules that are in front so a compression of air molecules (sound) moves through the air from teacher to student. Move the slinky back and forth as you speak, so students can see the compression wave move along the slinky to the student's ear.

To demonstrate the Doppler effect, take the class outside and bring a smoke alarm, rope about 2 m long, masking tape, and a cloth bag. Arrange the students in a large circle with you in the center. Tape the smoke alarm "on" so it emits a long, steady tone. Put the smoke alarm in the bag, tie the rope to the bag, and whirl the bag around your head in a horizontal circle. The students will hear a higher pitch sound when the alarm is moving toward them, and a lower pitch sound when it is moving away. Keep whirling the bag at a steady pace. Ask the students to close their eyes, and quickly raise their hands up and down when they hear the highest pitch sound. After several whirls and the students' hands are moving in a definite rhythm, have them open their eyes as they continue to raise their hands up and down. They will see a pattern of raised hands move around the circle, as each student raises his or her hand when the bag is moving directly toward them.

To help visualize the cause of the Doppler effect, put some water into a transparent baking dish and put the dish on an overhead projector. With an eyedropper, drops a few drops into the water to represent sound waves spreading out from a source of sound (such as a smoke alarm). Now slowly move the dropper forward as you drop the drops at regular time intervals. The students should see that the waves in front are bunched together, representing the shorter wavelength (and higher frequency or pitch) heard for an approaching source of sound. The waves in back are spread apart, representing the longer wavelength (and lower frequency or pitch) heard when a source of sound is moving away.

When a plane travels faster than the speed of sound through the air, a cone of compressed air spreads out behind the plane. This is similar to the wake that follows a boat that is traveling across a lake faster than the speed of a water wave. To demonstrate this, cut out a piece of styrofoam in the shape of a boat, and tape a thread to the front end. Put some water into a transparent baking dish on an overhead projector, and float the styrofoam boat on the water. Pull on the string and point out the wake that follows the boat. Explain that when a supersonic plane passes overhead, the cone of compressed air that is following the plane will passes over you — and when it does, you hear a *sonic boom*. Emphasize that a sonic boom is not produced by the act of the plane breaking the sound barrier, but is due to the cone of compressed air that always trails behind any supersonic plane.

11. Light

Demonstrate a light ray by turning out the room lights and shining a penlight laser across the front of the room. Ask the class if they can see they light. They will answer that they can see the red spot on the wall, but not the beam (ray) of the laser. Ask a student to clap two erasers together over the beam. Now the ray becomes visible to the class. Ask the class why they couldn’t see the laser beam before. Lead them to the answer that the ray was not going in their direction. Chalk dust in the air reflected some of the light toward their eyes. Point out that a light ray travels in a straight line unless something is in the way and changes its direction.

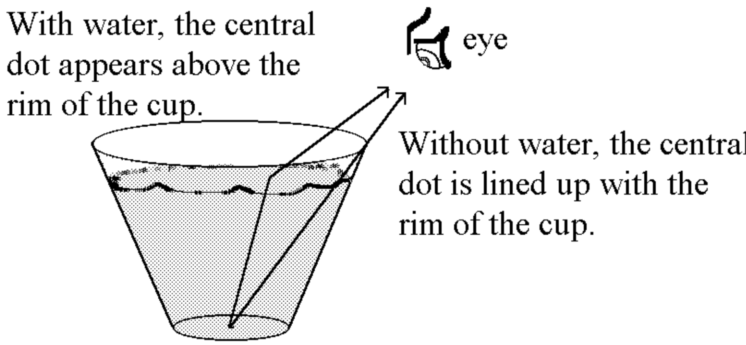
Light can be reflected. Hang a large mirror vertically in front of the class, and ask the students in the front row who can see whom. When their answers show that the mirror has been positioned properly (so they can see each other), attach a suction cup (with a hook attached to it) to the center of the mirror. Put a long piece of string through the hook, and give the ends to two students who say they can see each other. Tell the students to pull lightly on the hook, so the two sides of the string go string to the hook. The two sides of the string show the path of a light ray as it travels from one student to the mirror and is then reflected back to the other student. Ask the class to describe the angles made by the strings with the mirror, and lead them to the idea that the angles of the incident and reflected light rays are the same: *the angle of incidence equals the angle of reflection*.

Hold a flat mirror to the blackboard (so the shiny side points toward the ceiling), and in a darkened room shine a flashlight on the mirror so the incident and reflected beams are both visible on the board. Vary the angle at which the incident beam hits the mirror, and ask the class to compare the directions of the incident beam and reflected beam. They will notice that the reflected beam bounces out at the same angle the incident beam came in toward the mirror. Explain that this is just the law of reflection, that *the angle of incidence equals the angle of reflection.*

To show that waves exhibit reflection, put some water into a transparent baking dish on an overhead projector and place a flat surface (like a mirror balanced on one edge) in the water that can act as a reflecting "wall" for the water waves you will make. With an eyedropper, drop a few drops of water into the dish, and have the class watch as the waves are reflected from the flat wall. Ask the class to compare the directions of the incident and reflected waves, and they will notice that the reflected wave moves out at the same angle the incident wave came in toward the wall. Explain that this shows that waves obey the law of reflection, so that *the angle of incidence equals the angle of reflection.*

To show that particles show reflection, bounce a rubber ball or a tennis at an angle (not straight up and down) from the top of your desk. Ask the class to compare the directions of the incident and reflected balls, and they will notice that the reflected ball moves out at the same angle the incident ball came in toward the desk. Explain that this shows that particles can also obey the law of reflection. So reflection can't settle the question of whether light consists of waves or particles.

The path of a light ray bends when it travels from one transparent medium into another. The light ray's change of direction is called refraction, and can be demonstrated with a clear plastic cup. Have the students form teams of two. Pass out two cups to each team, one empty transparent cup and another cup filled with water. The transparent cup should have a small dot at the center of its bottom.



Instruct one student of each team to look at the cup with one eye closed, with the central dot lined up with the rim. Tell the students that they are looking at a light ray that travels straight from the central dot to their eye. Now, while the students continue to look at the rim of the cup lined up with the dot, tell the other student in each team to pour water into the cup. The student looking at the dot will now see the dot appear *above* the rim. Tell the students that they are now looking at a light ray that bends --- changes direction --- when it leaves the water and enters the air. Have the two students in each team exchange roles so both members of the team can see the refraction of the light.

Draw a diagram like the one above on the board to illustrate the process of refraction. Ask the students, "If you were fishing with a bow and arrow and aimed directly at the fish, would you hit the fish?" They should answer, "No." Ask them if the arrow would pass over or under the fish. They should answer, "Over the fish, since the arrow's path would go straight into the water instead of angling down to hit the fish."

Another simple refraction demonstration involves having the students place a pen or pencil in a cup of water, with it resting on the rim of the cup. Viewed from the side, the pencil will appear bent.

