106 Lab Module Contents

Soap Bubbles and Films

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 Bubble wands
- ☐ 8 Plastic framework kits
- ☐ 1 set: instructor prototypes
- ☐ 8 eye droppers

Shared Components:

- ☐ 8 plastic cups for tap water
- ☐ 8 plastic buckets of soapy water
- ☐ 8 blues trays
- ☐ Paper towels

Optional add-on:

- ☐ 8 pieces wire for shaped wands

Optional demonstrations at instructor's request:

- ☐ Giant bubble wand (Klutz)
- ☐ 2A10.30 - Surface Tension Measurements - Joly Balance
- ☐ 2A10.50 - Pressure within a Bubble
- ☐ 2A15.10 - Soap Films, Ring and Thread
- ☐ 6D30.20 - Soap Film Interference

Other additions:

Special notes for instructor:

Instructor Outline: **Soap Bubbles and Surface Tension**

Lab length: 50-55 minutes
Lab objective: Instruct the students about surface tension, minimal surfaces geometry, surfactants, film thickness, reflection.

This is generally the first lab of the semester so it is brief to allow for introductions and overview.

Materials

Cup of tap water
Soap-water bucket & wand
Plastic framework kit
Soap-bubble handout
Blue tray
Paper towels

Exploration stage: 20 minutes – group lab-work
The students blow soap bubbles and characterize the properties of bubbles and soap film. They observe some examples of surface tension in the form of water drops.

Analysis stage: 10 minutes – lecture
The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on surface tension, minimal surfaces, surfactants, and thin films.

Application stage: 20-25 minutes – group lab-work
The students build specific geometric shapes and analyze the fundamental surfaces they create when dipped in soapy water. They create the “2 rules about bubbles:” 3 points intersect with a point; 4 points intersect with a line. They repeat their observations to see if they can disprove these laws with an exception. They also puncture one surface and observe if the resulting surface maintains minimal surface.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Surface tension causes soap films to occupy the minimal surface possible.
2. Surfactant properties and their ability to enhance the bubble forming properties of water by preventing evaporation and reducing the powerful surface tension of pure water.
3. “Laws” are rules of behavior in nature based on observation. They remain laws until an exception is observed (and reproduced for verification). The students test this method with the “bubble laws.”
4. Thin films produce arrays of colors because of reflection and interference.

Suggested Demonstrations:

Giant Bubble with Klutz wand
2A10.30 - Surface Tension Measurements - Joly Balance (ST4)
2A10.50 - Pressure within a Bubble (ST2)
2A15.10 - Soap Films, Ring and Thread (ST6)
6D30.20 - Soap Film Interference

Supplemental Tasks (time permitting)

- Wet Parallel Plates – The students use the suction discs to create points between the plates. When the plates are submerged in soapy water, **minimal surface** planes form between the suction points.

- Soap Film – There is an opportunity for more instruction on **thin films**.

- Building shapes with wire can cause time over-runs and was omitted. Here is the question:

    - Make a wire frame with the provided wire and predict what shape the soap film will take. When you repeatedly dip the frame, does the shape repeat exactly each time? Explain why or why not.

SOAP BUBBLES AND SURFACE TENSION

ANALYSIS

Rules Guiding Bubbles

There are a few simple properties of fluids that guide the formation of soap bubbles. Surface tension is what keeps the surface smooth and creates a minimal surface (defined below). The soap optimizes the fluid for bubble formation.

Surface Tension

Surface tension is the property of fluids to maintain an intact surface. Molecules within fluids attract one another. If you measure that attraction at most points in the fluid it is equal in all directions because the area is completely surrounded by water. But there is an exception at the surface where the attraction is in the direction of the water contained within. This attraction towards the liquid results in the fluid seeking the smallest possible surface area, a minimal surface. This phenomenon only works on small scales or in an environment of zero gravity because at larger scales in the presence of gravity the effects of weight overwhelm the effects of surface tension. See diagrams below for a graphic of the fluids attraction.

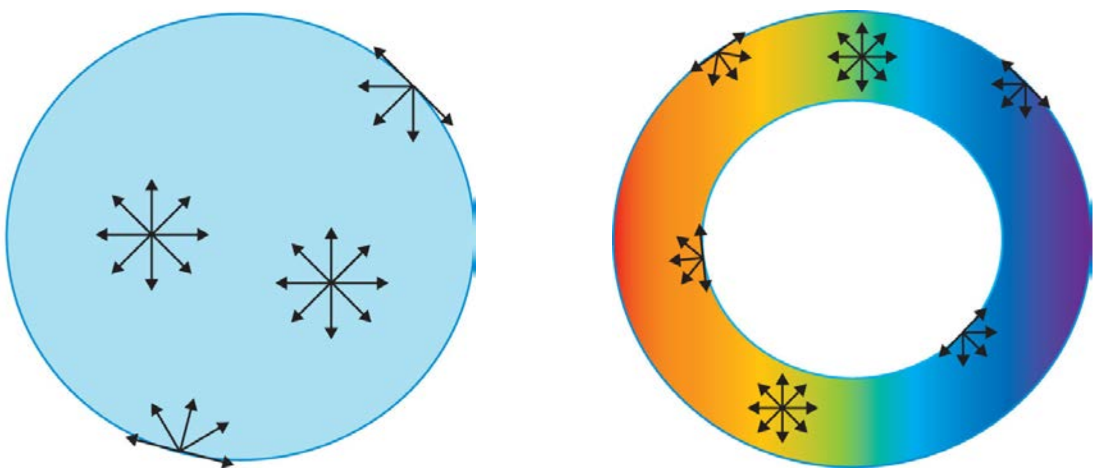


Figure 1: The cross-section of a water drop and a soap bubble. The soap bubble wall thickness is actually much smaller than shown, but was enlarged here to demonstrate the surface tension due to the attraction of the fluid molecules to one another. The shorter arrows in the soap bubble indicate reduced surface tension.

What you should observe about the bubble is that the outer surface has a surface tension that pulls it in AND the inner surface has a surface tension that pulls it out. This creates a stable minimal surface (a sphere).

Minimal Surfaces

A minimal surface is the smallest possible surface containing a given volume (such as trapped air). For a 3-Dimensional volume, that surface is a sphere. For a 2-Dimensional volume, that surface (or perimeter) is a circle. A cube has a volume to surface area ratio of 1:6. A sphere has a volume to surface area ration of 1:4.84. The sphere uses much less surface area to enclose a given volume than a cube does.

Soap
Soap optimizes the properties of water for the creation of bubbles. Soap is a surfactant (the name is derived from "surface active agent") which means that the soap molecule has a hydrophilic (water-loving) end and a hydrophobic (water-hating) end. Because of this property soap molecules seek the surface of the water. The repelled end sticks out of the water, and the attracted end is oriented toward the enclosed water, forming an interface layer on the water. In occupying space on the surface, the soap reduces the surface tension of the water. This is a good thing for bubbles because the surface tension of pure water is too strong to support a bubble shape for long. Moreover, soap is good because it resists evaporation, which is another bubble killer for pure water.

Soap cleans by forming micelles. Micelles are little pods of grease surrounded by soap molecules. When these micelles form, it is easy for the water to wash the clusters away from a dirty dish or pot.

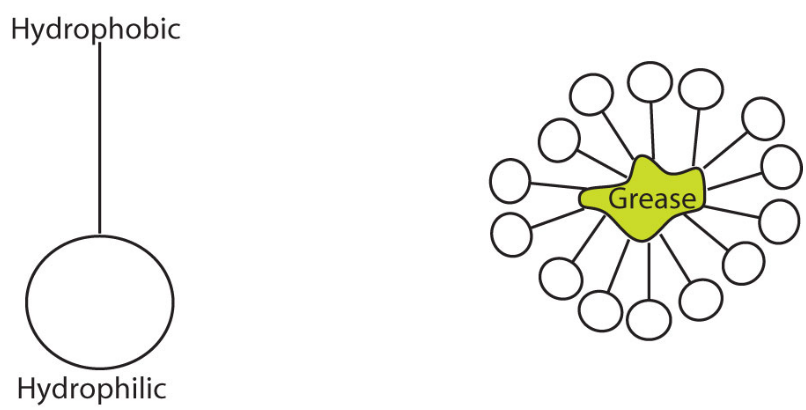


Figure 2: Surfactant with hydrophilic and hydrophobic ends, and a micelle of surfactants and grease.

Soap Films

When one observes a soap film, one can see an array of vibrant colors. The thin soap film has many colors while a large volume of soapy water (like that in your bucket) does not.

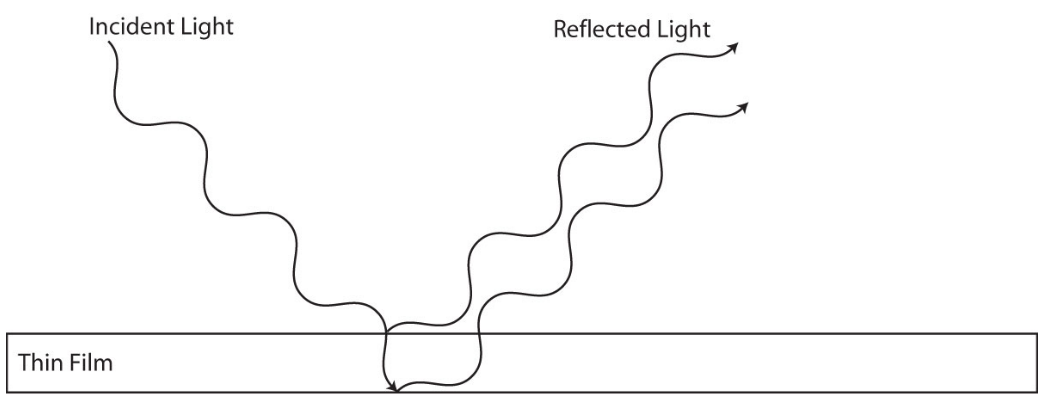


Figure 3: Film thickness and reflected light

This is because of how films reflect light. When the light hits the film it is reflected at two surfaces, the top and the bottom of the film. The two reflected beams interfere with each other and create a new beam. That beam is a combination that depends on the thickness of the film and has a color. As the thickness of the film changes by a little amount, the color of the film changes.

SOAP BUBBLES AND FILMS

Pre-Lab Question

What makes soap bubbles stay intact?

EXPLORATION

Materials

Cup of tap water
Eye-Dropper
Soap-water bucket & wand
Blue tray (to reduce the mess)
Paper towels

1. Use a bubble wand and the soap bubble solution to blow a bubble. Observe the bubble and record all your observations. Include observations about shape and motion.

2. Dip your bubble wand in the solution again. Observe the film in the ring, and record all your observations. Is the film stationary, or does it change with time. List any other materials that have similar properties as soap films?

3. Dip your bubble wand in tap water. Observe the film and record your observations. How is this different from the soap film? What conclusions can you draw about these two liquids (tap water and soap-water)?

4. Use the eye-dropper to put a single drop of pure water on the table. Then place a drop of soapy water on the table near the water drop. Observe and compare each drops characteristics. Record your observations.

5. How does soap make clothes clean?

6. Which has a higher surface tension, soapy water or pure water? Which of your observations from exploration experiments confirms this?

Everyday Applications

- Engineers used to use soap films to map out minimal surfaces of complex structures because it was faster and more accurate than hand calculations of the geometry (now computers are used).
- Minimal surface technology is used by many industries to optimize packaging for product shipment.

APPLICATION

Materials

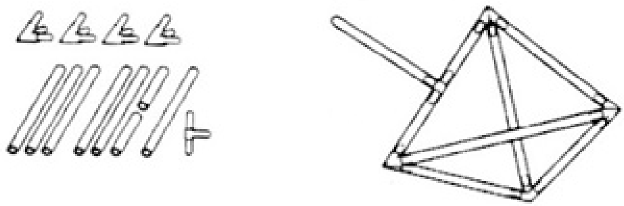
Soap-water bucket & wand
Plastic framework kit
Soap-bubble handout

1. Use the plastic framework kit to build some geometric shapes as shown on the next page: an octahedron and a cube. Dip the shapes in the soap water to make the fundamental surfaces. Extra challenge: Build the tetrahedron.

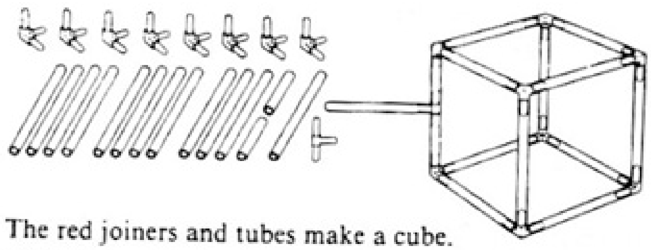
2. Puncture one of the film surfaces of the fundamental surface of the octahedron and the cube. Draw and describe the resulting surface. Explain why the shape has taken that form.

3. What rules or common features exist in all of the films that you have observed (the 2 “bubble laws”)?

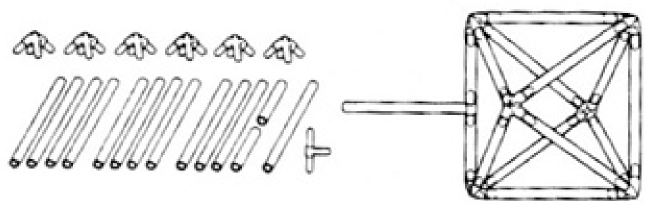
Assembly of the plastic frameworks



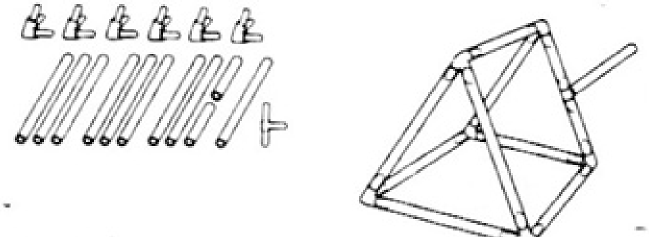
The grey joiners and tubes make a tetrahedron.



The red joiners and tubes make a cube.
White joiner for handle.



The green joiners and tubes make an octahedron.



The blue joiners and tubes make a prism.

Challenge Work (to complete if you have spare time):

1. Can you make trapped bubble structures with the geometric models you've built?

2. Explain how air bubbles form underwater in terms of surface tension.

3. Can you stick your finger through the film without popping it?

Summary

Final Clean-up

Please clean all table surfaces you used and return equipment to the carts. Do not dispose of the bubble solution (it may be used by another section). Please dismantle the geometric figures you built and return the pieces to the appropriate boxes and trays.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Soap bubble," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Soap_bubble&oldid=51628581 (accessed May 10, 2006).

Wikipedia contributors, "Surface tension," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Surface_tension&oldid=50947302 (accessed May 10, 2006).

Hipschman, Ron, "Bubbles," *Exploratorium Website,* http://www.exploratorium.edu/ronh/bubbles/bubbles.html (accessed May 10, 2006).

Isenberg, Cyril. 1974. *Soap Film Experiments with Kubic Bubbles*. Oxford: Cochranes of Oxford.

Surface Tension and Density

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 bent forks
- ☐ 8 paper clips
- ☐ 8 Petri dishes
- ☐ 8 pieces wire for water-bugs
- ☐ 8 brass blocks
- ☐ 8 aluminum blocks
- ☐ 8 wood blocks
- ☐ 8 Teflon rods
- ☐ 8 wood rods

Shared Components:

- ☐ 8 plastic rulers
- ☐ 8 cups soapy water
- ☐ 8 graduated cylinder
- ☐ 8 scales
- ☐ Paper towels

Optional demonstrations at instructor's request:

- ☐ 2A10.20 - Floating Dense Objects on Water

Other additions:

Special notes for instructor:

Instructor Outline: **Surface Tension and Density**

Lab length: 60-80 minutes

Lab objective: Instruct the students about mass, volume, density, quantitative measurements, and surface tension.

Materials

3 blocks (brass, aluminum, wood)
2 cylinders (wood, teflon)
1 scale
1 ruler
1 graduated cylinder
Fine wire
1 paper clip
1 bent fork
2 Petri dishes
Plastic ruler
Soapy Water

Exploration stage: 20-30 minutes – group lab-work

The students make some observations about surface tension, and observe that the cohesion of surface tension can exceed the force of dense objects to sink.

Analysis stage: 10 minutes – lecture

The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on surface tension. One successful analogy is comparing the surface tension at the surface to the membrane of a balloon.

Application stage: 30-40 minutes – group lab-work

They build water bugs that float. They measure the mass and dimensions of some materials. They calculate volume, and then density of these objects, and then test their buoyancy in Dennison water.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed, and a good opportunity to explain the Cartesian diver correctly. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Density is the ratio of mass to volume.
2. Surface tension is a powerful force.

Suggested Demonstrations:

2A10.20 - Floating Dense Objects on Water (ST5)

Supplemental Tasks (time permitting)

Meniscus observations and theory – The students can be instructed on the surface tension as it relates to the meniscus of fluids.

There is also an aluminum cylinder available, but can cause the lab to run over in time.

SURFACE TENSION AND DENSITY

ANALYSIS

Surface Tension
Consult the Analysis section of the Soap Bubbles and Surface Tension lab. The extension that we explore here is simply that surface tension not only creates a force to keep water in and intact, the force adheres to keep some surfaces out.

Density
Density is the ratio of mass to volume of a uniform material. It is independent of the shape of the object or the scale of the object (large or small).

The density of an object depends on its composite parts. A hollow metal ball may float in water even though the density of metal is greater than water because there is air in the ball. If there are holes in the ball, it will sink because water can displace the air, and the metal will be the only relevant density.

SURFACE TENSION AND DENSITY

EXPLORATION

Materials

1 ruler
1 graduated cylinder
Fine wire
1 paper clip
1 bent fork
2 Petri dishes
Plastic ruler

1. a) Pour water into a Petri dish as full as possible. How far **over** the rim can you go before it overflows? Draw a picture of the shape.

b) Why does the water go over the rim without spilling?

2. a) Prediction: Paper-clips are made out of steel. Will a paper-clip float or sink in water? Explain your reasoning.

b) Place a paper-clip in the water by lowering it onto the surface with the bent fork. Does this agree with your prediction? Explain your observations. Sometimes the paper clip will perform better if it is somewhat greasy, consider rubbing it with your fingers or on your forehead or nose.

Challenge Work:

1. Float a few paper clips in a Petri dish with tap water and observe the interactions between them. Also observe how they interact with the dish walls. Record your observations and conclusions below.

2. Will the paper clip sink if it is wet before it is placed in the Petri dish? Explain your prediction, test with a wet paper clip, and then compare your findings with your prediction.

Everyday Applications

- The most famous use of a density measurement was done by Archimedes (290-210 B.C.). He was hired by the king to verify that a gold crown he'd commissioned had not been substituted in part by less valuable (and less dense) silver. However, the crown was very expensive and Archimedes could not melt the crown to ascertain its volume. While stepping into a bath he observed the change in water level, and realized he could do a volume displacement measurement. In his excitement, he ran through the streets yelling "Eureka! Eureka!"
- Product manufacturers (in industries such a food, beauty, and health) use density measurements to verify consistency among products. They measure the density of product from different batches to make sure that there is consistency.

APPLICATION

Materials

1 graduated cylinder
Fine wire
2 Petri dishes
Plastic ruler
1 calculator

3 blocks (1 each: brass, aluminum, wood)
2 cylinders (1 each: wood, teflon)
1 scale
1 ruler
Soapy Water

1. Create a floating wire water bug. Explore the success and failure of different types of models to float on the water. We suggest making two so that there are more prototypes to experiment with in the group. Make a drawing of a successful water bug. Discuss with your group which parameters make the water bug float or sink and record.

2. While floating a successful water bug, add a drop of soap with your finger onto the surface of the pure water. Place the drop on the far side of the Petri dish from the bug. Observe what happens. Discuss with your group what you've observed and record your conclusions about what happened.

3. Properties of Matter

The periodic table organizes elements by the number of protons in each atom, and that is a precise way of identifying atoms. However, we live in the large scale world and counting the number of protons in atoms is not an easy way to identify something. Most materials are a complex combination of different elements, and the efficient and commonly used method for identifying unknown materials is by observing color, texture, and density.

Density is the ratio of mass to volume of a uniform material. You are going to calculate the density of some common materials and compare the densities.

Objects float or sink in water depending on their relative density to water. Fresh water has density of about $1 g/cm^3$. Predict which blocks and cylinders will float or sink in Dennison water, then test your predictions.

	Float or Sink (Prediction)	Float or Sink (Observation)
Brass Cube		
Aluminum Cube		
Wood Cube		
Wood Cylinder		
Teflon Cylinder		

Explain your predictions and observations.

4a. Measure the dimensions of the blocks using your ruler (use cm):

	Brass	Aluminum	Wood
Length (l)			
Width (w)			
Height (h)			

4b. Measure the dimensions of the cylinders (use cm):

	Wood	Teflon
Height (h)		
Diameter (d)		

5.

- Measure the **mass** (weight) of the blocks and cylinders in g with the scales.

- Calculate the **volume** of the blocks and the cylinders.
  The volume of a block is: $V = h \times l \times w$
- The volume of a cylinder is the area of the base times the height:
  $$V = \frac{1}{4} \times \pi \times (diameter)^2 \times l$$

- **Density** (d) is defined as the ratio of mass (m) to volume (v): $d = \frac{m}{V}$

  Calculate the density of each block and cylinder from your mass and volume findings.

	Mass (in grams)	Volume (in cm^3)	Density (in g/ cm^3)
Brass Cube			
Aluminum Cube			
Wood Cube			
Wood Cylinder			
Teflon Cylinder			

Challenge Work:

1. Which is denser: a 10 lb. bag of feathers or a 10 lb. bag of lead?

2. Calculate the density of water in Dennison. Use the graduated cylinder. First measure the cylinder alone, then measure the cylinder with some amount of water in it (preferably at an evenly round number e.g. 10mL). Subtract the mass of the cylinder from the cylinder with water in it to find the mass of the water. Milliliters are a unit of volume, 1 mL = 1 cubic centimeter. Calculate the density of Dennison water.

4. Some redwood trees on the coast of Northern California grow to a height of 122 m (367 ft) and a diameter of 7 m (22 ft). If one of these massive trees fell into the water, would it float or sink?

Summary

Final Clean-up
Please clean all table surfaces you used and return equipment to the carts. Please dry individual pieces that may be wet and dispose of water in the sink.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Density," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Density&oldid=53475076 (accessed May 18, 2006).

National Park Service, “About the Trees,” *NPS* http://www.nps.gov/redw/trees.html (accessed May 18, 2006).

Air Pressure and Water Flow

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- ☐ 8 large suction cups
- ☐ 8 medium suction cups
- ☐ 8 small suction cups
- ☐ 8 eye-droppers
- ☐ 8 lengths of transparent tube
- ☐ 8 plastic coke bottles
- ☐ 8 plastic plates
- ☐ Dyed packets

Shared Components:

- ☐ 8 buckets
- ☐ 8 yellow spring scales
- ☐ 8 rulers
- ☐ 8 calculators
- ☐ 8 cups soapy water

Optional demonstrations at instructor's request:

- ☐ 2B20.40 - Equilibrium Tubes
- ☐ 2B30.15 - Pop Can Collapse
- ☐ 2B30.30 - Magdeburg Hemispheres
- ☐ 2B30.u1 - Glass of Water and Card

Other additions:

Special notes for instructor:

Instructor Outline: **Air Pressure and Water Flow**

Lab length: 70-90 minutes
Lab objective: Instruct the students about pressure, suction, siphoning, hydrostatics, how straws work, and surface level equilibrium.

Materials

3 suction cups (different sizes)
Several flexible transparent tubes
2 buckets of water
1 plastic coke bottle
1 eyedropper
1 spring scale
1 plastic plate with string
1 ruler
1 calculator
Soapy water

Exploration stage: 20-30 minutes – group lab-work
The students observe the suction power of suction cups. They then quantitatively measure the pressure. The students observe equilibrium levels of fluids.

Analysis stage: 20 minutes – lecture
The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on pressure and hydrostatics (pressure dependent on depth). The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Application stage: 20-30 minutes – group lab-work
The students make some observations about equilibrium levels when one end of a tube is covered. They explore the fundamentals of siphoning, then build a Cartesian diver and have to explain the effects they observe.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed, and a good opportunity to explain the Cartesian diver correctly. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Air Pressure can exert extremely powerful forces, remember the large suction cup forced down simply by ambient air pressure.
2. Pressure in fluids depends only on the height of the water column, not on mass or volume.
3. Creating a pressure differential is a powerful tool (as with a siphon)

<u>Suggested Demonstrations:</u>

2B20.40 - Equilibrium Tubes
2B30.15 - Pop Can Collapse
2B30.30 - Magdeburg Hemispheres
2B30.u1 - Glass of Water and Card

Challenge Questions:

1. Air pressure is measured as pounds per square inch (psi) in the US (because we don't use the metric system). Ground level air pressure on Earth is about 15 psi. The air pressure in outer space is about 0 psi. When you measure the air pressure in a tire with a blow out gauge, it tells you pressure difference, not the absolute pressure. Most tractor tires are pressurized to 12 psi. If you were to slingshot a tractor tire into outer space, what pressure would the blow-out gauge read?

AIR PRESSURE AND WATER FLOW

ANALYSIS

<u>Suction Cups</u>

When a suction cup is pressed to a smooth surface two things happen.

First, the air is evacuated from the concave chamber. Once most of the air is evacuated, there is air pressure disequilibrium. The ambient air pressure is greater than the pressure inside the chamber and therefore exerts a force on the suction cup.

Second, the force exerted by the greater ambient air pressure presses the cup onto the surface, forming a hermetic seal (impenetrable to air). A hermetic seal does not allow air to pass between the inner chamber and the ambient, so the disequilibrium does not correct itself.

This is why the suction is successful.

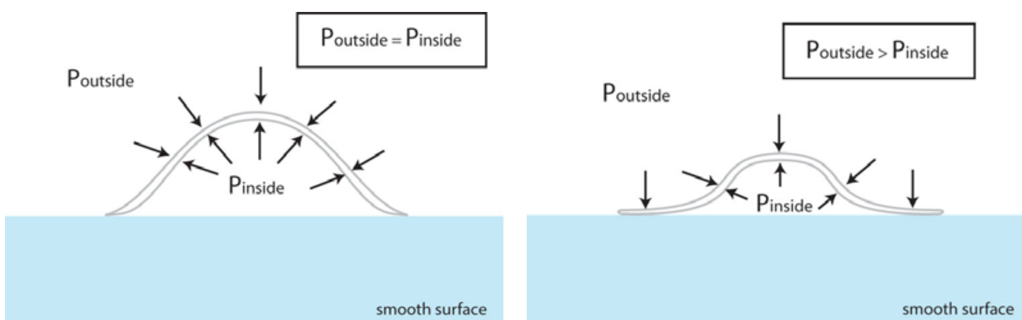


Figure 1: The left figure is the suction cup before being pressed. The inside and outside pressures are the same, so the cup can be easily removed. The right figure is the suction cup after being pressed. The inside and outside pressures are not the same, and so the cup has suction to the surface.

If a person wants to remove a suction cup from a smooth surface they must pull with a force greater than the pressure difference between the chamber and the ambient air.

Force (F) is equal to pressure (p) multiplied by the area (A):

$$F = p \times A$$

This means that as the area increases, the force increases. That is why with a larger suction cup, the force you needed to pull it off was greater than with a smaller suction cup.

Hydrostatics (Pressure in Liquids)

Gas is compressible and expandable which means that the same number of molecules can occupy a large or small volume. Liquids do not work that way, they cannot be compressed in an observable way.

Pressure is equal to Force divided by Area:

$$p = \frac{F}{A}$$

We know that force at a certain depth is equal to mass times gravity:

$$F = mass \times gravity$$

In the density lab we saw that:

$d = \frac{m}{V}$ which easily converts to $m = d \times V = d \times A \times h$

So we know that mass is equal to the density times the height and the area (the volume). The force is equal to the mass multiplied by the area so:

$$F = density \times area \times height \times gravity$$

With this equation we can solve for pressure:

$$p = \frac{density \times area \times height \times gravity}{area}$$

The conclusion from this work is that pressure is independent of the volume and the mass of the fluid; it only depends on the density and the height (because gravity is constant).

In other words: The only feature that determines pressure is height of a water column.

The result of this is that the pressure gradient (the pressure difference from top to bottom) of a gallon of water depends on its container. If you pour a gallon of water into a shallow bathtub the pressure gradient is much less than of a gallon of water in tall and narrow tube.

Surface Level Equilibrium

You observed with your U-shaped tube that the surfaces of all connected bodies of water exposed to the ambient air end up level with one another.

Now, pressure is exerted in every direction at any given point: up, down, and side-to-side. Consider what would happen if one of the columns of water were higher than the other.

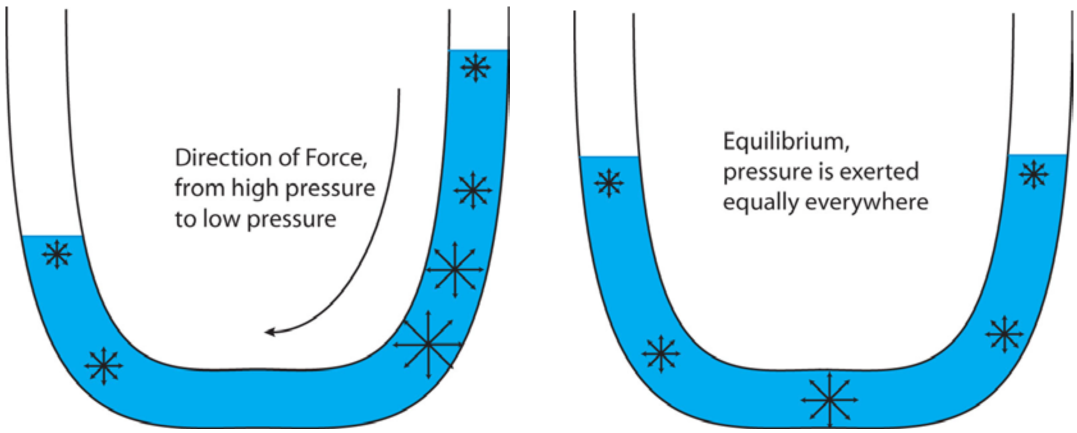


Figure 2: In this U-Tube, the pressure is shown with arrows. The arrows indicate that pressure is exerted in all directions at any given point. In the left hand figure, the right tube is exerting a greater pressure than the left, and so the water level will shift to the left. In the right hand figure, the levels are equilibrium, so pressure does not favor a direction.

Straws

Most young children master the skill of sipping on soda through a straw. Few probably know that they are mimicking suction cups. Ambient air pressure is everywhere, ready to push soda into your belly. All it needs is a little incentive, like pressure disequilibrium. Human's can create reduced pressure in their mouths, and the soda is just caught in the middle. The ambient air pushes the soda into your mouth until the pressure is at equilibrium, at which point you can repeat the process.

AIR PRESSURE AND WATER FLOW

EXPLORATION

Materials

3 suction cups (different sizes)
1 flexible transparent tube
2 buckets of water
1 spring scale
1 plastic plate with string
1 ruler
1 calculator
Soapy water
Dye packets

1. Push a dry suction cup onto the table, then pull to remove it. Repeat the experiment, but wet the cup before pushing it onto the table with soapy water. Which is harder to pull? Discuss with your group why this is and record your observations below.

2. The force required to remove the suction cups from a surface represents the difference in pressure between the inside of the suction cup and the ambient air pressure. The pressure inside a well-sealed (wet) suction cup is very low, so the force you exerted was almost exclusively counteracting the ambient air pressure.

- We can determine the magnitude of air pressure at ground level from the suction cups. Start by measuring the diameter of your smallest suction cups.

- Calculate the area of the suction cups: $A = \pi r^2$ and record. Remember: radius is half the diameter and π is roughly equal to 22/7. Measure the cavity of the cup, not the whole cup.

Suction Cup Size	Diameter (in mm)	Area (in mm^2)
Small		
Medium		

3. Take a quantitative measurement of how hard it is to pull the medium sized wet suction cup off the plastic plate. Three group members are needed. One holds the plastic plate down on the table *firmly,* providing a smooth surface. The second partner suctions the cup to the plastic plate with soapy water, and then hooks the spring scale onto the suction cup and prepares to slowly pull the suction cup off the plastic. These two group members should avert their eyes from the cup for safety. The final group member observes the mass on the spring scale from the side.

- Note the **force** on the scale in Newtons (N) right before the cup releases the plate. That force is the most the suction cup can lift.
- Calculate **pressure** given the equation: $P = \frac{F}{A}$ The desired units are m^2, so you must convert from mm^2 to m^2 (divide by 1,000,000).

Do the measurement three times for each cup to get a more precise measurement.

Small Suction Cup	Force (in Newtons):	Pressure (in Newtons/ m^2):
1st run		
2nd run		
3rd run		
average value		

Medium Suction Cup	Force (in Newtons):	Pressure (in Newtons/ m^2):
1st run		
2nd run		
3rd run		
average value		

Discuss your observations with your group. Do you observe any trends? How does surface area relate to the force you must exert to pull the suction cup?

4. Pour dye pack into a bucket of water. Form an upright U-shape with the flexible transparent tube and fill it ¾ of the way with the dyed water. Compare the height of the water in each upright part of the tube. Now change the relative water level by raising and lowering the tube ends, and bending or looping your tube. Record what shapes you try and the water levels at each attempt. What factors contribute to water level changes?

Challenge Work:

1. The large suction cup is extremely hard to pull straight off of the table. Try sliding the cup along the table and off the edge. Explain what you observe.

2. State your step 4 observations as a basic principle of water behavior.

Everyday Applications

- When dams are built, they must be reinforced at their base. You can see this feature in dams, such as this one from Australia. The angled base is strong enough to support the higher pressure at the floor of the reservoir.
- Siphons are frequently used to move massive volumes of water easily (such as in aquariums).
- Flexible tubing filled with water (just like you used today) is used by contractors to verify that a foundation is truly level.
- Siphoning is a **highly dangerous** tool used by some to steal gasoline when there are high gas prices.
- Your ears pop when you travel through elevation in planes or cars

APPLICATION

1. Take your flexible tube and fill it ¾ with water in case you emptied it. Cover or crimp one exposed end of the tube with your finger, and change the height of that end of the U. What do you observe? Are the two water surfaces level? Discuss with your group and record your explanation.

2. Fill a soda bottle from another bucket of water using a siphon. Place the source bucket on the table, and **predict** which height will fill the soda bottle more quickly (or if they will fill at the same time): if the soda bottle is on the chair or the floor. **Note: you do not need to put your lips on the tube; you can submerge the tube then cap the ends with your fingers so they are full of water.**

3. Place the soda bottle on the floor and fill it from both heights. Record the height that resulted in a faster fill time. Explain your observations.

4. Soda Bottle Diver

Fill a soda bottle full of water. Insert the air-filled eyedropper into the bottle pointed-tip down. Twist the lid on the bottle tightly making sure the bottle is still full to the brim. What happens when you squeeze the bottle? Discuss with your group what you've observed and explain the effect. (*Hint: Pay attention to the water level inside the eyedropper)

Challenge Work:

1. What would happen if the air in the eyedropper were sealed in with some putty at the tip?

Summary

Final Clean-up

Please clean all table surfaces you used and replace equipment on the carts. Empty the soda-bottle diver, and separate the pieces.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Fluid statics," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Fluid_statics&oldid=53180054 (accessed May 19, 2006).

Wikipedia contributors, "Dam," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Dam&oldid=53809203 (accessed May 19, 2006).

Pneumatics

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 16 large garbage bags
- ☐ 48 wood spacers
- ☐ 3 tape dispensers

Shared Components:

- ☐ 16 straws
- ☐ 8 calculators
- ☐ 8 rulers

Other additions:

Special notes for instructor:

Instructor Outline: **Pneumatics**

Lab length: 30-40 minutes
Lab objective: Instruct the students about pneumatics, pressure, and over pressure.

Materials

2 garbage bags
2 straws
Tape
6 wood spacers (1/4”)

Exploration stage: 10-15 minutes – group lab-work
The students build a pneumatic lift with garbage bags and two tables to lift a fellow student with their breath.

Analysis stage: 5 minutes – lecture
The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on air pressure and pneumatics.

Application stage: 10-15 minutes – group work
The students solve a worksheet problem on inflatable domed stadiums.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Pressure exerts a powerful force which scales with area.
2. Pneumatics is used to support structures.

Suggested Demonstrations:

None

PNEUMATICS

EXPLORATION

Materials

1 garbage bag
1 straw
Tape
6 wood spacers (1/4”)

1. Pneumatics is the use of pressurized gas to produce large forces, such as a lifting device. Close the opening to the bag around the straw and secure with tape. This is meant to be air tight, so test your bag for leaks by inflating a little bit, pinching the straw, and squeezing. If you hear air escaping, re-tape the straw so no air can escape. On the bottom table, place the garbage bag so it is flat and covers a large area of the table. Make certain the straw is sticking out the side you can inflate the bag.

Place the wood spacers on the table around the perimeter of the bag. Lift and invert the second table and place the table-top on top of the bottom table as shown below.

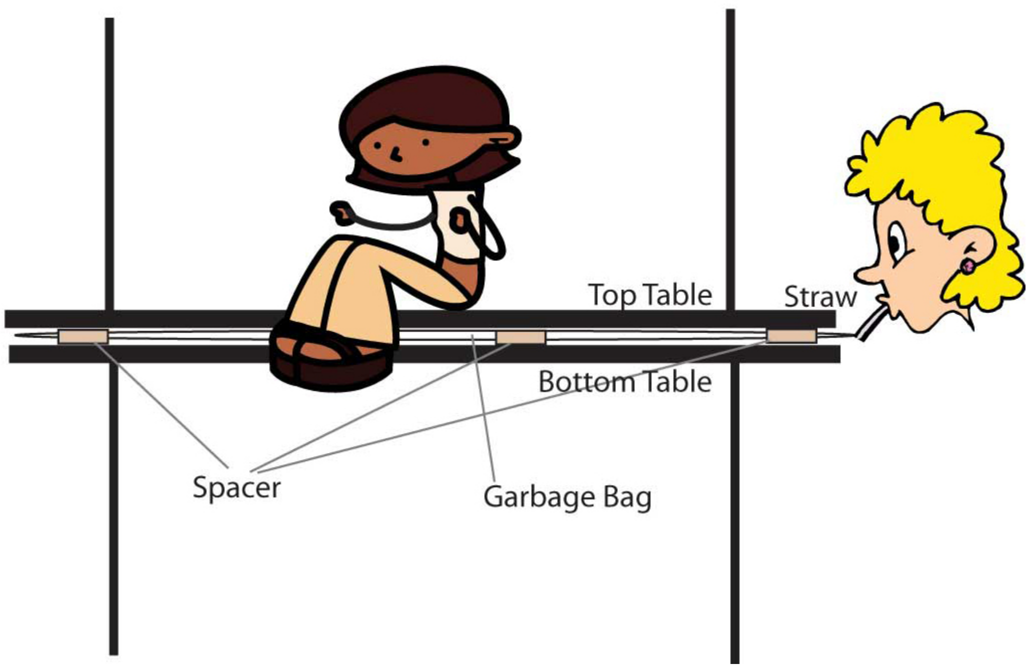


Figure 1: Pneumatic Lift Set-up

Put a chair on top of the table, and have one group member climb on top of the pneumatic lifter. Another two members are to inflate the garbage bags and see if they can lift the seated member.

Describe and explain what you observe.

Estimate the weight of the person and the table together.

Estimate the area of the garbage bag.

Given area and weight (force), what is the pressure inside the bag? Pressure is measured in pounds-per-square-inch (psi).

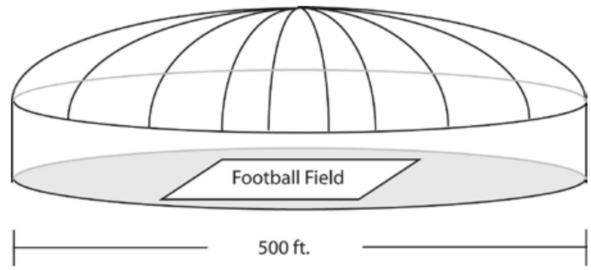
Challenge Work:

1. What would be the advantage of using a large bag?

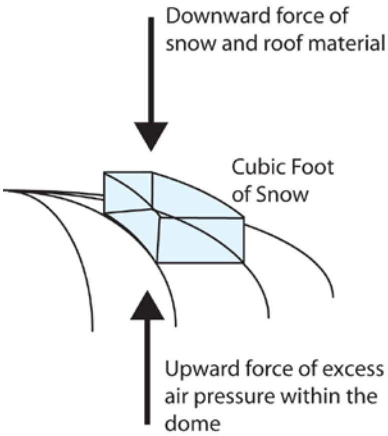
Everyday Applications

- Pneumatic brakes are sometimes used on roller coasters. The momentum of the car can only compress so much air before the forces are equal, but the transition is gentle compared to the jarring of friction brakes.
- Inflatable domed stadiums and structures.

APPLICATION



Inflatable domed stadiums are made of fabric to protect athletes from the elements during sporting events. Sometimes the "elements" means snow, so how does a layer of fabric support its own weight and the weight of the snow?



Engineers utilized concepts from pneumatics to support the weight of the roof. While the weight of the snow and the roofing material exert a downward force that would otherwise make the roof collapse, creating an over-pressure inside the dome can counteract the downward force.

Calculate the over pressure (above and beyond atmospheric pressure) required in the dome to support the weight of the roof with snow on it. Then calculate what percent of ambient air pressure that is.

Given:
1 cubic ft. of snow = 30 lbs.
1 sq. ft. of roof = 20 lbs.
Ambient air pressure = 15 psi lbs/in^2 = 2200 lbs/ft^2
Surface Area of a Sphere = $4\pi r^2$

Compare that to the pressure produced in the trash bags to lift your partners.

Challenge Work:
1. How much snow can the inflated dome support?