An aquarium filled with water can demonstrate refraction. Add several drops of milk to the water so the class can see a flashlight beam that shines through the water (in a dark room). Turn out the room lights, and ask a student to gently clap two erasers together above the aquarium as you shine the flashlight into the water. The chalk dust will make the beam visible in the air, and the class should see that the light beam bends as it enters the water. (A spray water bottle will also show the beam — cleaner, but the water spray doesn’t stay in the air as long.)

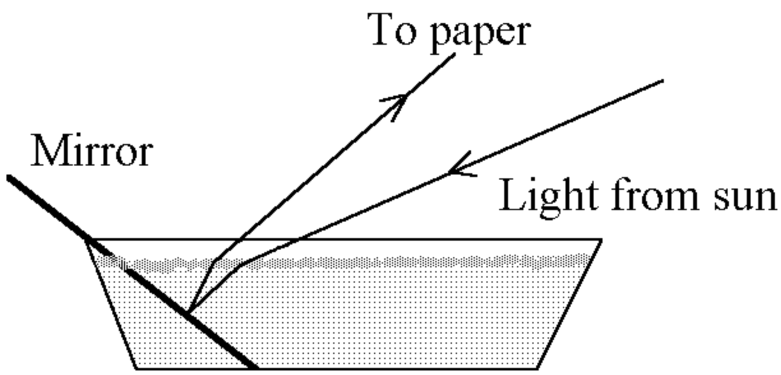
For another demonstration of refraction, put some water into a transparent baking dish on an overhead projector and put a pencil under one end so it is raised. The water will be shallower at that end. Slight jostle the deep end of the dish to create a wave. As the waves travels, it will change direction as it enters the shallow end of the dish.

The class may be surprised to learn that refraction can sometimes trap light inside a thin tube of water or glass. Drill a 1/4" inch hole in the side of a 2-liter pop bottle, about 2 inches from the bottom. Holding your finger over the hole, fill the bottle with water. Add several drops of milk to the water. Turn out the room lights and place the bottle on a platform over a sink or bucket. Remove your finger so the water runs out of the hole in an arc. Shine a laser penlight across the bottle and through the hole. The class will see that the laser light is trapped inside the falling stream of water. Explain that the same thing happens with a clear glass or plastic tube, and that this is how fiber optics works.

12. Lenses and Mirrors

Give each student a magnifying glass, and ask them to investigate the properties of the magnifying glass (a converging lens) for a few minutes. Then turn off the room lights and stand in front of the light from an overhead projector or a bright bare light bulb. Ask them to hold a piece of white paper vertically, and place the lens between you and the paper. They will discover a projected image on the paper. Wave to them. Ask if the image on the paper is reversed — upside down? left-right reversed? (Both!) Ask what very important optical device this reminds them of. Eventually they will say “the eye,” with the magnifying glass representing the lens of the eye, and the sheet of paper representing the eye’s retina (light-sensitive part).

Newton used refraction to show that white light consists of all of the colors of the rainbow --- red, orange, yellow, green, blue, indigo, and violet. An easy way of producing a rainbow in the classroom involves filling a square clear plastic box about 2/3 full of water. Place the box at the front of an overhead projector, so the back side of the box is about at the center of the projector. Cover the head of the projector with a towel. Turn out the room lights, and a rainbow spectrum will appear on each of the four walls of the room (or on the ceiling). Jiggle the water, and the rainbow spectrum will dissolve into a mass of shimmering white light before the water settles back down. This happens when the jiggling colors combine back into white light.



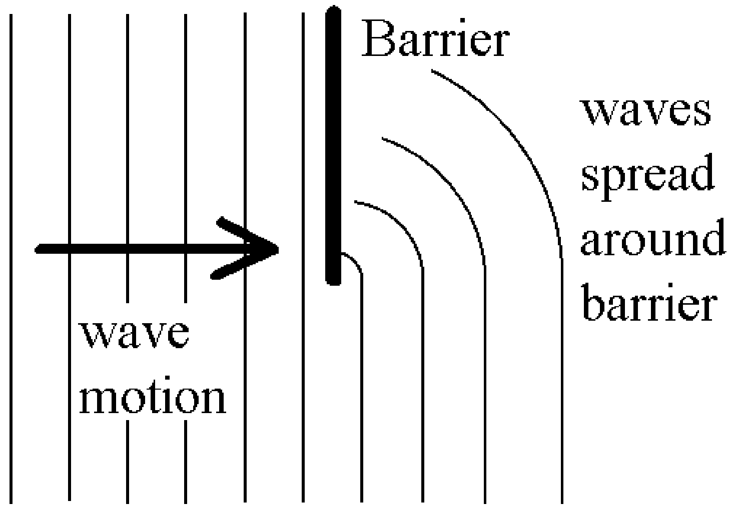
A rainbow can be made outside on a sunny day by using a hand mirror and a baking pan (about 8" x 8" or 9" x 13"). Fill the pan nearly full of water, and rest the mirror against one side at about a 45^{o} angle, so the mirror is facing the direction of the sun. Hold a piece of white paper above the baking dish, facing the mirror, and adjust the mirror so a rainbow spectrum appears on the paper. Explain to the students how combining all of the colors of the spectrum will produce white light, and demonstrate this by making waves in the water. The colors in the rainbow on the paper will dance and blend to produce white.

On this day the instructor should wear a white shirt or blouse. If the instructor stands in front of the pan, the rainbow will be seen on the shirt or blouse. Explain how the white material reflects all of the colors of white sunlight. Choose several students with clothing of various colors, and have them stand in the path of the rainbow. The students will see that the only color of the rainbow that is reflected from the clothing is the color of the clothing. The other colors have been absorbed by the cloth. Explain that we see the colors of nonluminous objects because of the colors of light they reflect.

Does light consist of a stream of particles or a wave? (Newton believed light is particles; Christian Huygens believed light is waves.) The following demonstrations lead to the answer, that light is a wave.