Static Electricity

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 Teflon rods
- ☐ 8 strips of fur
- ☐ 1 spool thread
- ☐ 8 empty soda cans
- ☐ 8 combs
- ☐ 8 ring stands
- ☐ 8 watch glasses
- ☐ optional: 8 nylon rods
- ☐ optional: 8 strips of silk

Shared/Consumable Components:

- ☐ 32 Hershey kisses
- ☐ 8 pairs of scissors
- ☐ 8 rulers (plastic)
- ☐ 8 solid Al cylinder (Density lab)

Optional demonstrations at instructor's request:

- ☐ 5A50.30 - Van de Graaff Generator
- ☐ 5B10.10 - Van de Graaff Hair
- ☐ 5B30.35 - Lightning Effects with Discharge Sphere
- ☐ 5A10.10 - Rods, Fur, Silk, and Piezo
- ☐ 5A20.20 - Pith Balls
- ☐ 5A22.22 - Mechanical Electrometers

Other additions:

Special notes for instructor:

Static Electricity

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 Teflon rods
- ☐ 8 strips of fur
- ☐ 1 spool thread
- ☐ 8 empty soda cans
- ☐ 8 combs
- ☐ 8 ring stands
- ☐ 8 watch glasses
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- ☐ 5A10.10 - Rods, Fur, Silk, and Piezo
- ☐ 5A20.20 - Pith Balls
- ☐ 5A22.22 - Mechanical Electrometers

Other additions:

Special notes for instructor:

Instructor Outline: **Static Electricity**

Lab length: 75-90 minutes
Lab objective: Instruct the students about static electricity. Concepts include: net charge, induction, charge transfer, Coulomb's law.

Materials

1 ring stand with arm
4 foot length of thread
2 pieces of packing peanuts
2-4 Hershey kisses (one for each group member)
1 Teflon bar
1 rubbing fur
1 rubbing cloth
1 pair scissors
1 empty soda can
1 aluminum cylinder
3 balloons

Exploration stage: 30-40 minutes – group lab-work

The students build pith balls. They charge a Teflon rod negatively and transfer charge to the pith balls. They observe repulsion in that scenario. The students then observe induction by bringing the rod near a neutral pith ball.

Analysis stage: 15-20 minutes – lecture

The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on charged particles, friction and electronegativity, conduction, attraction and repulsion, and induction. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Application stage: 20 minutes – group lab-work

The students make some observations about induction in conductors, and also observe the scale at which the force created by the rod fails.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed, and a good opportunity to explain induction with conductors. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Electrostatics is a very present and powerful force.
2. Charge can be built up from the friction between two materials with appropriate electronegativity.
3. Opposite charges attract toward the end of charge equilibrium.
4. Like charges repel.
5. Charge transfers with contact between charged materials.
6. Neutral conductors can be attracted to charged objects because charges are free to move inside the conductor.

Suggested Demonstrations:

5A50.30 - Van de Graff Generator (ES8)
5B10.10 - Van de Graff Hair (ES9)
5B30.35 - Lightning Effects with Discharge Sphere (ES9)
5A10.10 - Rods, Fur, Silk, and Piezo (ES1)
5A20.20 - Pith Balls (ES9)
5A22.22 - Mechanical Electrometers (ES3)

Notes on Difficult Concepts:

- Students didn't understand where in the rod or ball the charge was.

STATIC ELECTRICITY

ANALYSIS

On a dry day, many hapless individuals feel the shock of static electricity after traversing a carpet and touching a door-knob. The circumstances that precede such an event are exactly what Ben Franklin first used to observe and differentiate electric charge.

<u>Charged Particles</u>

All elements are a balance of charged particles: positively charged protons and negatively charged electrons. When the particles are present in equal numbers, the system has no net charge. When there is more of one type of charge (either electrons or protons), then the net charge is either positive or negative.

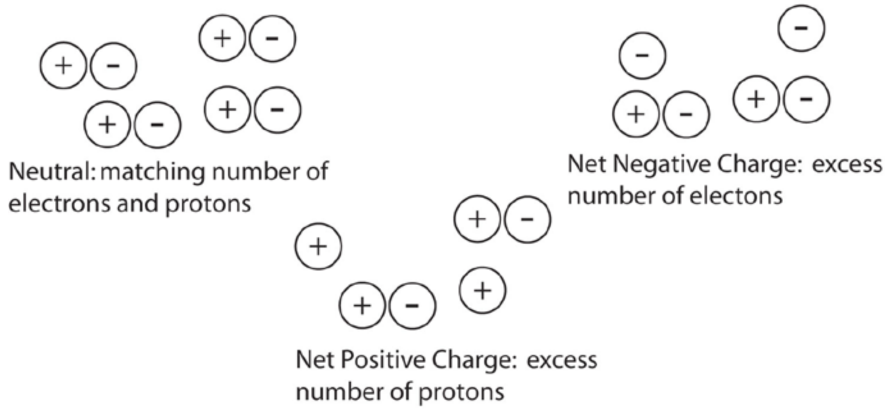


Figure 1: Net charges

When there is a net charge of either positive or negative, the system strongly wants to return to equilibrium. That strong desire can produce a spark. This is the phenomenon that causes lightning bolts. Storm clouds build charge disequilibrium until finally the electric fields are strong enough to force electrons onto the earth in a bolt of lightning.

<u>Friction</u>

From chemistry we learn that elements have electronegativity. This means that some elements are willing to surrender electrons, and others want to capture electrons. This transfer of electrons between these two types of material can be aided by rubbing the materials together. We did this intentionally by rubbing the Teflon and the fur; many people do it unintentionally when they rub their shoes across a carpeted floor or their clothes across a car seat.

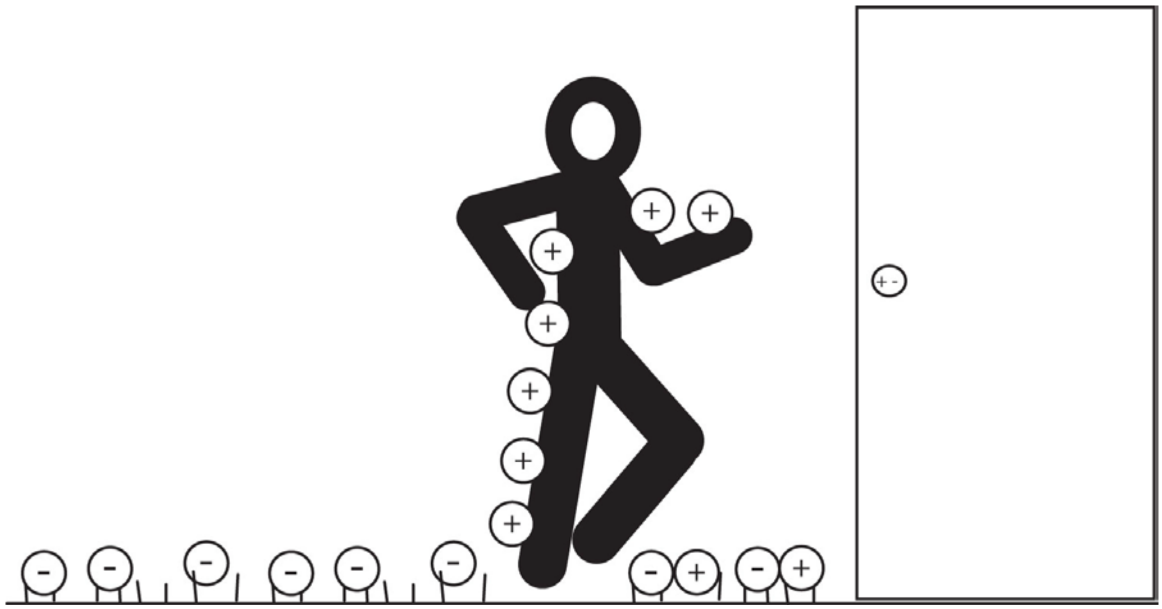


Figure 2: Static charge build-up on person just before touching the conducting door-knob.

Conduction

Charge passes from one material to another when the two materials are in contact. This phenomenon is called conduction. When a person walks across a carpet with their excess charge toward a conducting door, the excess charge passes between the two in the form of a spark.

Materials are classified in two ways: **conductors** pass charge readily, and **insulators** resist passing charge.

Conductors spread excess charge evenly when they come in contact. Silver foil wrappers for Hershey kisses are conductors; this is why when you touch the charged rod to the pith ball charge is transferred. They were in contact, and the charge could readily move on the conductor. When the two pith balls touch, the charged one is able to conduct charge to the other ball.

Insulators resist the transfer of charge, and do not spread it evenly.

Attraction and Repulsion

Once charge has transferred to a pith ball, it has the same charge as the rod. In step 2 you observed that the rod and the ball repelled each other. In step 3 you observed the two pith balls and the rod with shared charge repel each other. Like charges repel.

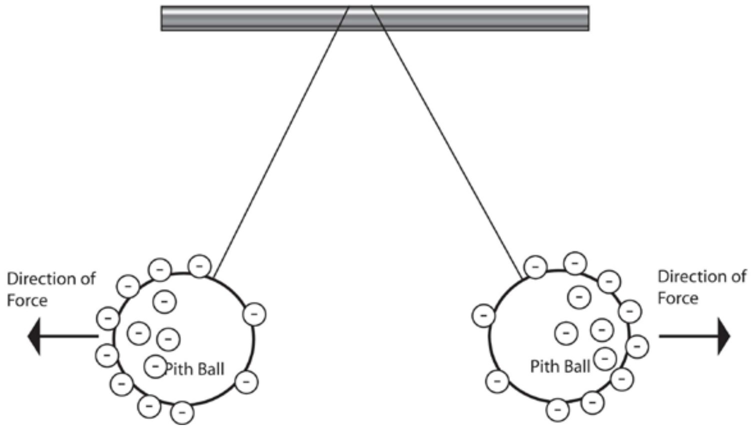


Figure 3: Excess negative charge repelling pith balls

The electronegativity of Teflon can harness excess electrons, creating a net negative charge. Negative charges repel, so the balls and rod repel from one another.

Other materials are unlike Teflon in that they are inclined to forfeit electrons, thus creating a net positive charge. When a positively charged rod comes into contact with a pith ball conductor, the rod takes electrons from the conductor and leaves behind a net positive charge. Positively charged objects attract negatively charged objects to transfer electrons so both can return to equilibrium.

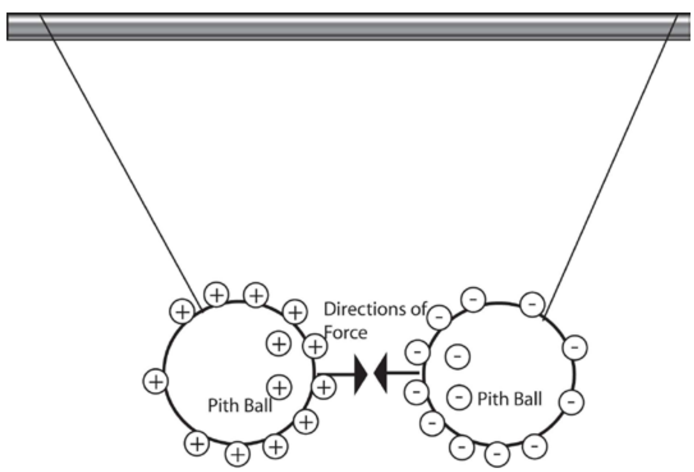


Figure 4: Opposite charges attracting

Induction

In step 4 you observed a neutral pith ball react to a charged rod. From what we've observed, electric attraction is felt between opposite charges, so why does the ball attract?

Charges are free to move inside conductors. They can shift from one side of the conductor to another in the presence of an excess of charges. This shifting allows a "neutral" conductor to be attracted to a nearby charged object, as shown in Fig. 6.

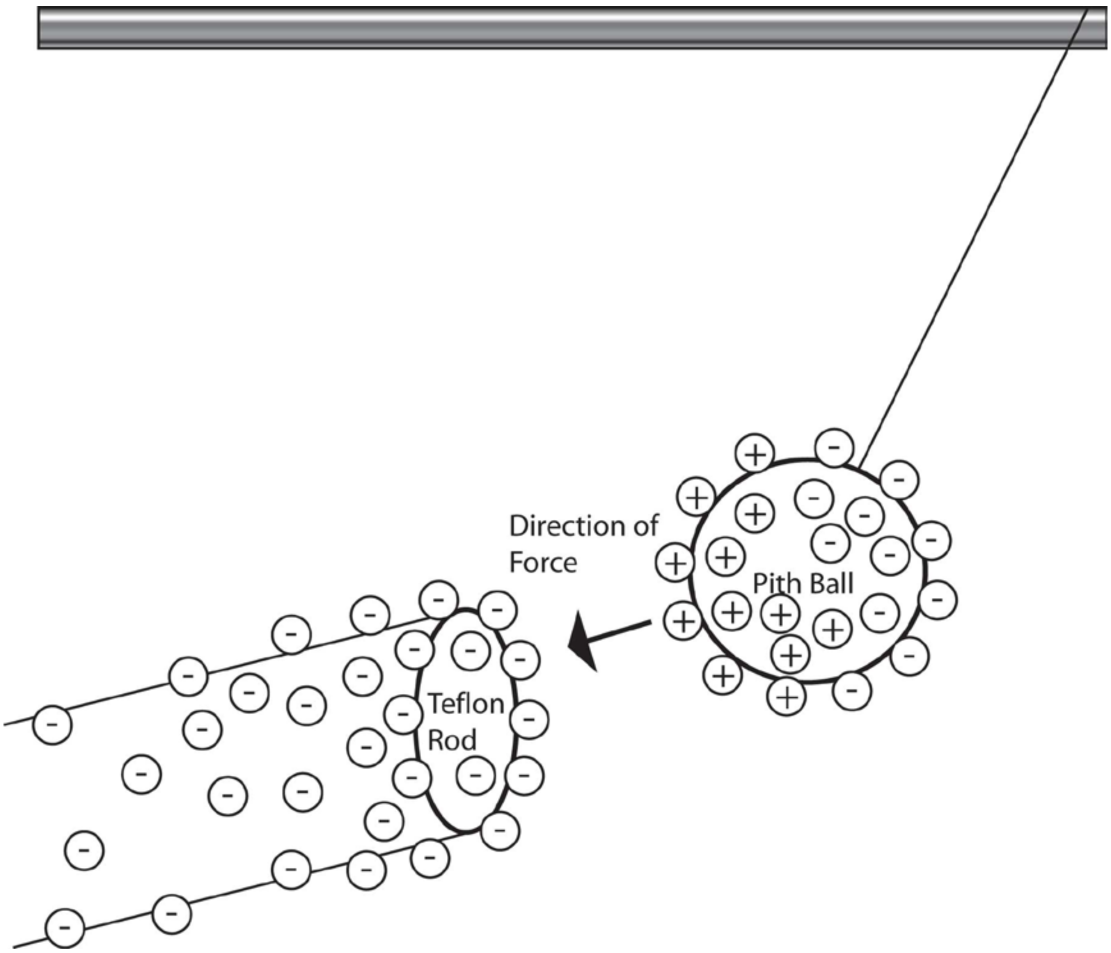


Figure 5: Rod attracting "neutral" conductor that is polarized by the nearby charge

STATIC ELECTRICITY

Pre-Lab Questions

What is electricity?

What is a spark?

EXPLORATION

Materials

1 ring stand with arm
4 foot length of thread
2 pieces of packing peanuts
2-4 Hershey kisses (one for each group member)
1 Teflon rod
1 Nylon rod
1 rubbing fur
1 rubbing cloth

1. Suspend two pith balls from the ring stand. To build the pith balls, start by eating two candy kisses. Salvage the silver foil, and smooth it on the table. Tear the packing peanut into two equal pieces (should be ball shaped, about ½" in diameter). Suspend each foam piece from the ring stand arm with about 12" of thread. Finally, carefully wrap the silver foil around each foam piece. Keep the wrappers as smooth and wrinkle-free as possible. Compare your work to the prototype in the front of the lab or to the figure below.

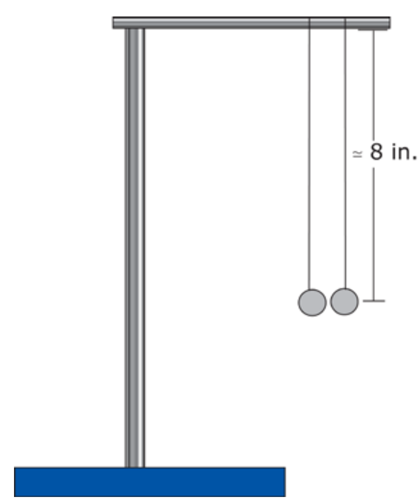


Figure 1: Pith Balls on Ring Stand

2. Start with one pith ball on the ring stand (remove the other and reserve for later). Rub the white Teflon rod with the fur until you get a nice crackling sound. When you rub the Teflon with the fur, you are scraping electrons off the fur and onto the rod, making it charged. Once you've charged the rod, touch it to the pith ball. Rub the rod a second time, and then slowly bring it near the pith ball. Observe how the ball and rod interact and record if they attract, repel, or are neutral toward one another. Discuss with your group what this means. Do they both have charge now?

Note: On humid days (rainy or damp) electrostatics observations from friction are more difficult. You can improve performance by rubbing the rod vigorously.

Touch the pith ball with your hand to "ground" it for the next step.

3. a) Mount the second pith ball on the ring stand very near to the first so the two balls are at the same level. When you rub the white Teflon rod with fur, **predict** what will happen to both pith balls when you touch the rod to one of the pith balls based on your findings in step 2. Will the balls be attracted, repelled, or neutral toward one another? Record your prediction below.

b) Rub the rod with fur and bring it in toward one pith pall along the same line as the two balls. Touch the rod to one pith ball, observe what happens, and record. Discuss with your group if the pith balls are charged or not, and if they have the same charge. From your observations, how is charge passed between the rod and pith ball, and the two pith balls?

4. a) Predict what will happen if you bring the charged rod to the pith balls again now that they are charged.

b) Rub the rod again, and bring it near the two pith balls. How do the balls react to the rod (attracted, repelled, or neutral)?

Touch both pith balls with your hand to “ground” them for the next step.

5. Remove one pith ball and rub the Teflon rod until crackling. Bring the rod near the lone pith ball, but do not allow the two to touch. What happens? You recently “grounded” the pith ball, does it have charge now that it is near the rod and if so how? Does this agree with what you just concluded about how charge passes?

Challenge Work:

Rub the *nylon* rod with the silk and touch it to a neutral pith ball. Bring the nylon rod near the pith ball and record what happens. Now rub the Teflon rod with fur and bring it near the charged pith balls (but don’t allow it to touch). What happens? Does the nylon produce the same type of charge as the Teflon? How can you tell?

Everyday Applications

- Lightning storms
- Makes televisions dusty
- Keeps pollen on bees legs for transport

APPLICATION

Materials

1 Teflon bar
1 rubbing fur
1 empty soda can
1 aluminum cylinder
1 plastic ruler
1 watch glass (concave glass disc)

1. Place the soda can on its side on the wooden table. Charge your Teflon rod with your fur and bring it near (but not touching) the side the can. What happens? Can you explain what is happening in the can?

Is the can a conductor? What is the can made of?

2. Place the solid aluminum cylinder on the table so it can roll. Charge the Teflon rod and bring it near (but not touching) the cylinder. What happens? Is this the same or different from the can, how?

3. Balance the ruler on the watch glass dome so it can spin freely on the glass and put it near the edge of the table. **Predict** what will happen when you bring the charged Teflon rod near the *plastic* ruler.

Charge the Teflon rod and bring it near the ruler. Explain what you observe and compare the ruler to the can.

Challenge Work:

1. Sometimes after the pith ball is charged, it comes into contact with the ring stand. What happens? Why?

2. Would these experiments work if we'd used copper wire instead of thread?

3. When you rub the Teflon rod you can hear crackling. Sparks passing through air generate a lot of heat, which causes the air around it to expand. That expansion is noisy. Name the large scale analog of this related to lightening.

4. Why does touching pith balls ground them? What happens?

Summary:

Final Clean-up

Please remove and discard the pith balls you built and replace the other equipment to the carts.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Electrostatics," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Electrostatics&oldid=54828058 (accessed May 24, 2006).

Batteries

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 beaker set-ups
  - 2 beakers
  - Cu/Zn bars
  - Cu & Zn U-bar
  - 2 plastic spacers
- ☐ Paper towel strips
- ☐ Cu/Zn strips

Shared/Consumable Components:

- ☐ 8 multimeters
- ☐ 8 “servings” of coke
- ☐ 8 special calculators
- ☐ 16 alligator leads
- ☐ paper towels
- ☐ Sandpaper
- ☐ Blue trays
- ☐ Scissors

Optional demonstrations at instructor’s request:

- ☐ 5A50.30 - Van de Graaff Generator & components
- ☐ 5E20.10 - Electrolysis of Water
- ☐ 5E40.25 - Lemon Battery
- ☐ Dissected Batteries

Other additions:

Special notes for instructor:

Instructor Outline: **Batteries**

Lab length: 75-90 minutes
Lab objective: Instruct the students about batteries, electrolytes, anodes, cathodes, voltage, current, resistance, and use of a multimeter.