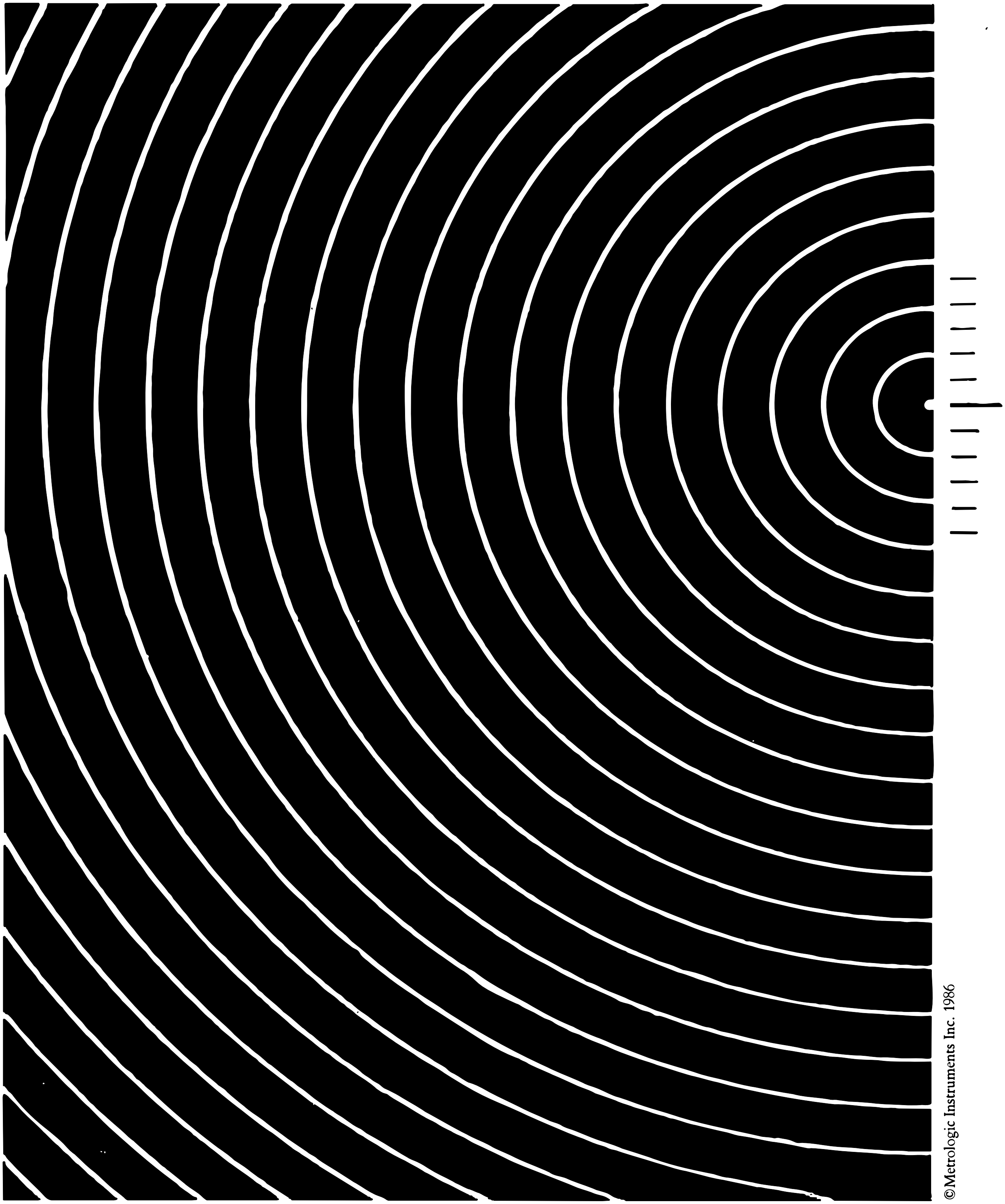
To follow-up the demonstrations of the refraction of light, explain that light shows refraction. Does this show that light is a wave or a particle? No, because both waves and particles exhibit refraction. Water waves change direction as they approach a beach, so they always come straight in toward the sand. A particle can also show a change in direction when it travels across a boundary, as when a car changes direction if one of its wheels drifts off the road into the mud. The car swings around the wheel that is slowed down by the mud. The class should conclude that refraction can't settle the question of whether light consists of waves or particles.

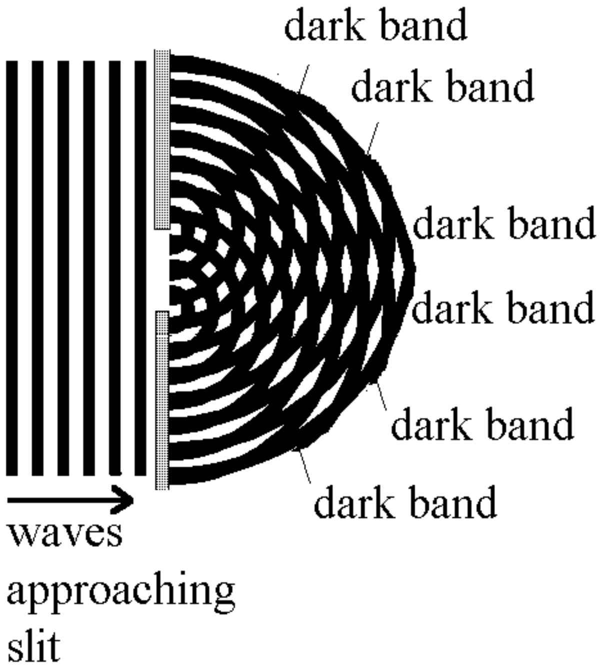
The question of whether light consists of waves or particles was finally settled in 1801 when Thomas Young demonstrated that light exhibits interference. Interference is a property only of waves, and occurs when the crests and troughs of one wave combine with the crests and troughs of another wave. You can demonstrate this using a people wave, with about eleven (it should be an odd number) students lined up in front of the room. Have the students hold their arms straight out (horizontally) in front of them. Ask the class to watch as a high wave travels from left to right (students raise their arms momentarily when the wave reaches them). Again, ask the class to watch as a low wave travels from right to left (students lower their arms momentarily when the wave reaches them). Now ask the class to watch as a high wave travels from both ends at the same time. The middle student should leap into the air as both high waves reach her at the same time. Again, ask the class to watch as a low wave travels from both ends at the same time. The middle student should kneel to the floor as both low waves reach her at the same time. Explain that these are two examples of *constructive interference*, when two wave crests or two wave troughs momentarily combine to create an even larger crest or trough. Finally ask the class to watch as a high wave travels from right to left while a low wave travels from left to right. Tell the students making the wave to freeze in place just as the waves reach the middle student. Ask the class what the middle student should do ... raise her arms for the high wave, or lower her arms for the low wave? Lead the class to conclude that the high and low waves will cancel, and that the middle student should leave her arms stretched out horizontally. Explain that this is an example *destructive interference*, when a wave crest and a wave trough momentarily cancel each other. Repeat this, but do not freeze the action. The students may not be sure what to do after the waves cancel at the middle student. Explain that the waves move right through each other, so the high wave continues to move from right to left, and the low wave continues to move from left to right. Finally, ask the class if they can imagine that two baseballs that are thrown together could possible cancel each other for an instant (resulting in no baseballs) and then move through each other. No way! The class should conclude that interference can occur with waves but not with particles. If something exhibits interference, it must be a wave.