Materials

2 plastic beakers
2 metal bars (1 Cu, 1 Zn)
1 U-bar, Cu & Zn
Stack of Cu & Zn strips
Cup of Coke (battery acid)
2 plastic spacers
1 yellow multimeter
1 calculator
4-6 blue paper strips
2 alligator leads
Paper towels
1 battery board
1 card of alligator lead
Sandpaper

**Optional Pre-Lab Demonstration: Van de Graaf generator. The VdG shows current pulses, forming a contrast with the constant current flow the students will be seeking with the batteries.

Exploration stage: 30-40 minutes – group lab-work

The students build coke batteries. They observe the role of electrolytes in a battery, and how series results in a voltage increase. The students then power a calculator with their coke battery.

Analysis stage: 15-20 minutes – lecture

The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on batteries, electrolytes, anodes, cathodes, voltage, current, and resistance. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Application stage: 20 minutes – group lab-work

The students build batteries with strips of electrolyte soaked paper. They are challenged to build a 6V battery, but 4.5V is the actual maximum we've observed.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Batteries are very simple devices; they depend on an electrolytic material, a cathode, and an anode.
2. Batteries work by displacing electrons in the battery cell and making it so they can only travel through a connected circuit to return to equilibrium.
3. Traveling electrons are current, the path they take is the resistance of the circuit, and the potential of the battery to produce electrons is the voltage.

Suggested Demonstrations:

5A50.30 - Van de Graaff Generator & components
5E20.10 - Electrolysis of Water (ME4)
5E40.25 - Lemon Battery
Dissected Batteries

BATTERIES

ANALYSIS

In the static electricity lab we saw that separated charges travel to recombine into equilibrium. The charges are separated in the first place by rubbing two materials together or by polarizing a conductor by induction. Another way to separate charges is electrochemically, and this is the principal that allows us to store electrical energy in a battery.

A battery is composed of three components: a cathode, an anode, and an electrolytic solution. See figure below.

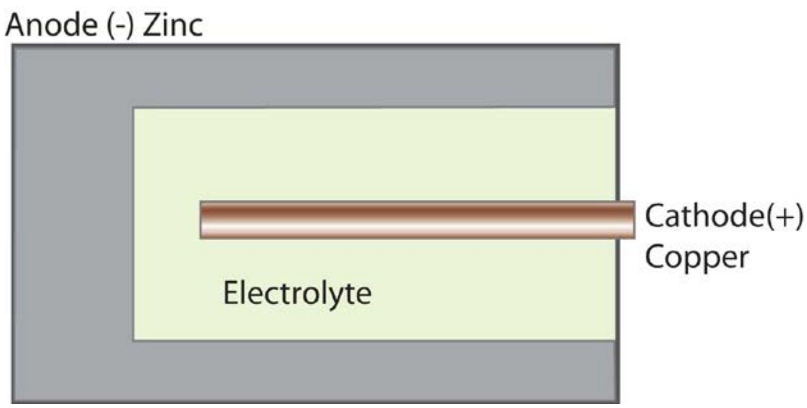


Figure 1: A simple battery

<u>Battery Acid</u>

An essential feature of a battery is the electrolytic solution that connects two electrodes. Coke, lemons, and potatoes are fun materials that can be used, but powerful acids are more commonly used for commercial purposes.

When the anode and cathode are immersed in the electrolyte, a chemical reaction takes place. The result of that reaction is a shortage of electrons on the cathode and a buildup of electrons on the anode. This charge imbalance makes the electrons want to travel from the anode to the cathode.

The elegance of a battery is that the chemistry of the electrolytic solution has a preferential current direction for a given voltage, and won't allow the electrons to flow back to the cathode within the battery. For the charge imbalance to neutralize, the current must travel through the attached electronic device. Those traveling electrons are what power your electronic device.

Traveling charges are called a **current**. The current is determined by two things.

1. The battery has a maximum **voltage** that depends on how the battery is built and how much of the battery has been used.
2. The **resistance** created by the electronic devices also controls the current.

Electrical current is much like a current of water. A pump gives elevation to the water as a battery gives voltage to a circuit. The flow of water to lower elevation is like the current of the circuit, and the constrictions in the water's path are like high resistance in a circuit.

BATTERIES

Pre-Lab Questions

How is electricity stored?

EXPLORATION

Exploration Materials

2 plastic beakers
4 metal bars
- 1 Cu, 1 Zn, 1 Cu-Zn U-bar
Cup of Coke (battery acid)
2 plastic spacers

1 yellow multimeter w/ leads
1 calculator
2 alligator leads
Paper towels (for messes)
Sandpaper

1. Build a battery cell. Place one copper (Cu) and one Zinc (Zn) bar in a beaker separated by a plastic spacer. Connect one lead from the multimeter to the Cu bar, and the other to the Zn bar as shown below. To make a good connection you can scratch the surface of the Cu and Zn with the test leads to get through the oxidation on the surface.

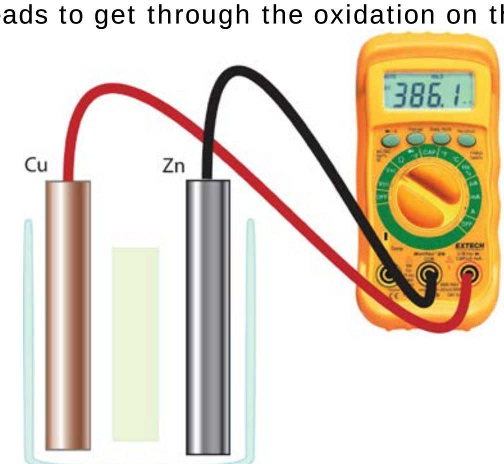


Figure 1: Cu and Zn bars in beaker connected to multimeter.

Set the multimeter switch to V_{DC} to read the DC voltage of the setup. What do you find?

2. Add a small amount of coke to the beaker (up to the first line on the beaker). Read the voltage of the system with the multimeter and record it below. Describe what the coke does to the system.

3. Predict what will happen to the voltage if you add more coke to the beaker.

Double the amount of coke in the beaker (up to the second line this time). Read the voltage with the voltmeter. Does this agree with your prediction? Explain how the quantity of coke affects the battery's voltage.

4. Now use the U-bar with the loose bars of Cu & Zn. Take the second beaker, and alternate the bars as shown below.

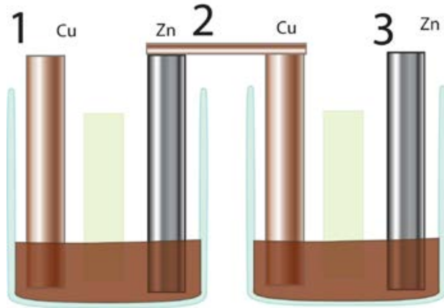


Figure 2: Two beakers connected in a row with alternating bars.

Predict what the voltage will be across two battery beakers at certain test points. Present your prediction to the GSI or instructor before measuring. After discussing you prediction, add at least an inch of coke to the new beaker. Read the voltage with the voltmeter at the different test points.

Test Points	Voltage (Predicted)	Voltage (Measured)
1 & 2		
2 & 3		
1 & 3		

Does this agree with your prediction? Explain how adding a second cell affects the battery's voltage.

Challenge Work:

1. You found different voltages with your tests in step 4. See what voltage the calculator needs to operate at. You need to make an electrical connection between the calculator and the battery, use the alligator leads to do this. They clip onto both devices and conduct electricity. Observe polarity by connecting the red lead to copper (positive charge) and the black lead to zinc (negative charge).

Record which connection points and what voltage you used to make the calculator work.

2. Try swapping one of the electrodes (Cu or Zn) with a piece of Aluminum foil (folded up a few times to make it stiffer and easier to handle). Record the voltage for a single cell containing this Aluminum electrode.

Everyday Applications

- Batteries are used everywhere. Electricity stored in batteries powers all our mobile devices. The industry sells US$48 billion annually.[1]

APPLICATION

Materials

Stack of Cu & Al 2” dia discs
Vinegar (battery acid)
1 yellow multimeter
4-6 blue paper discs
Paper towels (for messes)

1. Soak the blue paper discs with vinegar, and stack the Cu & Al correctly to create a multiple volt battery. Draw your design below (label the metal discs). Measure the voltage with the multimeter. Start with a 1-cell, then add a 2nd cell, and then build your way up.

Summary:

Final Clean-up
Please dispose of the blue discs and vinegar & Coke. Rinse the metal bars and discs in water, and then allow them to dry on paper towels. Replace the other equipment to the carts.

Bibliography and recommendations for further reading:

Brain, Marshall, "How Batteries Work," *How Stuff Works,* http://electronics.howstuffworks.com/battery.htm/printable (accessed May 25, 2006).

Energizer, "How Batteries Work," *Learning Center,* http://www.energizer.com/learning/howbatterieswork.asp (accessed May 25, 2006).

Wikipedia contributors, "Battery (electricity)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Battery_%28electricity%29&oldid=54981757 (accessed May 25, 2006).

[1] Wikipedia

Circuits

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- [ ] Flashlight bulbs
- [ ] Aluminum strips

Shared/Consumable Components:

- [ ] 8 alligator leads cards
- [ ] 8 battery boards
- [ ] 8 Multimeters
- [ ] 8 Batteries

Optional demonstrations at instructor's request:

- [ ] Flashlight

Other additions:

Special notes for instructor:

Instructor Outline: **Circuits**

Lab length: 65-85 minutes
Lab objective: Instruct the students about a complete circuit, continuous paths for electrons, measuring current and voltage to calculate power, preliminary series and parallel.

Materials

1 battery
1 flashlight bulb
1 strip aluminum
1 yellow multimeter (with leads)
1 battery board
1 alligator lead card

Exploration stage: 10-15 minutes – group lab-work

***Note: the students may short out the battery causing heat and discomfort. This isn't hazardous; you can warn them at your discretion.

The students build a basic flashlight with three ingredients (a battery, a bulb, and an aluminum strip). They see how a complete circuit works. The students then build a more complex circuit with a switch on the battery board.

Analysis stage: 15-20 minutes – lecture

The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on circuits, flashlights, and the pre-lab question about complete paths for electrons to travel. The concept of a schematic is introduced. Power, and how to measure current and voltage are also introduced. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Activity: Current travels quickly, but individual electrons do not. One group example of this is for everyone in the class stand in a circle and pass a gesture around the circle. The gesture can travel faster than individuals can move.

Application stage: 30-40 minutes – group lab-work

The students measure voltage and current to calculate power. They build different types of circuits including series and parallel to observe electron paths. They also build other types of circuits to explore using the lab materials.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to formalize the series and parallel observations that were just made. Christmas tree light technology is a good example of this.

Concepts developed:

1. Electrons require a complete circuit to travel.
2. Power is the product of voltage and current.

<u>**Suggested Demonstrations:**</u>

Flashlight (can be taken apart during analysis to show simple components)

CIRCUITS

ANALYSIS

In any working circuit the current flows from the high potential (+) to the low potential (-). The potential is designated as the voltage, V. A successful circuit will allow you to follow the path of current through the devices.

In reality electrons travel from low potential to high, but we only recently observed that behavior on the particle scale. Benjamin Franklin established the convention of high potential to low, and we still use his definition.

<u>Light Bulb</u>

Inside a light bulb, the complete path takes you from the electrical foot, through the filament, and then out through the threads. The entry and exit points are separated by an insulating material (usually glass or ceramic) so that the electrons must pass through the filament and cannot take a short cut (called a short circuit) that bypasses the filament.

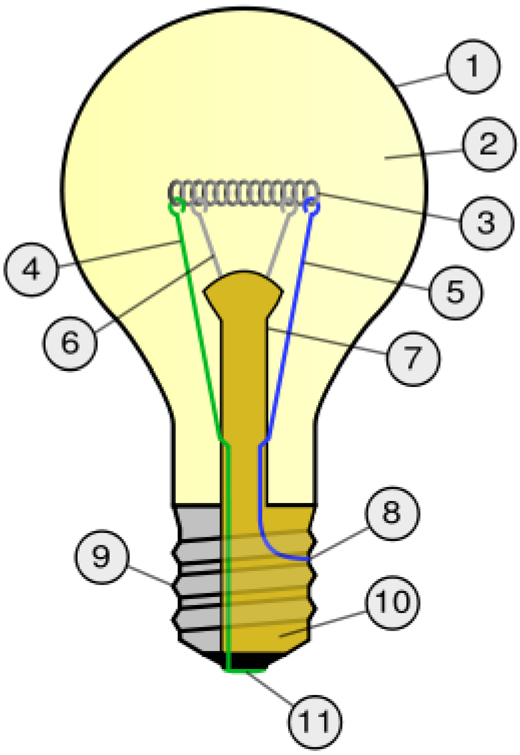


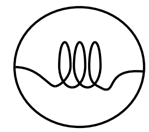
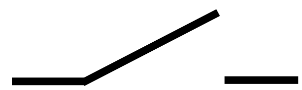
Figure 1: Anatomy of a Light Bulb[1]

1. Glass bulb (or "envelope")
2. Low pressure inert gas
3. Tungsten filament
4. Contact wire (goes to foot)
5. Contact wire (goes to base)
6. Support wires
7. Glass mount/support
8. Base contact wire
9. Screw threads
10. Insulation
11. Electrical foot contact

[1] Wikipedia 2006

Drawing a Schematic

When a circuit is drawn, it is not common to draw a literal representation of every component, but to instead use short-hand. The symbols for various components of a circuit are:

Light Bulb	
Resistor	
Wire	
Switch	
Battery	

A literal schematic for the flashlight you built would be:

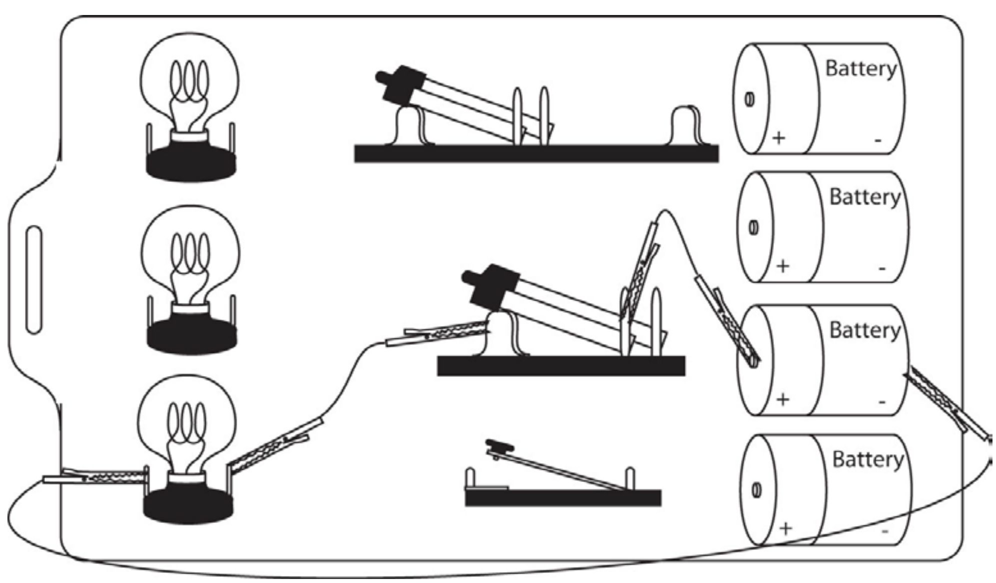


Figure 2: Battery board wired like a flashlight

The short-hand schematic of your circuit is:

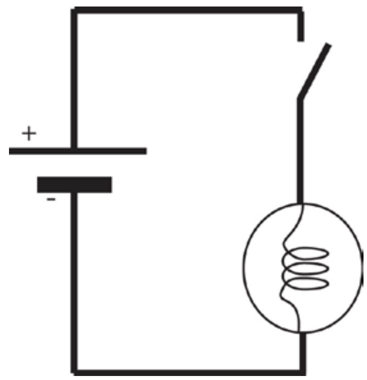


Figure 3: Flashlight schematic

The schematic is much simpler and includes all the essentials. The light bulb, and switch are on the right, and the battery is on the left.

<u>Current and Voltage Measurements</u>

When you purchase a light bulb, the wattage is usually listed. Watts are the units of energy used per second known as the power. Power is equal to the voltage multiplied by the current.

$$P = I \times V$$

The current and voltage of a circuit are measured in the fashion shown below.

<u>Voltage:</u> Voltage is the electrical "push" from the battery to produce current. Voltage is measured across the device, because we want to know the potential difference above and below the device. This is a direct current (DC) circuit, which means current only flows in one direction.

Use V_{DC} on the multimeter for these measurements. To make a connection, simply touch the probe to an exposed place in the circuit, like a metal prong or the teeth of an alligator lead.

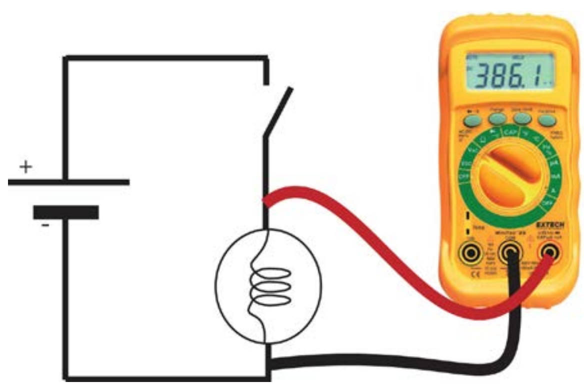


Figure 4: Measuring the VOLTAGE ACROSS the device

Current: Current is the electrical flow of electrons through the circuit. To measure the current, one must make the current flow through the multimeter. An alligator clip can be removed to do this in the lab. The units for current are Amps.

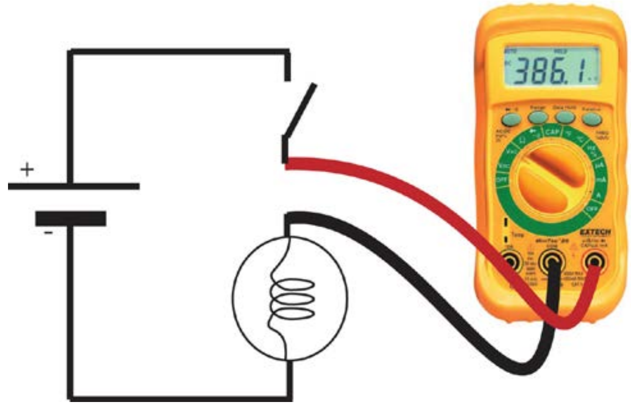


Figure 5: Measuring the CURRENT of the circuit.

WARNING: Do not measure current across a device, you will make a short circuit and blow a fuse.

CIRCUITS

EXPLORATION

Exploration Materials

1 battery
1 flashlight bulb
1 strip aluminum
1 yellow multimeter (with leads)
1 battery board
1 alligator lead card

1. Make the flashlight bulb light-up using only three materials: 1 battery, 1 strip of aluminum, and 1 flashlight bulb. Sketch your circuit below.

Describe what was essential to making your circuit work.

2. Build a “flashlight” circuit on your battery board. Flashlights are simple devices; yours should include a light bulb, a battery, and a switch. Make your connections with alligator leads. It doesn’t matter what color you use, all the leads are the same. The light should be controlled by the switch. Sketch the circuit below.

Everyday Applications

- Circuits are the building blocks of sophisticated electronic devices. Improving components and making circuits more efficient is what has enabled our electronics to shrink and size while becoming faster.
- If you have a faulty remote control or flashlight, it may be a connection issue! You can repair connection problems (sometimes) by tweaking a connection point for better contact. The electrons need an uninterrupted metal path to travel through.

APPLICATION

Materials

1 multimeter (with leads)
1 battery board
1 alligator lead card

Measurements

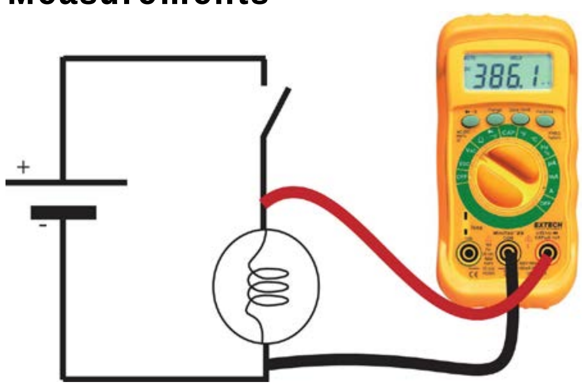


Figure 1: Measuring the VOLTAGE ACROSS the device

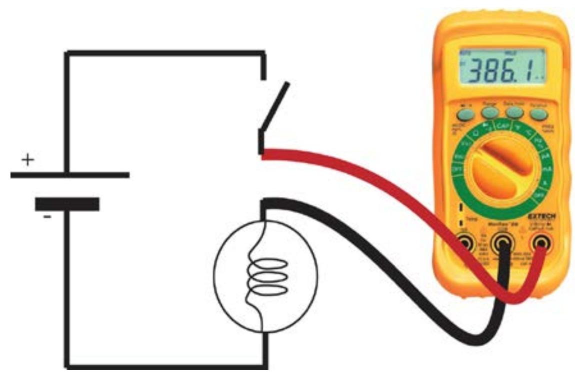


Figure 2: Measuring the CURRENT of the circuit.

1.