Hold your hand in front of your mouth and ask the class if they can hear you. The answer of "yes" demonstrates that sound waves (and waves in general) can spread out around a barrier --- your hand. Water waves do the same thing. Put some water into a transparent baking dish, and put the dish on an overhead projector. Place a barrier (such as a thin piece of wood) into the dish so it extends above half way across the dish. With an eyedropper, drops a few drops into the water, and watch as the waves from the drop spread around the barrier. The diagram above shows waves moving from left to right that move past the barrier and then spread out around it. (The lines in the diagram represent wave crests). Draw this on the board, and explain that this could be water waves spreading around the barrier in the dish, ocean waves spreading around a breakwater, or light waves spreading around a sharp edge. The class may wonder why, if light bends around corners, they couldn't see your lips move when you held your hand in front of your mouth while talking. If they ask, explain that the wavelength of visible light is *tiny* (about 500 billionths of a meter), and so the amount of spreading is rarely noticeable in our everyday lives.

Here's how to demonstrate the interference effect of waves. Make two transparencies of the pattern on the next page. Put two thin blocks of wood on an overhead projector so there is a narrow slit between them. Place one of the transparencies at one edge of the slit, and explain that this represents waves spreading out around one edge of the slit. Remove the first transparency and place the second transparency at the other edge of the slit, explaining that this represents the waves spreading out around the other edge of the slit. Ask the class to imagine what they will see if both transparencies are in place, to represent the waves spreading out around both slits. After hearing their responses, put the two transparencies in place. Point to the light and dark bands, and explain that if you look at light that has passed through a single narrow slit, you will see light bands and dark bands on both sides of the slit. This is where the light that has spread out around one edge interferes with the light that has spread out around the other edge. A bright band appears where the light waves undergo constructive interference (two wave crests adding up, or two wave troughs adding up). A dark band appears where the light waves undergo destructive interference (a wave crest from one edge canceling a wave trough from the other edge). The diagram on the next page shows the light and dark bands (the light bands are between the dark bands).





To show the interference pattern (light and dark bands) that are seen when you look through a narrow slit at a light source, pass out popsicle sticks to the class, two sticks per person. Turn on a light bulb in from on the room. A bulb that has a long (several inches) straight filament will work best; such a bulb is available in a hardware store. Have the students hold the sticks vertically with their edges together, like the boards in a fence. The edges of the popsicle sticks are not perfectly straight, and there will be a narrow slit between the two sticks. Turn out the room lights, and ask the class to look through the vertical slit at the bulb. They should see light and dark bands spreading out on both sides of the slit. Explain that they are looking at the interference of light waves. A bright band appears where the light waves undergo constructive interference (two wave crests adding up, or two wave troughs adding up), and a dark band appears where the light waves undergo destructive interference (a wave crest from one edge canceling a wave trough from the other edge). Only waves can exhibit interference, so *this proves that light is a wave.*

Another way of making a single slit is to take an index card (postcard size) and use a scissors to cut a single slit from the center of one edge to the center of the card. Widen the slit slightly by pushing one side of the cut slightly forward and the other side of the cut slightly back. Now look through the vertical slit at the bulb to see the light and dark bands.

Ask the class, "If sound waves are vibrations of the air, and water waves are vibrations on the surface of a body of water, what vibrates for light waves?" The answer is, "Light is made of vibrating electric and magnetic fields. It is an *electromagnetic wave*!" To understand what "electromagnetic wave" means, remind the that an electric (force) field surrounds every charged object. Repeat the demonstration of holding one end of a long string near a negatively charged balloon — the loose end of the string will be attracted straight toward the balloon as it lines up with the electric field of the charged balloon. Remind the class that this is just like when iron filings were sprinkled around a magnet. At that time the iron filings lined up with the magnetic field that surrounds a magnet, just as now the thread is lining up with the electric field that surrounds the charged balloon.

Now ask the class to imagine some electrons that are flowing up and down and up and down ... along a thin metal wire. Hold a meter stick vertically to represent the wire, and move the negatively charged balloon up and down beside the stick to represent electrons moving up and down a metal wire. After a few up and down motions, hold the balloon still and hold one end of a rope in the hand that is holding the balloon. Have a volunteer hold the other end of the rope so it is stretched across the room (not too tight). Explain that the rope represents an electric field line that is pointing toward the balloon. Now move your end (and the balloon) up and down and a vertical wave will travel outward along the rope away from the balloon. Explain that this represents a vertical wave in the electric field that travels away from the vibrating electrons in the wire. Finally, remind the class that the moving electrons form an electron current in the wire, so there is also a magnetic field that forms horizontal circles around the vertical wire. Every time the electrons change direction, the magnetic fields changes direction also, and this horizontal back-and-forth wave in the magnetic field travels away from the vibrating electrons in the wire. So summarize for the class: as electrons move up and down the vertical wire, vertical waves are produced in the electric field, and horizontal waves are produced in the magnetic field. They combine to form an *electromagnetic wave* — light — that moves away from the wire at the speed of light. For example, the wire can be thought of as a transmission tower that produces radio waves, which are a long-wavelength variety of electromagnetic waves.

All light is produced by jiggling (accelerating) electric charges. Usually these charges are electrons. Turn on a light bulb that has a dimmer switch, and in a dark room slowly turn up the light. Ask the class to watch as you turn it up from cool and dim to hot and bright. Explain that as you turn up the light, more electrons flow through the filament. More electrical friction heats up the filament, which increases the thermal energy (randomly directed kinetic energy) of the electrons in the filament. This means more jiggling of the electrons in the filament, so more light is produced.

Ask the class to recall when you turned off the lights in the room, and had the students hold their hand flat in front of their forehead. Remind them (or repeat the demonstration) that as they brought their hand close to their forehead, they felt a sensation of heat. The electrons are jiggling slightly in their warm bodies, and they are feeling the infrared radiation --- another invisible form of electromagnetic radiation --- that they are emitting. Infrared light has a slightly longer wavelength than visible light.

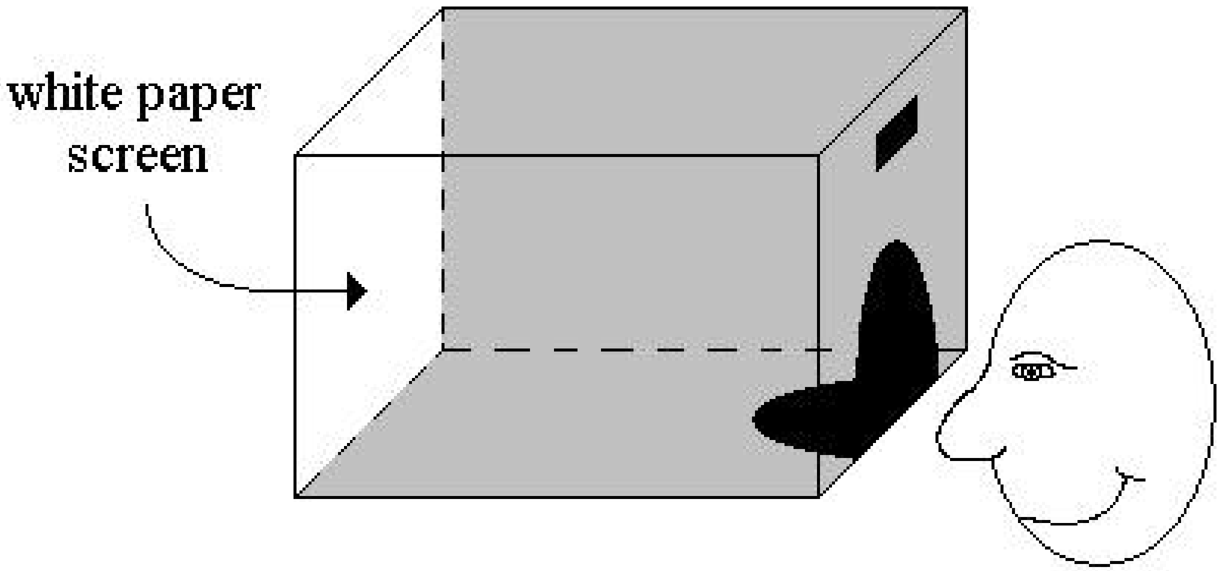
The arrangement of the electrons in atoms determine the chemical properties of substances. If you bite down on a Wint-O-Green lifesaver in the dark, you will see a brief flash of light. Pass out some Wint-O-Green lifesavers to the class so they can take the lifesavers home to crush in a dark room with a pair of pliers. (Putting the candy in a sandwich bag will produce less of a mess and prevent pieces from the cracked lifesavers from flying into the children's eyes.) Explain that in cracking the candy, you are changing how the electrons in the candy's atoms are arranged. This jiggling of the electrons produces the light. (More precisely, if an electron in an atom falls from a higher to a lower orbit, the electron loses energy. The energy lost by the electron is carried away from the atom in the form of light.)

Some substances fluoresce --- emit visible light --- when they are exposed to ultraviolet light. (Ultraviolet light has a slightly shorted wavelength than visible light.) The electrons in the atoms of the fluorescing substance absorbs the energy of the ultraviolet light, and when the electrons lose this energy they emit visible light. Some stores carry ultraviolet light bulbs or lamps, and you can show the class examples of fluorescent rocks (which can be found in any rock shop) and fluorescent chalk. Water will fluoresce when it is dropped on the branch of a horse chestnut tree (with the outer bark removed). Newly cut grass that has been soaked overnight in alcohol will create a green chlorophyl solution that fluoresces a red color. Water with quinine in it (such as Schwepp's Tonic Water) will fluoresce a ghostly blue. And clothes washed in a detergent that has a brightening agent will fluoresce a blue color. (In the daylight, this makes the clothes appear whiter!)

A projection box is a fun activity. Make a projection box as shown on the next page. Go outside and put the upper part of your head in the box. (You may want to put a towel around your neck and adjust the towel to prevent light from leaking into the box.) After your eyes have become adjusted to the dark, you will see the outside world projected onto the paper at the end of the box!

A pinhole camera is an alternative to a projection box. Instructions are given on the page after the projection box instructions. (It is easier to make than the projection box, but doesn't work nearly as well!)

INSTRUCTIONS FOR PROJECTION BOX



1. Tape white paper to the inside left end of the box to make a screen.

2. Carefully tape up the box to make it light-tight, covering all holes.

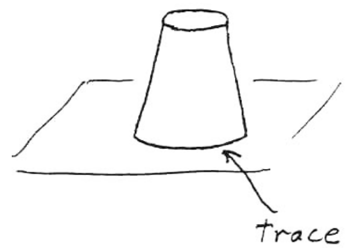
3. Cut a hole large enough to admit the upper part of your head in the right-end and bottom of the box.

4. Cut a small hole (a few centimeters across) above the head hole in the right end of the box.

5. Tape a piece of aluminum foil over the small hole.

6. Poke a VERY SMALL hole in the aluminum foil (you can always enlarge it).

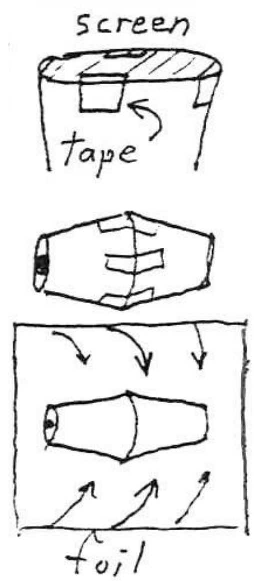
A SIMPLE PINHOLE CAMERA



Materials: two foam insulated cups (8.5 fl oz)
wrapping tissue paper
sheet of aluminum foil (1 foot long)
scotch tape and scissors

1. Put a cup upside down on the tissue paper, and use a pencil to trace around the mouth of the cup. Carefully cut out the circle of tissue paper. This will be the screen for your camera. For better results, paint the cups black inside or line them with black paper.

2. Cut a hole about the size of a nickel in the center of the bottom of each cup. (It doesn't have to be neat and round.)



3. Tape the screen over the mouth of one of the cups. Use tape only at the edges of the screen, not all the way across.

4. Tape the mouths of the two cups together, so the screen is where the wide ends of the cups are joined.

5. To make your camera light-tight, roll it up in the aluminum foil sheet. At the ends, fold the aluminum foil over in just one direction, so there is just one thickness of foil covering the hole at the bottom of each cup.

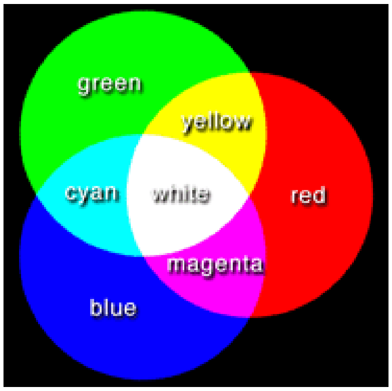
6. Cut a hole about the size of a nickel in the center of the bottom of *one* end. This will be the viewport, the end you look through. Be sure that the foil around the edge of the viewport is folded back, so it can't harm your eye. Look through the viewport to be sure that it is dark inside the cup, with no holes in the aluminum foil to let light leak through. (You may have to shade the viewport with you hand to keep light from entering though the viewport.)

7. Carefully use the fine point of a pin, pen, or pencil to poke a *small* hole (about 1 millimeter across) in the other end of your camera. You can always make a hole bigger, but it is hard to make it smaller!