- Measure the **voltage** across the flashlight circuit you built in step 2 of exploration with the light bulb lit. Make sure your multimeter is set to V_{DC} and record below.

- Measure the **current** of the light bulb when it is lit. Measure the current using the mA setting; convert to amps from milliamps by dividing the milliamps by 1000.

- Calculate the **power** of the bulb from your measurements given the relation: $P = I \times V$

Voltage (in Volts)	Current (in milliAmps)	Power (in Watts)

2. Draw a schematic of a two bulb circuit with two batteries and a switch below. Place the light bulbs and batteries in series (one after the other).

Build a circuit on the battery board of the schematic you drew above. Light the two bulbs by closing the switch. While the bulbs are lit, unscrew one bulb. What happens? Why?

3. Can you create a circuit with two bulbs such that the other bulb stays lit when one bulb is unscrewed? Test your circuit, and then draw the schematic below. (Do not power each bulb with a separate battery.)

How is this different from the circuit in step 2?

4. Build a circuit so that one bulb is lit when the double-pull double-throw switch is to the right, and another is lit when it's to the left.

Challenge Work:

Work with another group (and their battery board because you'll need two) to see if you can build a three-way switch. A three-way switch circuit allows two switches to control one light bulb such that either switch can turn the bulb on and off. Draw the successful schematic below. Where would you encounter such a circuit in your everyday life?

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the board. Replace all equipment to the carts.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Incandescent light bulb," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Incandescent_light_bulb&oldid=55104753 (accessed May 26, 2006).

Series and Parallel

Demonstration Lab Assembly

Shared/Consumable Components:

- ☐ 8 alligator leads cards
- ☐ 8 battery boards
- ☐ 8 Multimeters

Other additions:

Special notes for instructor:

SERIES AND PARALLEL - 1

Pre-Lab Question

What is the difference between voltage and current?

EXPLORATION

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card

1. Build the circuit shown in the schematic below. The numbers indicate contact points where you will use the multimeter probes to measure voltage.

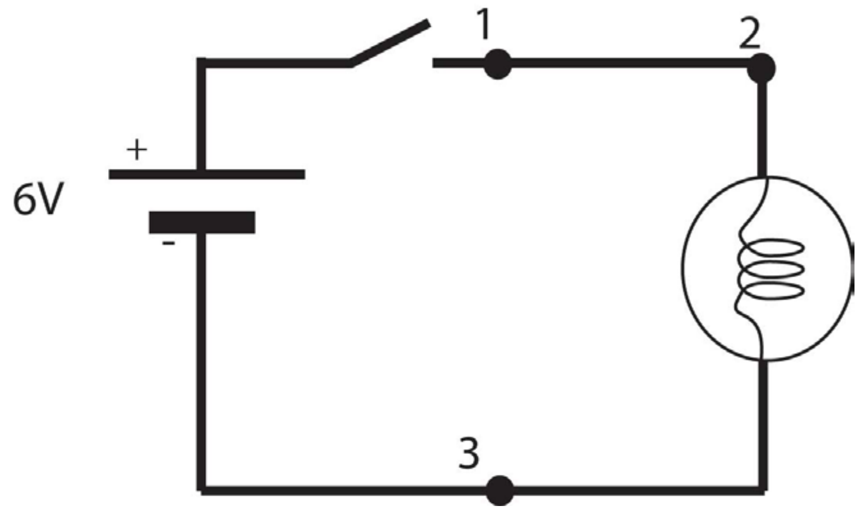


Figure 1: Simple Circuit

Measure the voltage across the batteries to establish a benchmark. Although they are labeled 1.5V, the actual voltage may vary. Actual voltage can be greater than the labeled level with brand new batteries, and less than the labeled level for batteries that have been used. It is alright if the actual voltage is not exactly 6V.
To measure the battery combination voltage, be sure to measure from tip-to-toe of the whole combination.

Actual Voltage of Battery Combination: ___________________.___________

2.

- First, predict and explain what **voltages** (V) you will measure between the labeled points on the circuit. After, close the switch, and measure the voltage of the pairs on the circuit. Place the probes at contact points shown on the circuit diagram above and record below.

- Second, predict and explain what **current** (I) you will observe at each labeled point on the circuit. After, measure the current. To measure, you interrupt the circuit with the multimeter which means you disconnect the circuit at a point and use the multimeter to complete the circuit. Measure the current at the test points with the mA setting and record below.

Contact Points	Predicted	Measured	Explanation of Prediction and Measurement
V_{1-2}			
V_{2-3}			
V_{1-3}			
I_1			
I_2			
I_3			

Explain your observations. What determines the voltages? How does the voltage of the components compare to the batteries voltage? Does current behave differently than voltage in a circuit and how?

Series Circuits

3. Build the circuit drawn in the schematic below.

- First, predict and explain the voltage for each pair of test points. After, measure the voltage and record below.
- Second, predict and explain the current for each test point. After, measure the current and record.

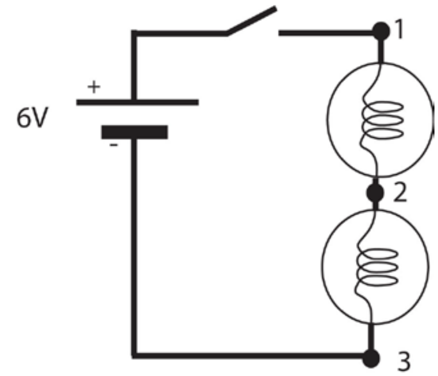


Figure 2: Series Circuit

Contact Points	Predicted	Measured	Explanation of Prediction
V_{1-2}			
V_{2-3}			
V_{1-3}			
I_1			
I_2			
I_3			

Explain your observations. How do light bulbs in series share voltage? How does this compare to the voltage of the battery? Why are they the same or different?

Parallel Circuits

4. Build the circuit shown below.

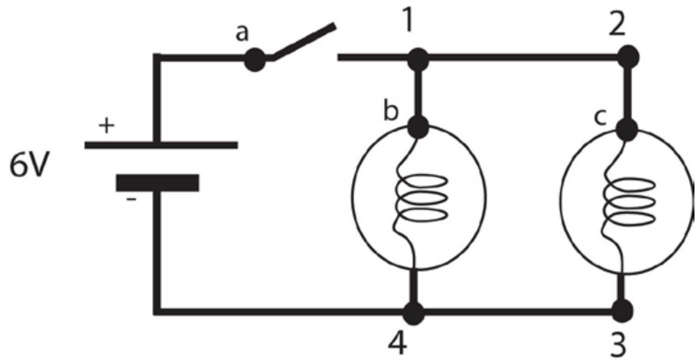


Figure 3: Parallel Circuit

5.

- Predict what the voltage will be across each light bulb when you close the switch. How does this relate to the total voltage potential of the battery? Discuss with your group. After recording your prediction, close the switch and measure the voltage across the two light bulbs. Explain what you observe.

- Predict the current at each light bulb and for the whole circuit (test points a, b, and c). Discuss with your group and explain your prediction. Will current behave the same as with two bulbs in series?

Contact Points	Predicted	Measured	Explanation of Prediction
V_{1-4}			
V_{2-3}			
I_a			
I_b			
I_c			

How do voltage and current behave in a parallel circuit compared to a series circuit?

Power

6. Fill in the table below with the values for voltage and current you measured for a series circuit of two bulbs at 6V and a parallel circuit of two bulbs at 6V (steps 3 and 4). Calculate and compare the power of these bulbs.

Recall from the circuits lab: $P = I \times V$

Bulb	Current	Voltage	Power
1 of 2 in series			
2 of 2 in series			
1 of 2 in parallel			
2 of 2 in parallel			

Challenge Work:

1. Describe a fast way to check if a light bulb circuit is series or parallel.

2. (Series) Using the series circuit, remove one battery from the circuit by re-wiring. How did this change the brightness of the bulbs? How does the voltage of the batteries affect the brightness of the bulbs?

3. (Parallel) Why do you think most Christmas tree lights are wired in parallel?

4. Is the circuit in Fig. 2 or Fig. 3 more of a power drain on the battery? Explain.

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Replace all equipment to the carts.

SERIES AND PARALLEL - 2

EXPLORATION

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card

1. Build the circuit shown in the schematic below.

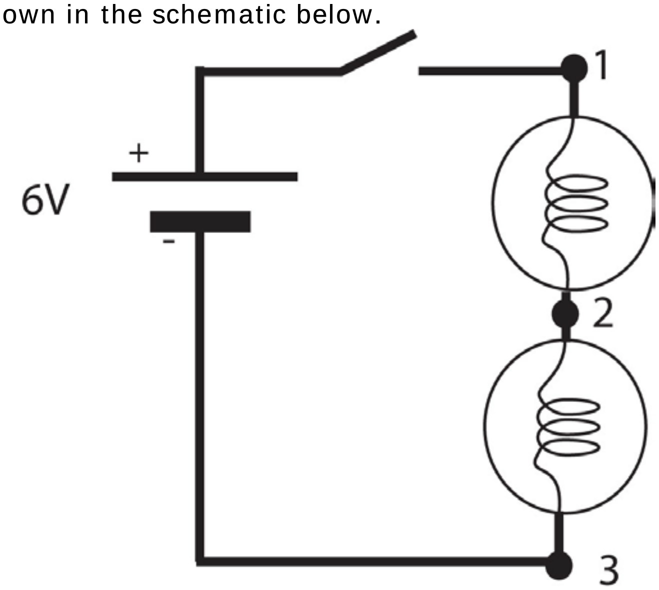


Figure 1: Simple Series Circuit

First **predict**: If you attach an alligator lead between point 1 and 2, what will happen to the first light bulb when you close the switch? How is it different from the system without the alligator lead? Will it affect the second light bulb? Discuss with your group and explain your prediction.

Attach an alligator lead between point 1 and 2 and close the switch. Observe what happens to the first and second light bulbs. Does this observation agree with your prediction? Explain why or why not.

2. Build the circuit shown below.

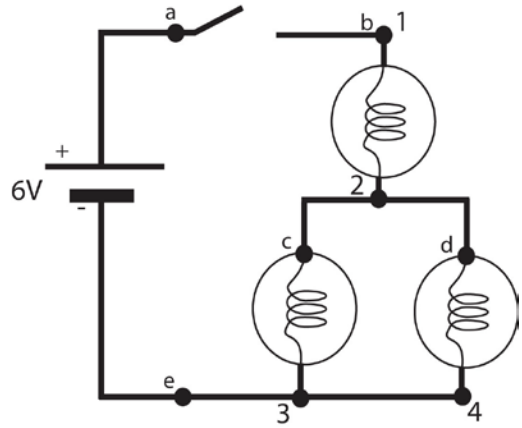


Figure 4: Series and Parallel Circuit

2. Predict the voltage across each bulb and across all the bulbs. Once you've recorded your prediction, measure the voltages. Explain your observations.

Contact Points	Predicted	Measured	Explanation of Prediction
V1-2			
V2-3			
V2-4			
V1-4			

3. Predict the current at each point in the circuit. Once you've recorded your prediction, measure the currents at each test point. Explain your observations.

Contact Points	Predicted	Measured	Explanation of Prediction
I_a			
I_b			
I_c			
I_d			
I_e			

4. Observe the lights with the switch closed. Are all the bulbs equally bright? Explain what you observe.

What happened to the current after point 2 when there are two paths it could travel on?

5. Predict what will happen when you unscrew light bulbs in the series and parallel circuit.

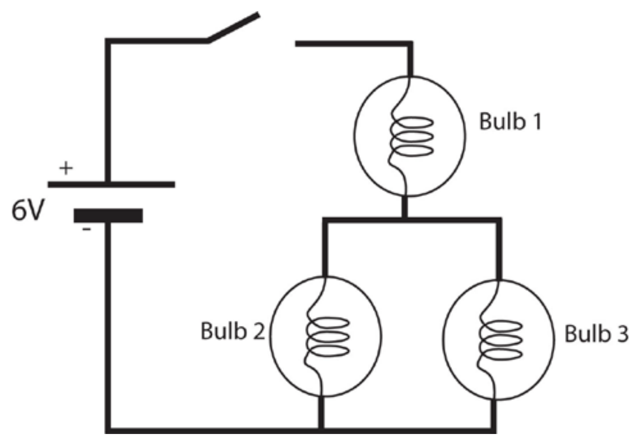


Figure 5: Series and Parallel Circuit

a) Predict what will happen if you unscrew bulb 1. Explain your prediction.

b) Predict what will happen if you unscrew bulb 2. Explain your prediction.

c) Predict what will happen if you unscrew bulb 3. Explain your prediction.

6. Unscrew each bulb and observe what happens. Record your observations. Do they agree with your predictions? Explain.

a) Bulb 1 unscrewed.

b) Bulb 2 unscrewed.

c) Bulb 3 unscrewed.

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Replace all equipment to the carts.

Instructor Outline: **Series and Parallel**

Lab length: 75-100 minutes
Lab objective: Instruct the students about series circuits, voltage, current, voltage addition, and power.

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card

Exploration stage: 40-50 minutes – group lab-work

The students build a simple circuit and measure voltage and current. They observe that current is the same throughout the circuit, but that voltage depends on the enclosed components. The students then build a two-bulb circuit and measure voltage and current. They add a third bulb and see how that affects the overall voltage and current. They then build a two bulb parallel circuit. They measure voltage and current for that, then calculate power for two bulbs in series and parallel.

Analysis stage: 15-20 minutes – lecture

The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on series circuits, parallel circuit, voltage, current, and power.

Application stage: 20 minutes – group lab-work

The students measure current and voltage for a circuit that combines series and parallel. They observe where the current flows based on what happens when they unscrew various bulbs.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Total voltage of a circuit depends on the source.
2. The sum of the component's voltages in a series circuit is equal to the voltage of the source.
3. The current is the same throughout a series circuit.
4. The current is inversely proportional to the number of resistive components in the circuit.
5. The current diverges in a parallel circuit.
6. The voltage across each component in a parallel circuit is greater than the voltage across each in a series circuit.
7. Power/brightness is a product of voltage and current.

Suggested Demonstrations: None

ANALYSIS

Current and voltage are two related measures of electricity flowing through a circuit.

Voltage

The total voltage of a circuit cannot exceed the voltage of the power source. The power source is stored electrical energy ready to flow through a complete circuit.

The voltage across a single component depends on three factors. It depends on the component itself (the resistance of the component), the resistance of all components in the circuit, and the total voltage of the power source.

When you measure the voltage across a light bulb (a device with resistance) the voltage is high. When you measure the voltage across a length of wire (very low resistance), the voltage is very low.

Current

Current depends on the potential of the power source and the challenge of the circuit (high or low resistance). It is the same at any point in a series circuit. The current is not the same everywhere in a parallel circuit; it splits up between the two parallel paths.

Current is conserved quantity. This means it is conserved in a parallel circuit; the total current at the source is equal to the sum of all parallel branches:

$$I_{tot} = I_1 + I_2 + I_3 + \cdots$$

Ohm's Law

Demonstration Lab Assembly

Dedicated Components
(located in box):

- [ ] 8 25 Ω resistors (long)
- [ ] 8 100 Ω resistors (short)
- [ ] 8 carbon pencils

Shared/Consumable Components:

- [ ] 8 alligator leads cards
- [ ] 8 multimeters
- [ ] 8 battery boards
- [ ] 8 calculators

Optional demonstrations at instructor's request:

- [ ] 5D10.10 - Assorted Resistors
- [ ] 5D10.u1 - Resistance Board

Other additions:

Special notes for instructor:

Instructor Outline: **Ohm's Law**

Lab length: 75-85 minutes
Lab objective: Instruct the students about resistance in series and parallel, Ohmic, and non-Ohmic resistors.

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card
2 different resistors (long and short)
1 carbon pencil
1 calculator

Resistor Values:
Long: 25 Ω, 50W
Short: 100 Ω, 25W

Exploration stage: 30 minutes - group lab work
The students measure the resistance of the short or long resistors with the multimeter. They then measure voltage and current to find that the resistance is the slope. Next, they determine the resistance of a light bulb using the slope in the V-I diagram.

Analysis stage: 10-15 minutes – lecture
The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Going over the material from exploration will be time consuming. Concept development is done on ohmic and non-ohmic resistors.

Application stage: 25-30 minutes – group lab work
The students build resistors by shading in regions with a carbon pencil (1 worksheet per group is sufficient). They see how the length and series and parallel paths of resistors contribute to total resistance.

Summary: 10 minutes – discussion
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts Developed:
1. Resistance is the ratio of voltage to current in a component of a circuit.
2. The current of a circuit depends on the total resistance of the circuit.

Suggested Demos:
5D10.10 - Assorted Resistors
5D10.u1 - Resistance Board

OHM'S LAW

ANALYSIS

Resistance is a measure of how much the component resists the flow of current. A component with high resistance will not allow as much current to pass for a given voltage as would a low valued resistor.

Ohmic Resistors

Resistors like the one you used in Steps 1-7 are "ohmic" in that they obey Ohm's law:

$$V = IR$$

Ohm's law states that voltage in a circuit is equal to the current through the circuit multiplied by the resistance of the circuit (i.e. V varies linearly with I, and vice versa).

Non-Ohmic Resistance

All resistors, such as the light bulb in the challenge work, become non-Ohmic when sufficiently hot. Your measurements should have shown that the bulb did not draw linear current with voltage. In the case of the light bulb, the resistance changes as the light bulb heats up more and more.

Resistors that heat up when current passes through them are commonly used tools in our daily lives.

Ohm's Law Worksheet

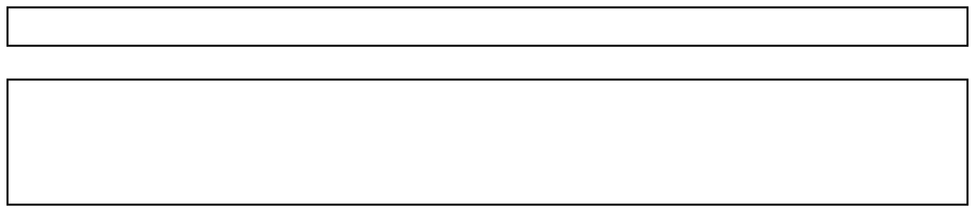
Fill in regions completely so there is no white.

Height in Inches

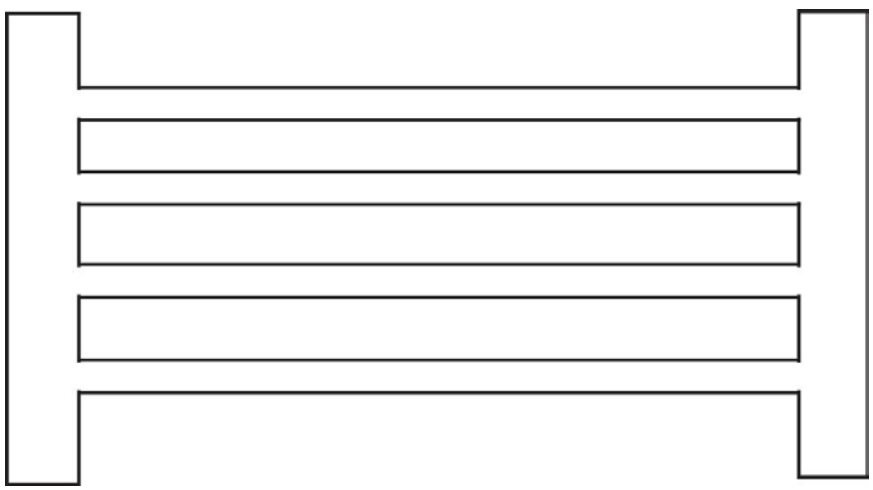
Single-Strip Shading Regions

0.2

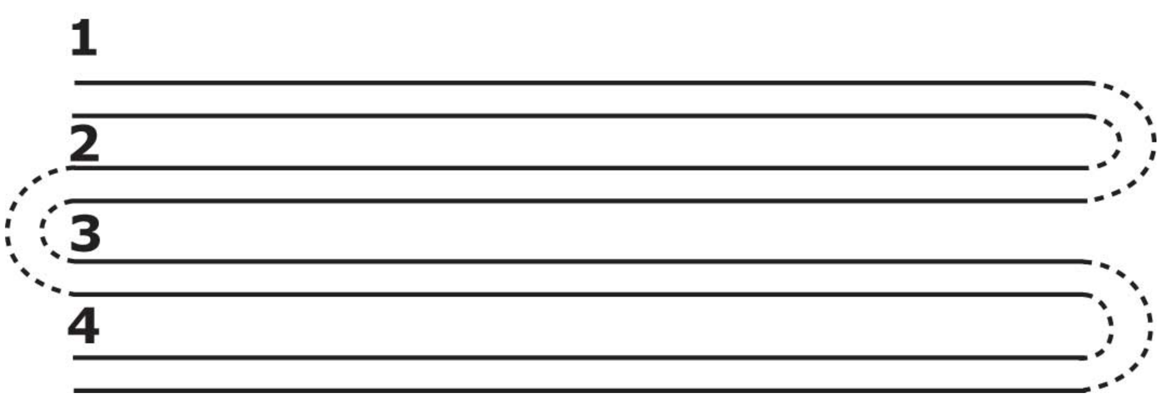
0.6



Parallel Paths Shading Regions



Series Shading Regions



OHM'S LAW

Pre-Lab Question

How does a component in a circuit affect voltage and current?

EXPLORATION

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card
2 different resistors (1 long, 1 short)
1 calculator

1. Direct measurement of resistance

Take the long resistor (NOT THE SHORT RESISTOR) and measure its resistance with the multimeter set to Ω. The Greek letter omega (Ω) is the symbol for Ohms, the unit of resistance.

You measure resistance across a resistor, just as you measure voltage but using the Ω on the multimeter.

Resistance of Long Resistor:_______________.

2. Resistor performance in a circuit

Build a circuit with 4 batteries in series, a switch, and the resistor that you just measured (connecting all with alligator leads). Measure the voltage and current of the circuit with different applied voltages.

Make it easy on yourself: Measure the **voltage** first. Connect the multimeter across the resistor, and change the applied voltage from the batteries by moving one alligator lead to include fewer and fewer batteries in the circuit. Record your findings in the table on the following page.

Second, complete **current** measurements. This time, interrupt the circuit with the multimeter and measure in mA. Again change the applied voltage from the batteries by moving one alligator lead for each measurement. Record your findings in the table on the following page.

Number of Batteries	Voltage (Volts)	Current (mA)
4		
3		
2		
1		
0		

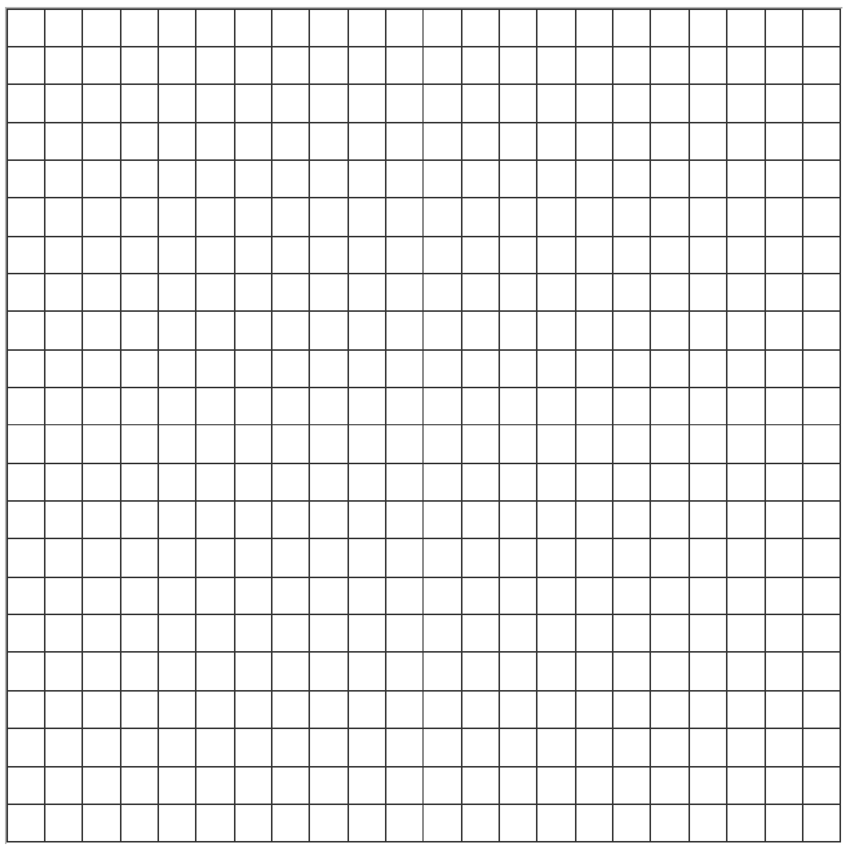
3. Plot a graph with the values for voltage and current you found. Plot the voltage (in volts) on the vertical axis and the current (in Amps, note: you measured in mA) on the horizontal axis. Label your graph well.

Is there a trend? What is the relationship between voltage, current, and resistance?

4. Remove the resistor from the circuit and replace it with light bulb. *Do not measure the resistance with the multimeter*. Repeat your measurements of voltage and current with different numbers of batteries.

Number of Batteries	Voltage (Volts)	Current (mA)
4		
3		
2		
1		
0		

5. Plot a graph with the values for voltage and current you found. Use the same vertical and horizontal scales you used in the previous graph.



Find the resistance of the light bulb from the data you measured.

6. Measure the resistance with the multimeter:_____________.
Note the similarities and differences of this plot with your resistor graph. Does your finding in step 5 agree with the multimeter? Discuss with your group and describe what resistance is.

Everyday Applications

- Elements in ovens and on ranges
- Heat lamps
- Toaster ovens
- Tea kettles

APPLICATION

Materials

1 yellow multimeter (with leads)
1 battery board
1 alligator lead card
1 carbon pencil

1. Starting with the **Single-Strip Shading Regions** on the Ohms Law Worksheet, shade in the 0.2 and 0.6 inch regions with a carbon pencil. Press firmly with the pencil to get a thick layer of carbon on the sheet.

- Measure the resistance of 0.2 inch region.
- Predict the resistance of the 0.6 inch region. That region will have three times as much carbon because it is three times as high as the first region. Will the region have the same, higher, or lower resistance? Discuss with your group and explain your prediction. Measure the resistance.

To measure the resistance of the region set the multimeter to ohms (Ω)**.** Lay one probe along one end of the region horizontally (more surface area means better reading), and the other probe on the other end of the region horizontally.

Region	Predicted Resistance	Measured Resistance	Explanation of Prediction
0.2 inch			
0.6 inch			

Does this measurement agree with your predictions? Explain how the height of the shaded region affects resistance.

3. Now use the **Parallel Paths Shading Regions** section of the worksheet. Shade in the two large boxes on the left and right.

- Then shade in one of the parallel paths which can be thought of as an individual connecting wire. First predict what the resistance will be, then measure the resistance by placing the probes in either of the large boxes on the end. Remember where you place the probes and measure from the same place each time for consistency. Record the resistance of 1 path alone below.

- Predict and explain what the resistance of 2 paths will be. Continue to predict and add paths until you've filled all 4.

Number of Parallel Paths	Predicted Resistance	Measured Resistance	Explanation of Prediction
1			
2			
3			
4			

Explain how parallel paths contribute to resistance.

Challenge Work:
Shade in the horizontal sections (1, 2, 3, and 4) of the **Series Shading Regions** of the worksheet, but do not shade in the connecting paths marked with dashed lines.

1. Measure the resistance of each individual region.

Horizontal Region	Resistance (ohms)
1	
2	
3	
4	

2.

- Predict the resistance of paths 1 and 2 combined in series. Explain your prediction. Measure and record.
- Predict the resistance of paths 1, 2, and 3 combined in series. Explain your prediction. Measure and record.
- Predict the resistance of paths 1, 2, 3, and 4 combined in series. Explain your prediction. Measure and record.

Remember, the resistance is measured across the longest length of the two regions (e.g. for 2 series paths you should be measuring near where it's labeled "1" and "2").

Number of Series Paths	Predicted Resistance	Measured Resistance	Explanation of Prediction
2 (1 and 2 combined)			
3 (1, 2, and 3 combined)			
4 (1, 2, 3, and 4 combined)			

Discuss with your group and explain how series connections contribute to resistance. How does this compare to parallel?

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Discard the Ohms Law Worksheet. Replace all equipment to the carts.

Capacitor

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- ☐ Roll of Aluminum Foil
- ☐ 8 Transparency films
- ☐ Catalog Sheets
- ☐ 3V bulb

Shared/Consumable Components:

- ☐ 8 alligator leads cards
- ☐ 8 Scissors
- ☐ 8 battery boards
- ☐ 8 Heavy Items (Book)
- ☐ 8 Rulers
- ☐ 8 Multimeters
- ☐ 8 Capacitors (from Motors & Gen)

Optional demonstrations at instructor's request:

- ☐ 5C10.20u1 - Potential voltage rise in a parallel plate capacitor
- ☐ 5C10.10 - Examples of Capacitors
- ☐ 5C30.20-2 - Killer Capacitor

Other additions:

Special notes for instructor:

Capacitor

Demonstration Lab Assembly

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- ☐ 5C10.10 - Examples of Capacitors
- ☐ 5C30.20-2 - Killer Capacitor

Other additions:

Special notes for instructor:

Instructor Outline: **Capacitor Lab**
Lab length: 60 minutes
Lab objective: Instruct the students about capacitors, capacitance, electrical energy storage, and equation analysis.

Materials

Battery Board
Alligator Leads
Capacitor
Aluminum Foil
Transparency film
Catalog Sheets
Multimeter
Scissors
Heavy Item (Book)
3V bulb
Ruler

Exploration stage: 10-15 minutes - group lab work
The students work in groups on the exploration stage of the lab. In this time they will use a capacitor and observe its behavior in a circuit. This unguided work time at the start allows the students to collect data without any prior knowledge about capacitors.

Challenge Work in this section may be too time consuming, consider omitting.

Analysis stage: 20 minutes – lecture
At this stage the instructor analyzes the exploration stage and explains electrical energy storage and advantages and disadvantages of using capacitors. This is a time for concept development to inform the curiosity and the observations made by the students in the exploration stage with physics. It would also be a good time to go into $C = \frac{Q}{V}$. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Application stage: 20-25 minutes – group lab work
The students work in groups again to build capacitors and explore what physical components of capacitors contribute to capacitance. These capacitors cannot store enough energy to power a bulb or LED, they are merely to show the fundamental components.

Concepts Developed:
1. Capacitors are energy storage devices, similar to batteries
2. Capacitance depends on surface area, spacing between surfaces (plates), and the dielectric medium.

<u>Suggested Demonstrations:</u>
5C30.20-2 - Killer Capacitor
Shows the magnitude of the electrical energy stored in a capacitor.
5C10.10 - Examples of Capacitors
Includes unraveled miles of aluminum
5C10.20u1 - Potential voltage rise in a parallel plate capacitor
Good for after application stage of lab to test the equation they learned

<u>Supplemental Tasks:</u>

- Go into dielectric materials and permittivity.

- Build a functional capacitor: fill a film canister with water. Puncture the lid, insert a nail. Wrap the canister with aluminum foil. The capacitor can be charged with a electrophorus plate or a piezo-charger. It can be used to light an LED.

CAPACITOR LAB

ANALYSIS: CAPACITOR FUNCTIONS

Electrical Energy

Batteries store electrical energy. When a battery is connected in a circuit with a light bulb, it spends that electrical energy flowing through the circuit and lighting the bulb. You can think of the battery as a chemical electrical energy storage device.

Examples of electrical energy consumers are light bulbs, toasters, televisions, and other electronic devices. They get energy from the wall outlet and convert it into other energy so they can operate.

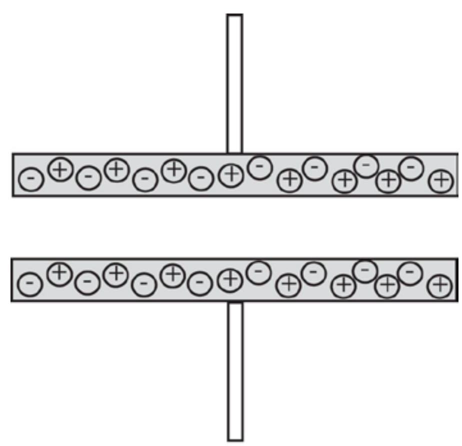
Another example of an electrical energy storage device is a capacitor.

Storing Electrical Energy

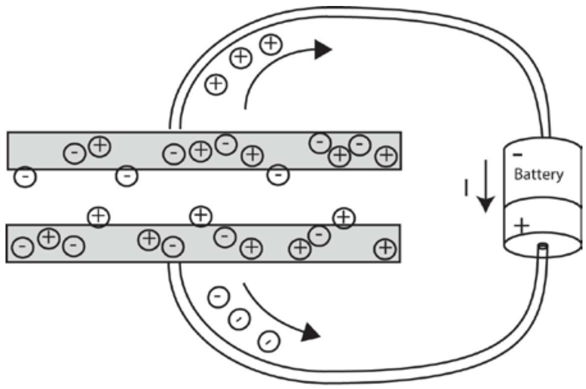
Batteries are an electrical energy storage device: chemical energy is stored in the battery ready to be converted to electrical energy. We use it up at our leisure until it's gone, then we replace the battery. The chemicals have a limited use, and then they need to be replaced.

There is another type of device that stores energy called a capacitor. Capacitors are used in many electronic circuits, but one use that many of you may know about is a camera's flash. Capacitors can discharge more quickly than batteries producing the characteristic and ideal "flash". The diagrams below take you step by step through how a capacitor is charged up to be an electrical energy storage device, and how it can spend its energy on a circuit.

This is a **discharged capacitor at equilibrium**. The basic features of the capacitor are two conductive plates separated by a thin non-conductive dielectric (such as air, paper, or plastic). The dielectric in these graphics is simply the space between the plates that has no conducting material in it. On each plate is a balanced equilibrium of charges, evenly distributed so neither side is charged differently than the other side.



Discharged Capacitor

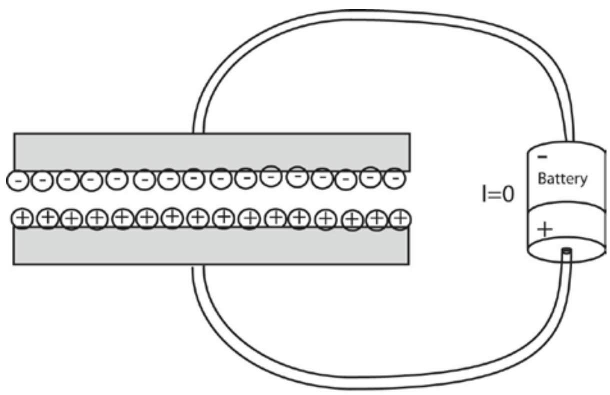


Capacitor Charging

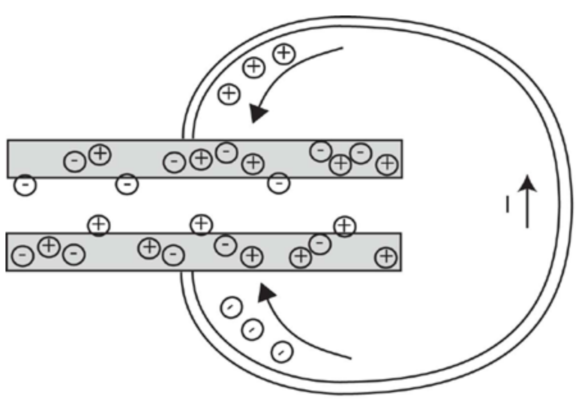
This is an uncharged **capacitor that is charging**. A battery with a voltage has been put across the capacitor. The energy from the battery displaces the charges in the capacitor from equilibrium and causes them to flow as a current. They do this even though there is a gap in the circuit between the capacitor plates! The displacement results in a charge imbalance on the plates. One plate is accumulating positive charges on its surface, and the other is accumulating negative charges on its surface. The charges cannot leap across the dielectric gap, but they are attracted to the opposite charges accumulating on the opposite plate.

As the plates accumulate these opposite charges, an electric potential (voltage) forms between the plates. The attraction of the opposing charges is the powerful potential voltage.

At some point, the capacitor is **fully charged**, as shown here. When the capacitor is charging, the opposing charges accumulate on the plates and create a potential voltage between the plates. That voltage increases until it is the same as the voltage of the battery power source (e.g. 3V or 1.5V). The current does not flow anymore because the plates are charged to equilibrium with the battery. The charge is stored on the surface of the plates because the opposing charged plate attracts the charges toward the gap.



Charged Capacitor



Capacitor Discharging

If we remove the battery and connect a wire across the capacitor (basically shorting the capacitor) we will see the **capacitor discharge**. Previously in the disconnected circuit, the charges were attracted to each other across the gap, but unable to travel back to equilibrium. Now as a part of a connected circuit, they can travel to the opposite plate along the wire connecting them, and

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rsity of Michigan, Ann Arbor, Michigan 48109

the plates can return to equilibrium (a voltage of zero).

The experiment you did with the battery, light-bulb, and capacitor circuit was exactly this process. Here is the physics explanation of what happened:

Starting Conditions: The capacitor was uncharged (in equilibrium).

Step 1: With the light-bulb in series, you charged the capacitor from the battery. At first, the current was flowing, so the light-bulb lit up. When the capacitor was fully charged, it no longer took charge from the battery, so the current stopped and the light-bulb went out.

Step 2: After the capacitor was charged, you removed the battery from the circuit. With the light-bulb still in series with the capacitor, the switch was closed. The opposing charges in the capacitor rushed back to equilibrium, thereby creating a current, and once again lighting the light-bulb. Once the capacitor returned to equilibrium, the light went out again.

CAPACITOR LAB

EXPLORATION: USING A CAPACITOR IN A CIRCUIT

Materials

Battery Board
Alligator Leads
Capacitor
3V bulb
Multimeter

1. Take the battery board and the loose 3V bulb. Wire the battery board, the 3V bulb, and capacitor according to the diagram below. The 3V bulb has two connection points; connect the alligator leads across the bulb. The capacitor is will only work in the correct orientation, red is the + lead.

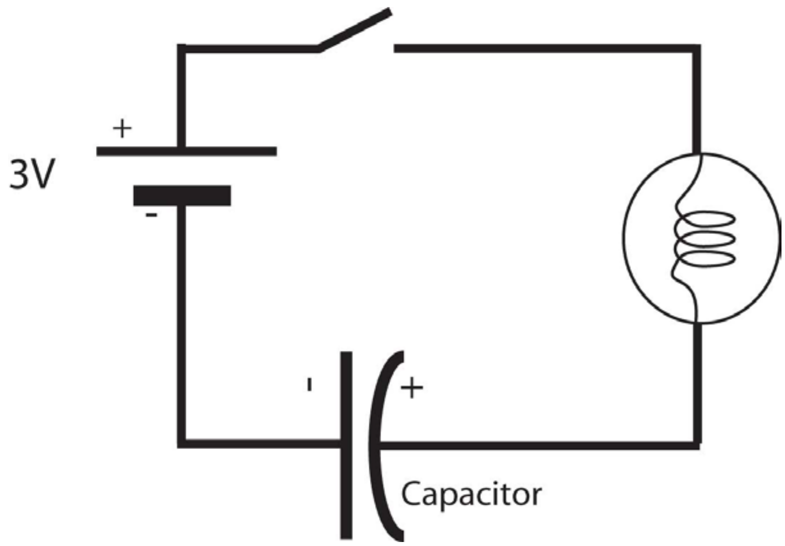


Figure 1: Simple Capacitor-Battery-Bulb Circuit

Observe and write down what happens to the light bulb when you close the switch, remember to be patient:

2. Open the switch again and re-wire the circuit to bypass the battery, as shown below.

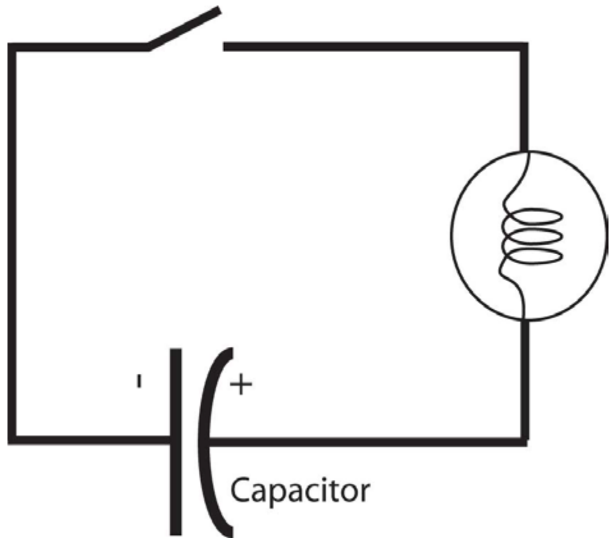


Figure 2: Simple Capacitor- Bulb Circuit

Close the switch. Again observe (and write down) what happens to the light bulb:

Obviously the capacitor has an impact on the circuit, describe below what the presence of the capacitor does to the circuit from your observations.

The circuits above are two different types of circuits. The first circuit could be described as a **capacitor charging circuit** and the second as a **capacitor discharging circuit**.

APPLICATION: THE PHYSICAL COMPONENTS OF A CAPACITOR

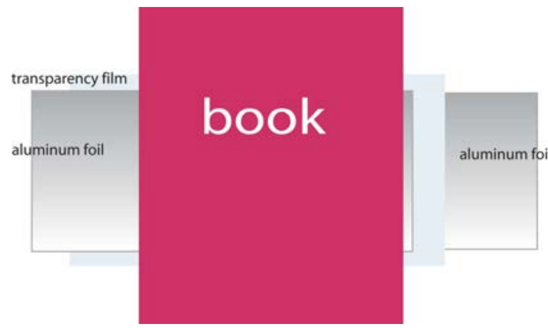
Materials

Aluminum Foil
Transparency film (given: 8.5 x 11")
Catalog Sheets
Multimeter
Scissors
Heavy Item (Book)
Ruler

1: Build a parallel plate capacitor and measure its capacitance.

Cut the aluminum into two rectangles of about 10 inches by 8.5 inches (narrower than the transparency film). Flatten the aluminum on the table by pressing and smoothing with your hands.