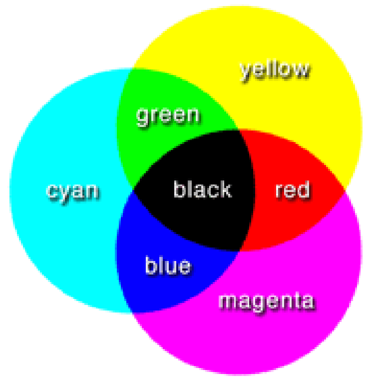
8. Take your camera outside and look through the viewport. You should see an image of the outside world on the screen. The image can be made brighter by slightly enlarging the pinhole, but the image will not be focused as well. *Never point the camera (or any other optical instrument) directly at the Sun!*

13. Color Mixing

Additive Color Mixing



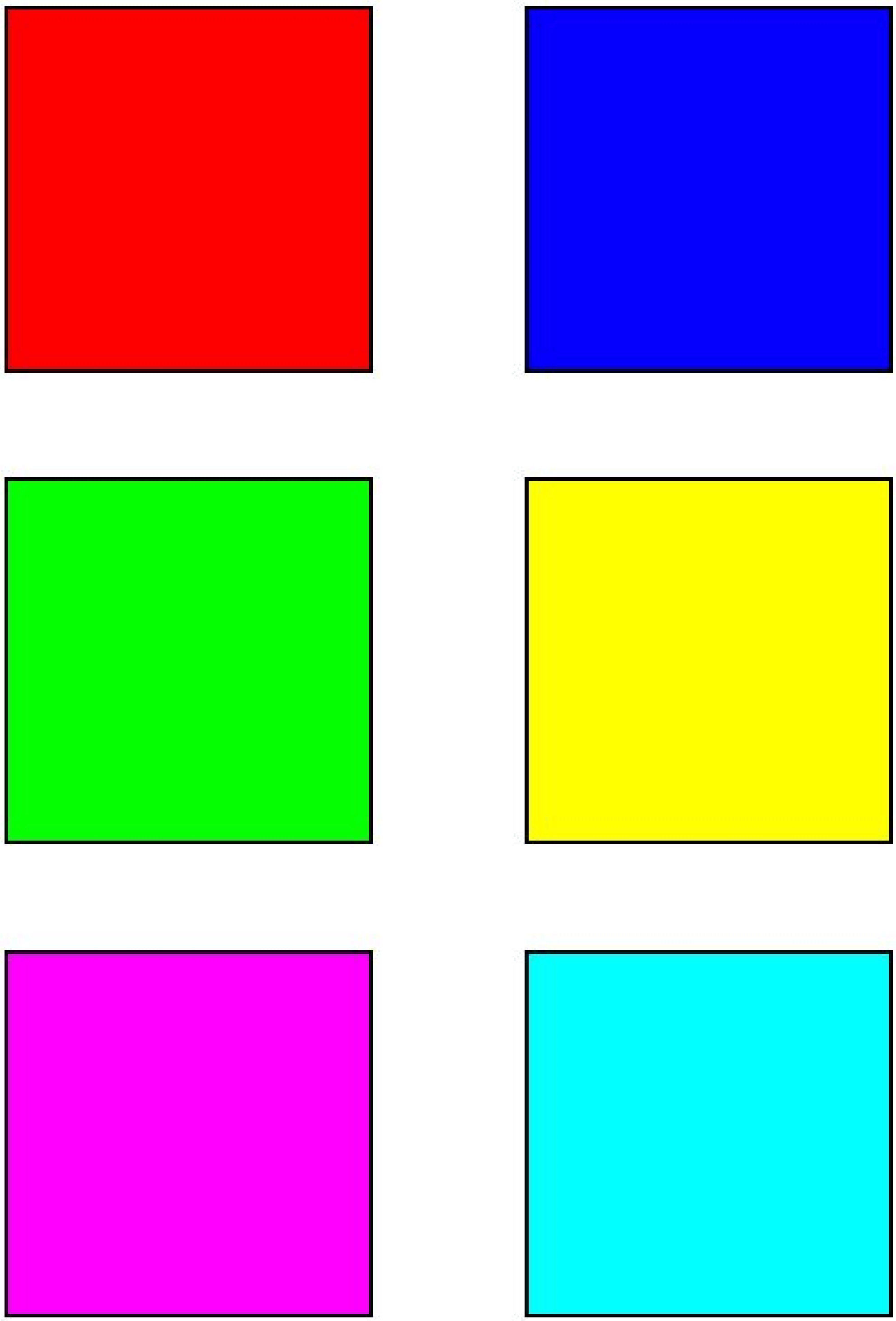
Subtractive Color Mixing



To show subtractive color mixing (like when mixing paints or using an inkjet printer), find three color filters: cyan, yellow, and magenta. You can order these from a science supply store, like Edmunds Scientific on the web, or you can try to find some transparent colored objects like report covers and wrapping paper. You could even try printing the color squares on the next page on a transparency using an inkjet printer! (You may have to print the squares twice and overlay them to get the colors deep enough.) On an overhead projector, show that cyan + yellow = green, cyan + magenta = blue, and magenta + yellow = red. If you can find a paint set with these color, let the students draw something with a pencil and then paint it using only cyan, yellow, and magenta.

To show additive color mixing (like your TV), find three color filters: blue, green, or red. Place these three filters on an overhead projector, and shine the projector toward the side of the room, away from the screen. Use mirrors to reflect the blue and green light toward the screen, and show that blue + green = cyan. The screen reflects both of these colors to your eye, and you see cyan. In the same way, show that green + red = yellow, and that red + blue = magenta.

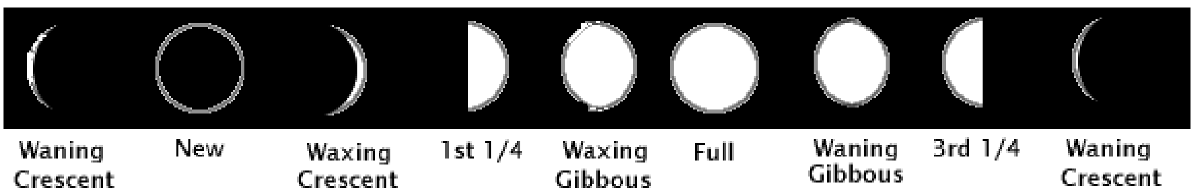
Find three pieces of cloth: red, blue, and green. Select three students to hold these pieces of cloth in front of the class. Explain that you see the colors red, blue, and green because the white light from the room lights contain all the colors of the rainbow. The red cloth absorbs all of these colors except red; the cloth reflects the red light to your eye. The blue cloth absorbs all of these colors except blue; the cloth reflects the blue light to your eye. The green cloth absorbs all of these colors except green; the cloth reflects the green light to your eye. Now put a deep blue filter over a flashlight and turn off the room lights. Shine the blue flashlight on the cloth, and ask the students what colors they see now for the pieces of cloth. Explain that the blue light contains no red or green light (if the blue filter is a deep blue), so the red and green cloth don't look the same. In fact, they should look black because they aren't reflecting any of the blue light. (Your results may vary according to how effective the flashlight filter is and what your pieces of cloth are. Don't use any shiny material for the cloth.)