Create an aluminum and transparency film sandwich, making a bottom layer of aluminum, middle layer of transparency film, and a top layer of aluminum. It is important that the top and bottom layers NOT touch (if they touched, it would short out the capacitor).



Put the heavy item on top of the capacitor. This compresses the plates around the dielectric as tightly as possible. Leave some aluminum showing for the top and bottom plate.

Your capacitor should look like the photo below. Notice that the overlapping surface area of aluminum is really only 2/3 of either sheet of aluminum.

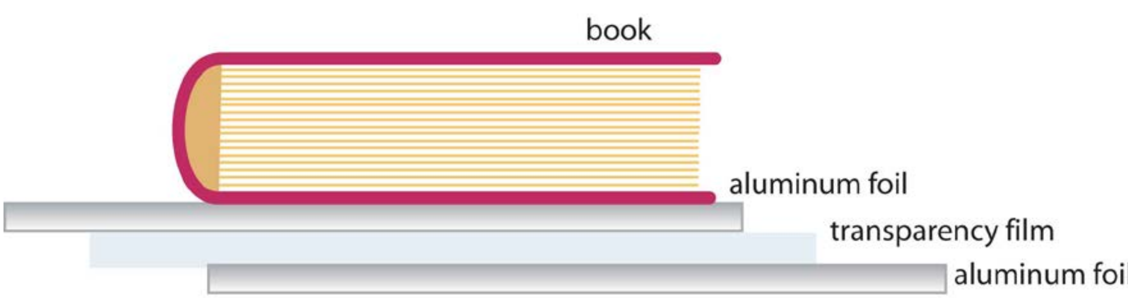


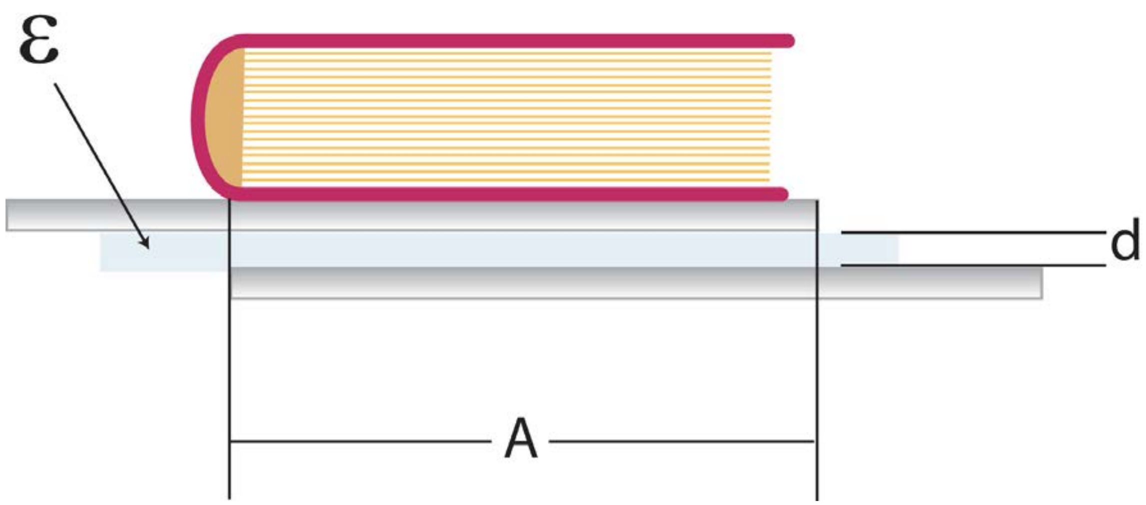
Figure 3: Side View of Aluminum Foil Capacitor

2. The multimeter has a “CAP” setting, test the capacitance of this simple capacitor by putting a test lead on the top aluminum plate, and the other on the bottom aluminum plate. The units of capacitance are called Farads, denoted by F. Record this capacitance below, remember to include units.

Simple Capacitor Capacitance	

A capacitor is a physical object. Capacitance is a capacitor’s ability to store charge at a certain voltage. The capacitance of a capacitor is only determined by the features of its construction, you’re going to manipulate various parameters to see what features control the capacitance of this capacitor and how.

The diagram below shows the various features you must consider when thinking about the capacitance of a capacitor:



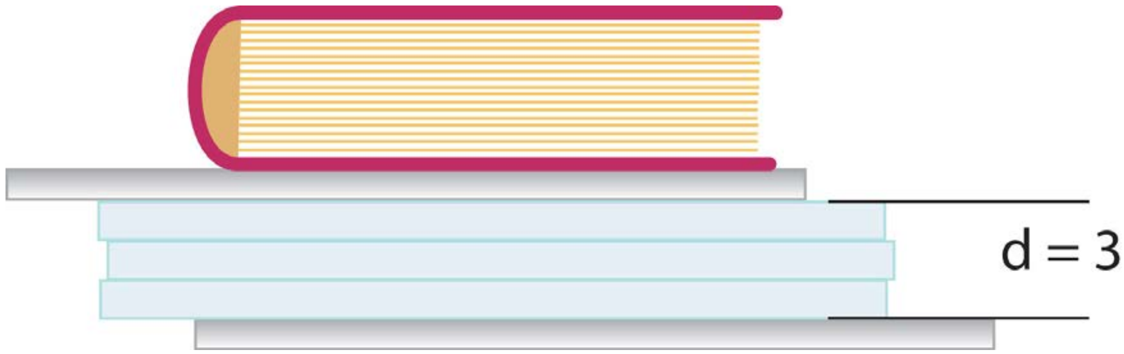
The parameters you’re going to manipulate:

- the distance between the plates (d)
- the overlapping surface area of the plates (A)
- the type dielectric material between the plates (ε)

3. Distance between plates

As you add sheets between the plates, you are adding distance between the plates. Add sheets of transparency film between the plates, and measure the capacitance. Try not to change the overlapping surface area of the plates (i.e. if you had 60% overlapping, try to keep that constant).

Here is an example of d = 3, you can see that the distance (d) increased, but the dielectric hasn’t changed because we are still using transparency film. The overlapping surface area won’t change if you’re careful to keep it consistent.



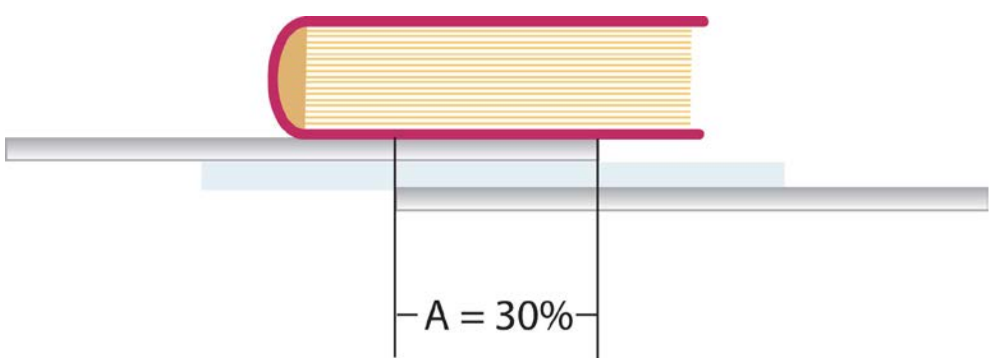
Keep using the heavy book to compress the capacitor. Record the values below:

Layers of film (distance)	Capacitance
1	
2	
3	

Record your observations: Did an increasing distance between the plates (i.e. adding more dielectric material between the plates) increase or decrease the capacitance of the plates?

4. Surface Area

Reduce the layers of transparency film to one. Now you are going to vary the overlapping surface area of the capacitor. The original overlap was about 60%. Below is a diagram of roughly 30%.



We suggest some overlapping ratios below; also select one ratio of your own. Vary the surface area and record your observations.

Overlapping Surface Area	Capacitance
80%	
20%	

Record your observations: Did increasing A (the overlapping surface area of the plates) increase or decrease the capacitance of the plates?

5. Dielectric Material

There are many types of dielectrics that will work between capacitor plates: plastic, paper, and air are just a few examples. Each dielectric has a characteristic known as permittivity. Permittivity is the susceptibility of a material to an electric field and is denoted in equations as ε. For the purposes of this lab all you need to know is that the **permittivity of transparency film is greater than that of catalog pages**. Permittivity is similar to density in that it is independent of volume. It doesn't matter how thick the dielectric is, the permittivity is constant throughout the material.

We are going to vary the permittivity of the dielectric to see what effect permittivity has on a capacitor. To do this accurately, we must be careful to keep the distance (d) the same. The thickness of 3 catalog pages is about the same as 1 sheet of transparency film.

Measure the capacitance of the basic capacitor with one sheet of transparency film and again with three catalog pages.

Permitivity	Capacitance
High ε - 1 sheet of transparency film	
Low ε - 3 sheets of catalog pages	

Record your observation: Did the permittivity of the dielectric increase or decrease the capacitance of the plates?

Considering what you observed, discuss in your group which of the following equations is most likely the equation that defines the capacitance of a parallel plate capacitor.

C is capacitance
A is area (the overlapping surface area)
d is the distance between the plates
ε is the permittivity of the material

Circle the equation that best fits the observations you made from the options below. Consider that components on the numerator (top) of the right side make the capacitance larger as they increase, and components on the denominator (bottom) make the capacitance smaller as they increase:

Equation 1 $$C = d\varepsilon A$$

Equation 2 $$C = \frac{\varepsilon}{dA}$$

Equation 3 $$C = \frac{\varepsilon A}{d}$$

Equation 4 $$C = \frac{d}{\varepsilon A}$$

Write briefly why the equation you chose fits the data you observed.

Everyday Applications

- Flash bulbs in cameras

Home Wiring

Demonstration Lab Assembly

Dedicated Components
(located on Home Wiring Cart):

- ☐ 14-2G Wire
  - At least 1.5 spools
- ☐ 8 Receptacles
  - 5 screws
- ☐ 8 Switchs
  - 3 screws
- ☐ 8 Light Fixtures
  - 2 screws
- ☐ 8 Light Bulbs
- ☐ 8 Home Wiring Boards
  - 4 ground screws per board
  - 2 fixture mounting screws
- ☐ 32 face plate screws
- ☐ 8 receptacle face plates
- ☐ 8 switch face plates
- ☐ 8 screwdrivers
- ☐ 8 pliers
- ☐ Multi-purpose wire tool
- ☐ 40 Wirenuts (5 per group)

Shared/Consumable Components:

- ☐ 8 Multimeters (2nd day)
- ☐ 2 Power Screwdrivers
  - (charge in advance)

NOTE:
-The students rarely leave these pristine; check every device for proper screws.
-Spare parts are located in the cabinets.

Other additions:

Special notes for instructor:

Instructor Outline: **Home Wiring Lab**

Lab length: 160 minutes (two lab periods)
Lab objective: Give students a hands-on opportunity to learn about wiring that is actually used in their everyday life: switches, receptacles, and lights.

We recommend that the lecturer go over the content of the “Theory Overview” at the beginning of the first lab period, and then allow the students to assemble the lab according to the directions while referencing the analysis handout for the method.

At the end, all the units will be plugged into 120V and tested. For safety, first verify that everyone’s resistance readings are correct. Have the students turn all their switches to off before applying power. Turn on one switch to “on” at a time to check each board individually.

Note that the bulbs may light up even if the wiring is not done to code. This can be checked with a receptacle tester.

Materials

14-2G Wire
Receptacle
Switch
Light Fixture
Light Bulb
Home Wiring Board
Multi-purpose wire tool
Wirenuts (5)
Multimeter

Instructor Materials

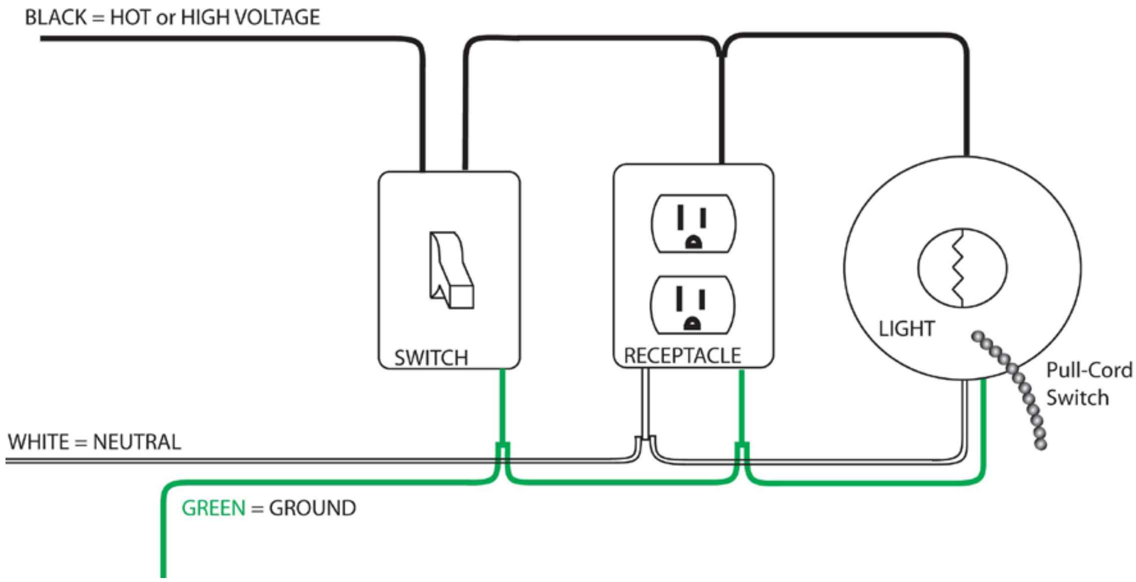
2 power tools for quick unscrewing of components
Receptacle tester and circuit analyzer (tool to check proper wiring in receptacle)

Home Wiring Lab: Analysis Handout

Contents

Theory Overview:

Here is a sample diagram of a receptacle and a light connected with a switch in a home. The black and white wires are connected to the power company's hot and neutral leads respectively. Connecting to the hot and neutral leads of a power company is the same as connecting to the positive and negative ends of a battery, except the power company has a more powerful potential (voltage). The green wire (called the ground wire) is added for safety.



First look at the receptacle and the light fixture. They each have a black wire going in and a white wire coming out. This is how the light and receptacle become "hot" components in the circuit. The power company creates a potential (voltage) across the black and white wires that drives the current. When the light is connected across the wires, it is lit. When the receptacle is connected it is ready to power what you plug into it.

Most people want the option to turn devices (such as light fixtures) on and off. To interrupt the current from the power company, we must break the circuit at some point. This can be done by unplugging a wire, but a better solution is a switch. A

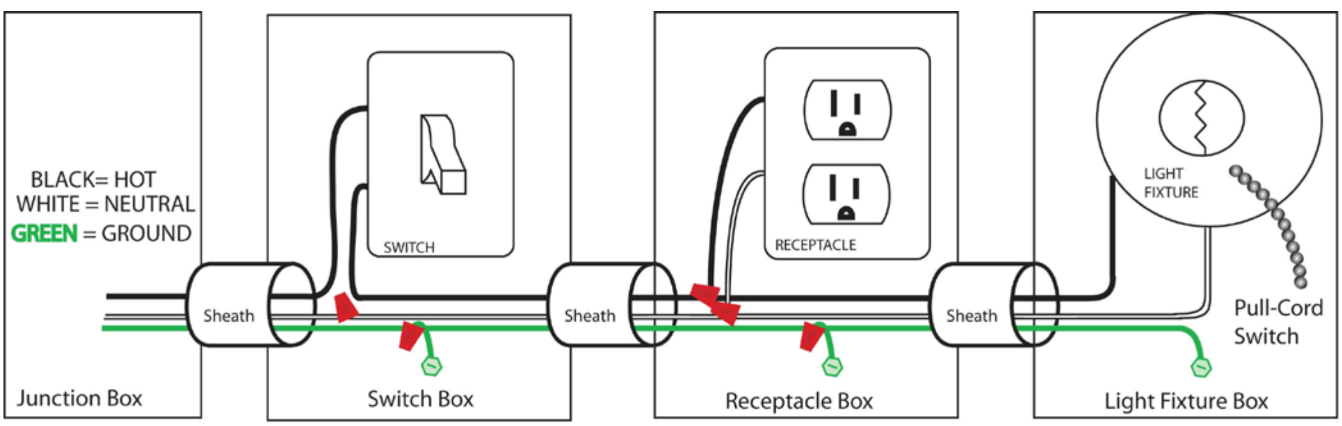
switch has an elegant, ergonomic, and safe plastic knob to break the contact between two wires. For safety, switches are put on the hot wire (black).
Notice that the white wire doesn't connect to the switch. This is because the switch doesn't need power across it, it's only job is to interrupt the circuit. The ground is connected to the switch for safety.

So, we create a system of the switch in series with the receptacle and the light. The whole system (switch, receptacle, light series) is put in parallel across the power company's supply.

Theory is nice, but it doesn't tell you what goes where when you have a switch, a receptacle, a light, wire and screwdriver. The "light" doesn't even look like a light in the schematic. So below are some more realistic schematics.

Electricians don't need the hot, neutral, and ground leads to be in physically different places to know the difference between them. It's easier for the wire to be bundled together, and so it is. Two of the copper wires are insulated with black and white plastic. The remaining wire is unclad copper. The three wires representing hot, neutral and ground are color coded like this: Black is hot, white is neutral, and unclad copper is ground.

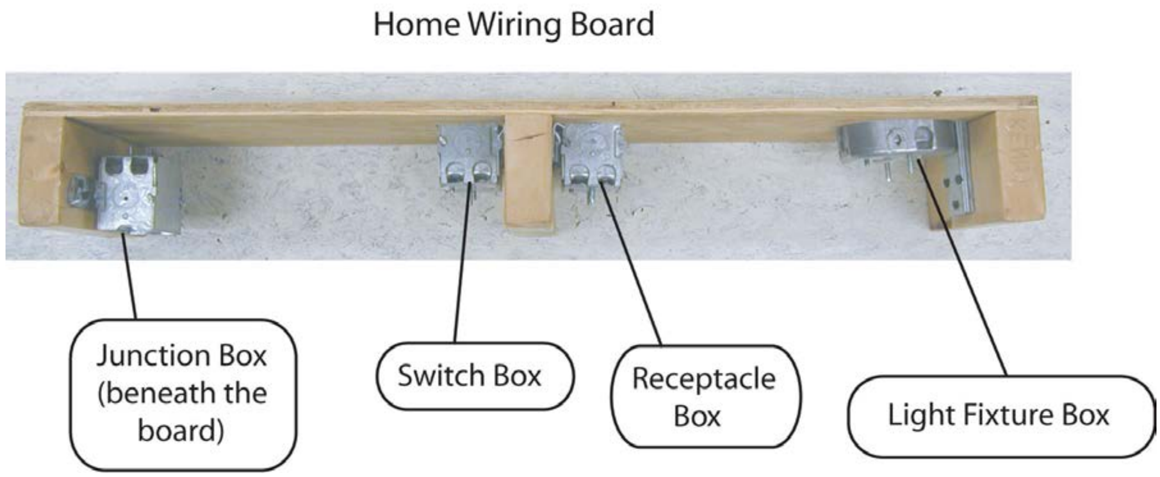
The schematic below shows a more physically representative schematic, with all the wires sheathed together. The red knobs are wire-nuts, used to connect multiple wires safely.



Physical Components of the Lab:

The Home Wiring Board

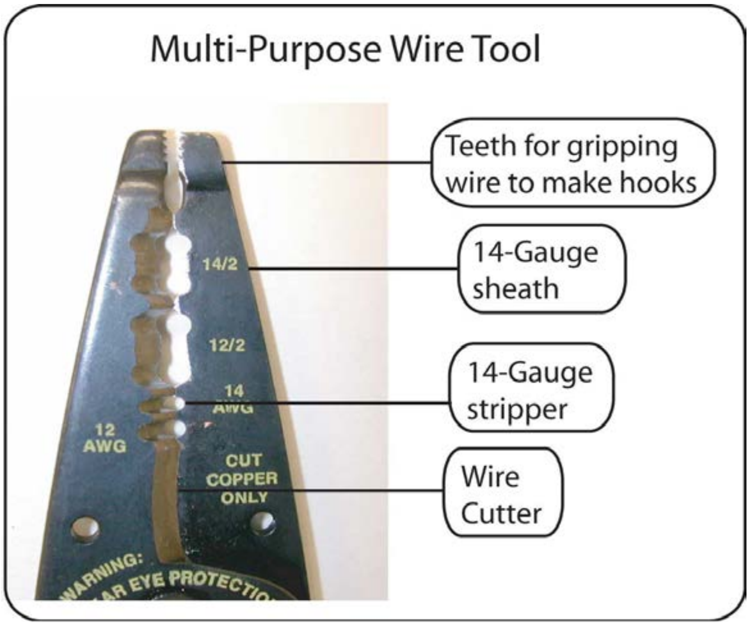
The home wiring board is meant to represent a wall in a home. There is plywood mounted on a frame of 2x4's, similar to the frame of a wall in a home. On this home wiring board there are four metal boxes, three facing out and one beneath. The three facing boxes are often called switch boxes, and the one beneath is called the junction box.