14. Astronomy

To show the phases of the moon all you need is a a bright bare lightbulb and a styrofoam ball stuck on a stick or pencil. (It is nice if the ball is spray-painted gray, but not necessary.) the only light in the room is that produced by the bulb. The bulb represents the Sun, the ball is the moon, and your head is Earth.

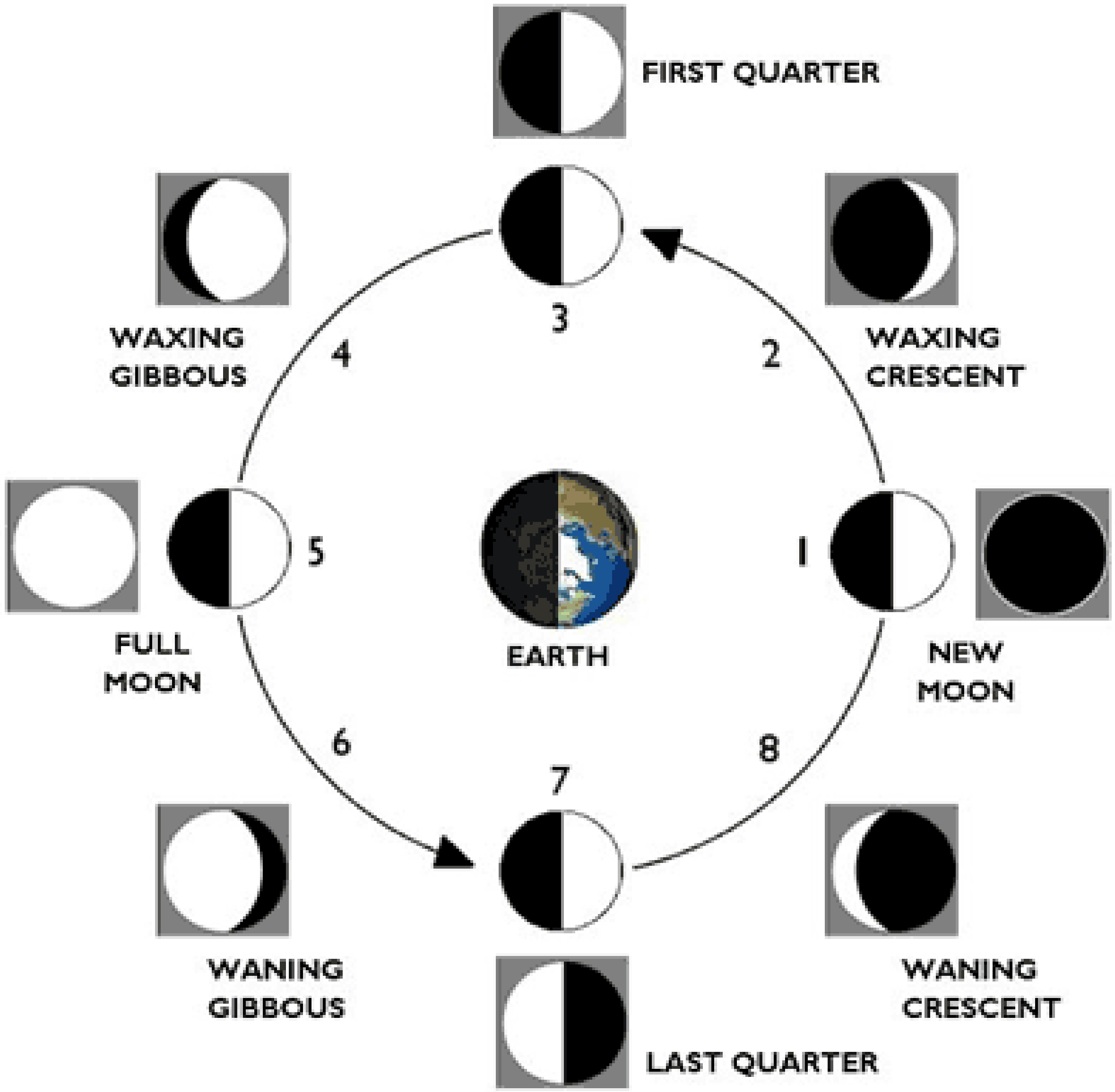
To begin with, don't use the styrofoam ball. Imagine that your nose be Mt. Ogden and that the north pole is at the top of your head. Then the United States' east coast is toward your left cheek, and the west coast is toward your right cheek. Turn around counter-clockwise, to your left, several times. Notice that the Sun (bulb) is first seen by your left eye as it rises in the east, and that the Sun (bulb) is last seen by your right eye as it sets in the west. You have just demonstrated that Earth rotates toward the east, causing the Sun and planets and stars to appear to rise in the east and set in the west every day.



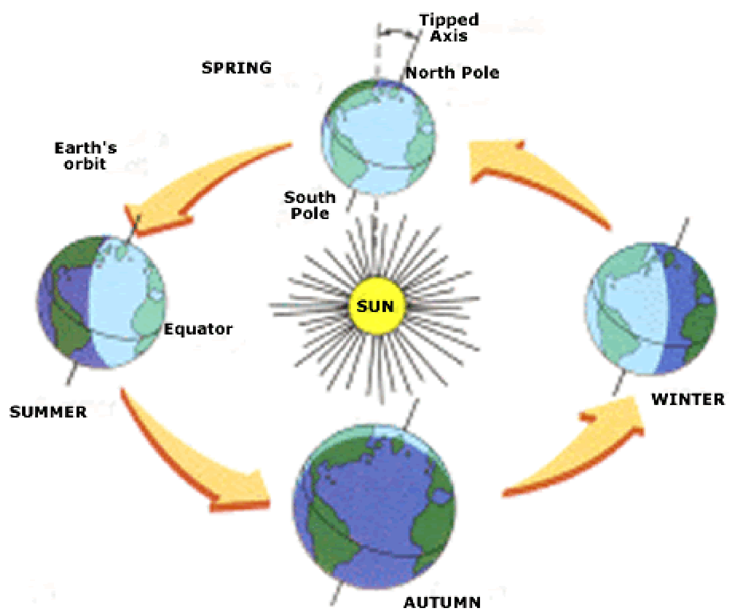
Now hold the moon (ball) slightly straight up in front of you, and lift it up so it is a bit higher than your head. If you face the Sun (bulb), you will see that the side of the moon facing you (Earth) is completely in shadow. This is the **new moon** phase. The Sun (bulb) is directly in front of you, and your nose (Mt. Ogden) points right at the Sun. That means the Sun is in the middle of the sky, so it is 12 noon. The new moon is overhead at 12 noon.

Now turn 1/4 turn (90 degrees) to your left, keeping the moon straight out in front of you. You can just see the Sun with your right eye, so the Sun is setting in the west. It is 6 pm. Looking at the moon, you see that it is half lit, on its right side. This is the **first quarter** phase. the first quarter moon is overhead at 6 pm. Turn another 1/4 turn (90 degrees) to your left. Now the Sun is directly behind you, and it is 12 midnight. Looking at the moon, you see it is completely lit, the **full moon** phase. The full moon is overhead at midnight. Turn another 1/4 turn (90 degrees) to your left. You can just see the Sun with your left eye, so the Sun is rising in the east. It is 6 am. Looking at the moon, you see that it is half lit, on its left side. this is the **third quarter** phase. The third quarter moon is overhead at 6 am. And another 1/4 turn takes us back to the new moon. The actual time between full moons is 29.5 days, a little more than four weeks. Thus, for example, there is about a week from new moon to first quarter. Each night, at a specific time, the moon moves eastward against the background stars.

The diagram on the next page shows the phases of the moon.


FIRST QUARTER
WAXING GIBBOUS
WAXING CRESCENT
3
4
2
5
1
FULL MOON
EARTH
NEW MOON
6
8
7
WANING GIBBOUS
WANING CRESCENT
LAST QUARTER

Why is it hot in Ogden during the summer? Earth is tilted by 23 degrees on its axis (see the diagram on the next page). If Earth were not tilted, the Sun would always shine directly down on the equator, and there would be no seasons. During the summer, Earth is tilted toward the Sun. This means that the northern hemisphere gets more sunshine than the southern hemisphere, so the days are longer during the summer. That mean's more hours of sunshine for heating. Also, the sunlight is striking the ground in Ogden more directly (more nearly perpendicular to the ground) in summer, when the northern hemisphere is tilted toward the Sun. To see this, get a cardboard tube about 6 inches long (or make one out of heavy paper), and fill it with uncooked spaghetti. The spaghetti represents the Sun's rays. Hold out your hand, and let the spaghetti tube fall vertically on your hand (as the sunlight does when the Sun is high in the sky in summer). Look at the end of the spaghetti tube, and notice the end area that the sunshine is spread over. Now let the spaghetti tube hit your hand at an angle, as the sunlight does when the Sun is low in the sky in winter. Look at the end of the spaghetti tube, and notice that the end area is now much larger. In summer, the Sun's rays are spread over a lot less land area, making the heating by the Sun more efficient. That is why it is hot during the summer in Ogden.



As Earth moves around the Sun, you see the Sun in front of 13 different constellations. Twelve of these constellations make up the zodiac; for historical reasons, Ophiuchus is not included in the zodiac. Make signs for the 13 constellations, give them to 13 students, and arrange them in a big circle so the constellations are in the correct order going counterclockwise around the circle. Choose another student to be the Sun, and place her in the center of the circle. You be Earth (holding an Earth globe) and move around the Sun counterclockwise inside the constellation circle. When the Sun lines up with a constellation, ask the class, "What constellation is the Sun in now." They will answer whatever constellation the Sun is lined up with. Point out that different constellations are hidden by the bright daytime sky at certain times of the year, while others are visible in Earth's nighttime on the side of Earth facing away from the Sun.

The Astronomically Correct Signs of the Zodiac

Jan 19	Sun leaves Sagittarius, enters Capricornus
Feb 16	Sun leaves Capricornus, enters Aquarius
Mar 12	Sun leaves Aquarius, enters Pisces
Apr 19	Sun leaves Pisces, enters Aries
May 14	Sun leaves Aries, enters Taurus
June 21	Sun leaves Taurus, enters Gemini
July 21	Sun leaves Gemini, enters Cancer
Aug 10	Sun leaves Cancer, enters Leo
Sept 17	Sun leaves Leo, enters Virgo
Oct 31	Sun leaves Virgo, enters Libra
Nov 23	Sun leaves Libra, enters Scorpius
Nov 30	Sun leaves Scorpius, enters Ophiuchus*
Dec 18	Sun leaves Ophiuchus, enters Sagittarius

* The Sun actually travels through 13 constellations during the course of a year.

Some Science Activity References for Physics:

From Dover Books (oldies but goodies):

Science Projects for Young People, by George Barr

Physics Experiments for Children, by Muriel Mandell

Electricity Experiments for Children, by Gabriel Reuben

Science Experiments & Amusements for Children, by Charles Vivian

From Usborne Publishing (available from Scholastic Books):

The Usborne Big Book of Science Experiments

Usborne Science and Experiments: Our World

Usborne Science and Experiments: The Power of Nature

From McGraw-Hill:

Teaching Physics with Toys, by Beverley A. P. Taylor, James Poth, and Dwight J. Portman

From the American Association of Physics Teachers (maybe a bit advanced, but still contain some ideas for elementary teachers):

String and Sticky Tape Experiments, by R. D. Edge

A Potpourri of Physics Teaching Ideas, by Donna A. Berry (ed)

From John Wiley & Sons, Inc. (not activities, but good explanations):

How the World Works: The Physics of Everyday Life, by Louis A. Bloomfield

From Chicago Review Press:

Exploring the Sky, by Richard Moeschl - astronomy activities for young children

These all contain good ideas, some more than others. The best source of teaching activities comes from talking with your fellow teachers and going to meetings!

A Selection of Interesting Websites — (active as of December 2, 2007)

http://www.goenc.org/ — Eisenhower National Clearinghouse

http://www.scilinks.org/ — SciLinks

http://books.nap.edu/catalog.php?record_id=4962 — National Science Education Standards from National Academy Press (many of their books are available free online at http://www.nap.edu/)

http://whyfiles.org/ — The Why Files: Science Behind the News

http://crux.astr.ua.edu/4000WS/4000WS.html — 4000 Years of Women in Science

http://physics.weber.edu/carroll/personal/EQUITYH.HTM — *Nine Steps to Achieving Gender Equity in Science Classrooms* from Brown University

http://www.eskimo.com/~billb/amasci.html — Amateur Science

http://scienceclub.org/ — The Science Club

http://www.nsf.gov/dir/index.jsp?org=EHR — National Science Foundation: Education

http://www.sciencenetlinks.com/ — Science NetLinks from the American Association for the Advancement of Science

http://howthingswork.virginia.edu/ — How Things Work

http://content.scholastic.com/browse/article.jsp?id=3615 — Physics on the Playground

http://www.nyelabs.com — Bill Nye The Science Guy's Nye Labs

http://www.nsrconline.org/ — National Science Resource Center

http://www.astrosociety.org/education/publications/tnl/tnl.html — sign up for a free subscription to *Universe in the Classroom* for K-12 teachers

http://www.earthsky.org/teachers/ — *Earth and Sky* Teachers Center

http://www.skymaps.com/ — free sky maps every month