The switch boxes are meant to mount the various devices people hook up to electricity such as lights, switches and receptacles. They are also a hiding place for all the leftover wire length from wiring a device, which can just be crammed in at the end. There are three things you need to know about switch boxes. One, each box has a screw hole at the top and bottom to allow the desired device to attach to the switch box so it's flush with the wall. Two, the boxes all have large holes on the bottom or side to allow the sheathed wire to come in. Finally, each of our boxes has a green ground screw in the bottom. Conventionally, boxes are the ground for devices, but now some boxes are made out of plastic so most devices have an alternative ground screw on them. This is why you'll see a ground screw on receptacles and switches. These are redundant with the screw on the box, so you only need to use one ground screw either on the device or in the box.

The junction box is just the place where you will eventually connect your board to power. All you need to send to this box is the sheathed wire with striped ends.

The Multi- Purpose Wire Tool

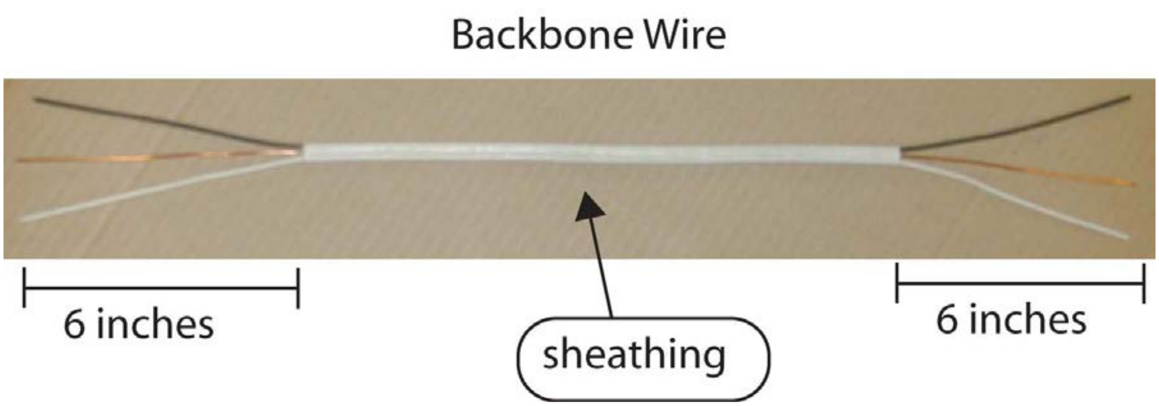


The multi-purpose wire tool does many jobs well. It has a sheath cutter, a wire stripper, a gripping tip, and a wire cutter. It does all the jobs to prepare wire for wiring.

The Wire

The first step to this lab is to cut some appropriate lengths of wire. There are three preparations of the wire you will need to complete.

<u>Creating Partially-Sheathed Backbone Portions</u>



For the wire's long trips from box to box, it is best to leave the white sheathing that binds the three wires on the wires. These parts will be the backbone of the wiring system.

There are three such trips:

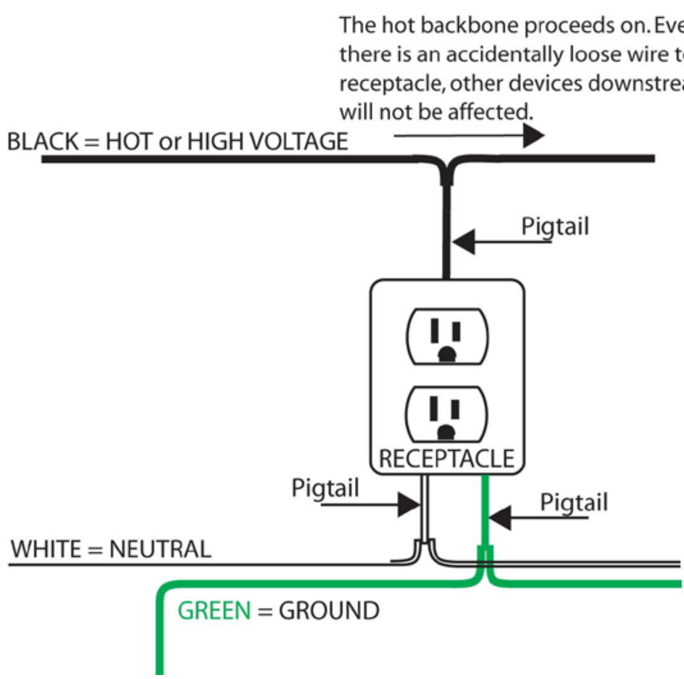
1. **Between the junction box and the receptacle.**
2. **Between the receptacle and the switch.**
3. **Between the switch and the light fixture.**

The length of the sheathed portion should be at least the distance between the boxes you are connecting. Once you get to the box, you will want enough additional length of loose wire to make connections easy. **We recommend (and the national electric code requires) about 6 inches of extra length for both sides of the wire for use inside the switch boxes and junction box.** So your calculation should go as follows: the junction box is separated from the receptacle box by (guess) 15 inches. Since you want 6 inches on each end, you want to cut 27 inches of the provided 14-2G wire. Use the multi-purpose wire tool to cut the wire.

The next step is to strip 6 inches of the sheathing off each end. The multi-purpose tool makes this easy because it has a 14-gauge sheath cutting bite shown in the multi-purpose wire tool diagram above. Simply cut the sheath with the tool 6 inches shy of the end on each end, and slide the sheath off to expose the wire.

Repeat this for all three box to box connections.

Pigtails



Pigtails are the names given to short lengths of wire used to connect devices (e.g. receptacles and light fixtures) to the backbone wiring. It is considered poor wiring (and in some cases not up to national electric code) to directly connect the backbone to a device.[1] Pigtails are connected to the two sheathed backbones coming into the switch box using wirenuts (described below).

[1] If you directly connect your backbone to the device (e.g. receptacle or light fixture) you run the risk of knocking out your entire circuit (the whole room or house as the case may be) if the device fails. Then you won't even know which device failed in the event of a failure because every device is an integral part of the circuit.

Pigtail Wires
(about 6 inches long)

To create pigtails first consider how many you need by consulting the basic schematic. We don't need pigtails in the junction box because we can simply connect our power supply to loose backbone ends we sent there. We don't need pigtails on the light fixture because it's the end of the line so we can just directly connect it to the backbone. And we don't need pigtails for the hot connection to the switch because we don't want the backbone hot/black circuit to bypass the switch; we want the switch to be able to interrupt it. So, we need **one black pigtail for the receptacle, one white pigtail for the receptacle, and two ground pigtails (one for the receptacle and one for the switch).** We recommend that the pigtails be 6 inches long. To get pigtails cut a 6 inch section of 14-2G sheathed wire, then crimp and remove the sheathing from one end of the strip. Slide the enclosed wires out. This will produce three 6 inch pigtails, one white/neutral wire, one black/hot wire, and one unclad/ground wire. Repeat until you have a sufficient number of pigtails.

<u>Stripping Insulated Wire</u>

Now you have appropriate cuts of wire, but they are not yet usable. We need to strip some of the insulation off the wire so we can make a connection that conducts electricity. Look at the photo of the pigtails above, notice the inch of bare wire on each end of the insulated wires, those ends have been stripped. It's important not to strip too much insulation off or we risk creating a "short" so the current bypasses the device. We recommend stripping no more than one inch of insulation off the insulated wires.

To strip the insulated wire, slip one inch of the wire into the multi-tool 14-gauge stripper hole (labeled above), crimp the tool, then slide the wire out. This should slide the insulation off the wire. Do this on all exposed insulated wires.

The ground wire is only insulated with a thin coat of enamel. The reason for this is that it does not normally carry current. It only carries current when it needs to trip the Ground Fault Circuit Interrupter (GFCI), and wire manufacturers save money by not insulating a rarely used wire. The GFCI is included to protect people from dangerous current flow by noticing if the hot incoming current doesn't match the outgoing current on the neutral line.

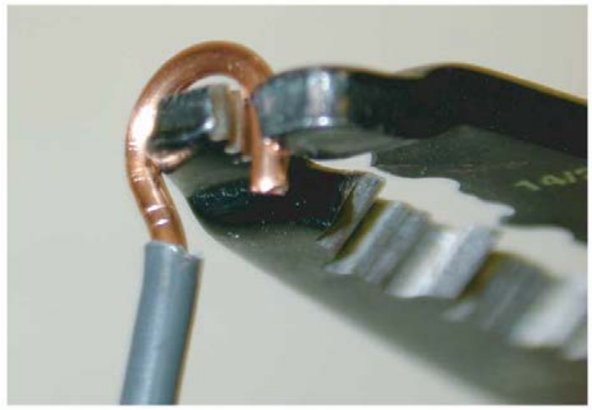
Do not leave too much of the other wires exposed or the wiring may short out.

Connecting Wire

<u>Screw</u>
The standard way to attach wire to a device is by screwing it to the device. There is a standard way to do this. Create a hook on the end of the wire by holding the end of the wire in a clenching tool (such as needle-nose pliers or the multi-purpose wire tool) and then wrapping it around the tip.

Creating a hook on the tip of your wire

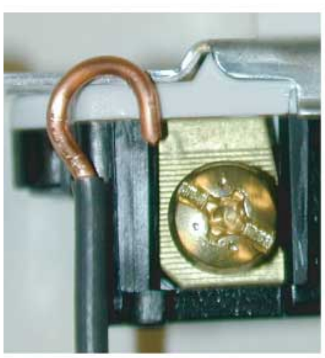
A nice looking hook.



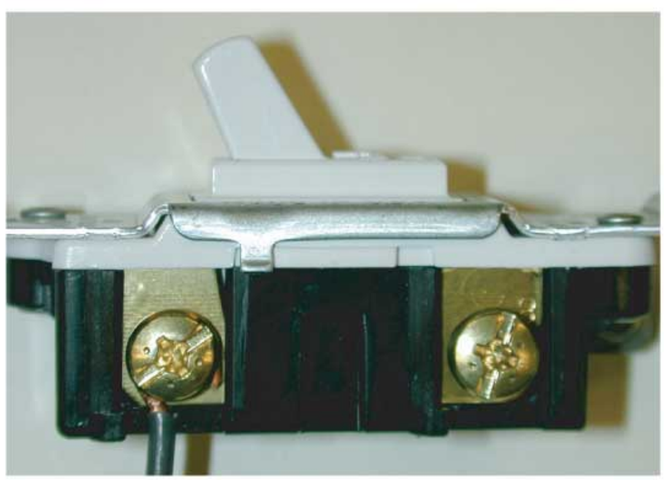
Wrapping the wire around the tip to make a hook.

Screws tighten when turned clockwise and loosen when turned counter-clockwise (righty-tighty, lefty-loosey). Hook the wire so tightening the screw secures the wire rather than loosening it as shown below, this brings the attachment up to electrical code.

Connecting the Wire to the Device



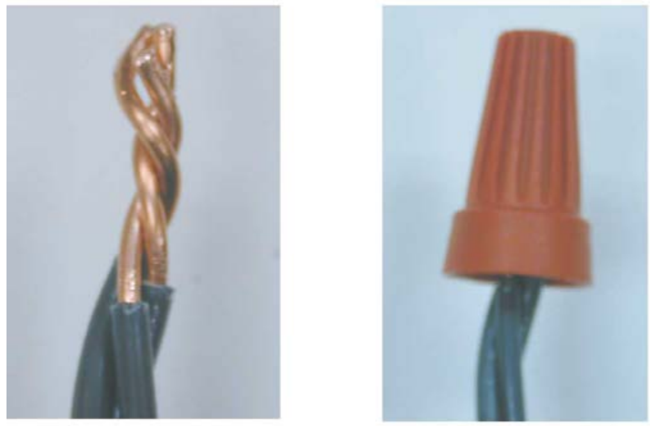
Orienting the hook correctly



An attached wire

Wirenut

Mounting a Wirenut



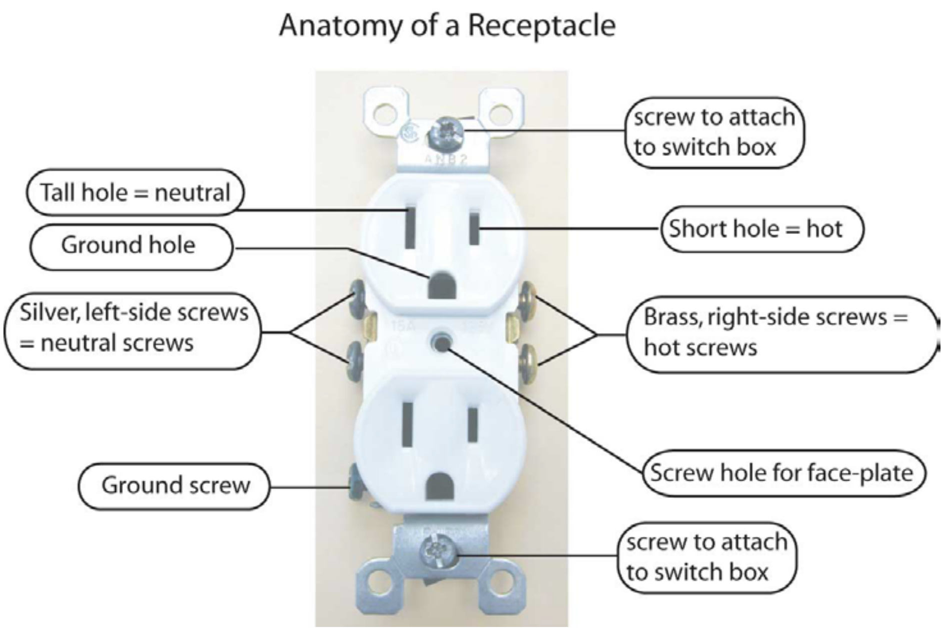
twist the wires — screw the wirenut onto the twisted wires

When joining several loose wires (such as when using a pigtail), it’s best to use a wirenut to connect them all. To prepare the wires, **strip the insulation off an inch of the wire as directed above, and then twist the wires together. Trim the tips so they are even, and then simply screw the wirenut onto the twisted ends.**

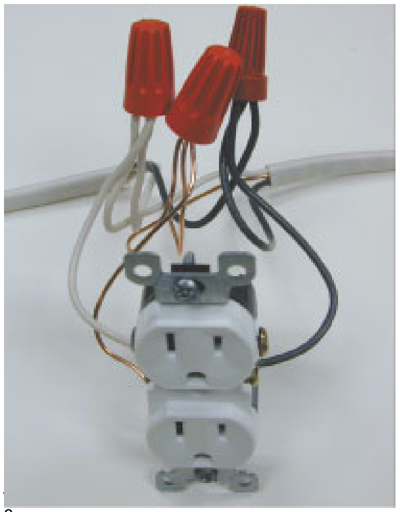
WARNING: IT IS VERY IMPORTANT NOT TO HAVE EXPOSED WIRE BELOW THE WIRENUT!

The Receptacle

Here is a diagram that describes the parts of a receptacle.



You are probably familiar with receptacles, they are where you plug in electronic devices. When you plug a device into the two slits, a circuit is completed and the device has power.

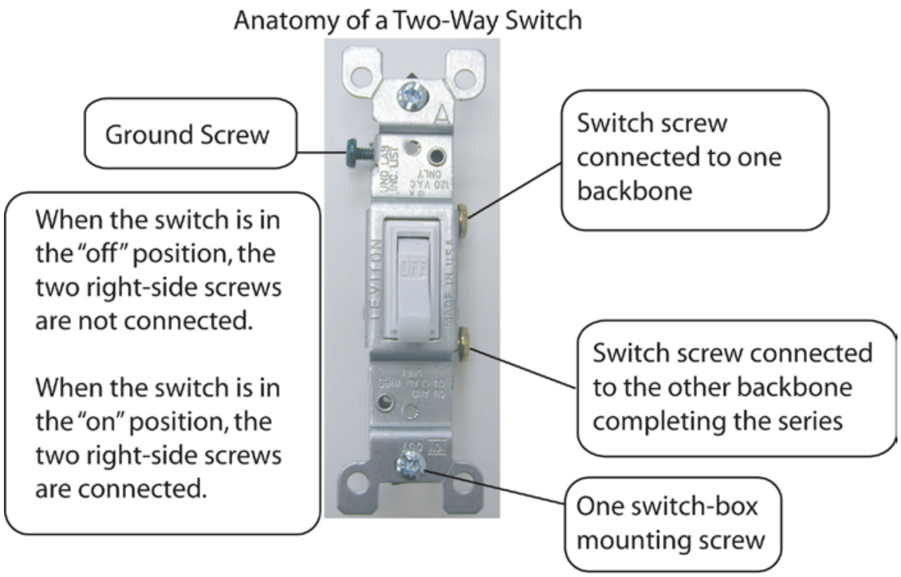


The left side screws connect to the neutral slits, and the right side screws connect to the electrically hot slits. For our purposes, we only need one screw on each side because they are all connected.[2] If you wish to wire to both screws on each side you may, but it will only be redundant and create more work. [3]

[2] Two technical anecdotes: One, there are two screws on a receptacle when we only need one because occasionally one outlet is connected to a switch, and the other is left constantly hot. Two, when you buy a new receptacle, the right-side "hot" screws are always brass and the left-side "neutral" screws are always silver-colored, but since the screws are physically interchangeable, this may not be the case with the receptacle you have and it does not pose a problem.

[3] If you were installing this device into a plastic switch box, you would need to use the receptacle ground screw to ground your device properly. Since we are providing metal switch boxes, you can choose to either ground to the receptacle or the switch box.

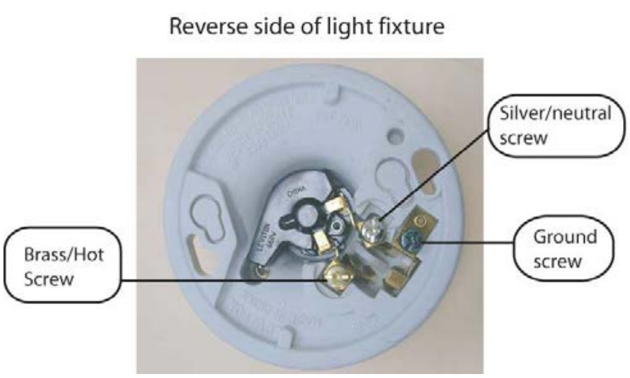
The Switch

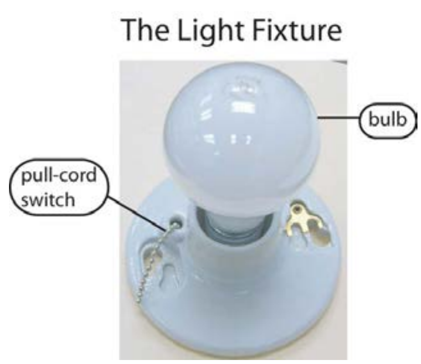


Switches are common household features for controlling lights. When a switch is connected in series with electrical devices, the switch controls the power supplied to those devices. A switch doesn't need power across it, so you won't see a black and a white wire coming from it. **The two-way switch only needs to be in series with the backbone, and it is safest if the switch is placed along the hot wire.** If you were to use a pigtail with the switch, you would defeat the purpose of the switch because the current could bypass the switch.

The Light Fixture

The light fixture is a very simple device to wire, **only requiring a hot input and a neutral output.** The wiring takes place on the back before the fixture is attached to the switch box.





The light fixture we provide has a switch built in, so not only will the wall rocker switch control the current going to the light, the pull-cord switch on the fixture controls the current too.

Home Wiring Lab: Assembly Handout

Materials

14-2G Wire
Receptacle
Switch
Light Fixture
Light Bulb
Home Wiring Board
Multi-purpose wire tool
Wirenuts (5)
Multimeter

Building the Home-Wiring Board

Reference the analysis handout as needed to understand each component of assembly. Appropriate page numbers are cited in the text.

1: Prepare the Wire

Prepare according to the directions in the analysis handout:

- sheathed wire **backbones** (p.4, backbone wire section of the analysis)
  Do not strip the ends of the backbone until you feed it through the boxes.
- **pigtails** (p.5)

2: Attach the Light Fixture

Since the light fixture is the end of the line, it is only connected to one backbone making it very easy to start with. Starting from the back of the board, feed the loose wires of one end into the light-fixture box so they will be ready to be attached to the **light fixture** (see light fixture text, p. 10).

The sheathed plastic wire backbone should now be prepared according to the directions in the analysis handout. There should be 6 inches of exposed wire on either end, and the insulated wire should have 1 inch of insulation stripped off. These wire ends are going to be attached to the device by screws, so you must create hooks on each of the three ends (p. 7, **connecting wire** text).

Remember, black is hot, white is neutral, and bare copper is ground. Attach the hot wire to the screw connected to the center contact of the light fixture. Attach the neutral wire to the outer-threaded ring contact for the fixture. Attach the ground wire to the ground screw in the metal box, or to the fixture itself.

You do not need to attach the light fixture to the board yet, but notice that the fixture slips onto the mounting screws.

3: The Receptacle

Now we must wire the receptacle (p. 9). We want the receptacle to be wired in parallel to the whole circuit. You are going to be connecting three components together here: the backbone wire coming from the light, the receptacle, and the backbone wiring that will soon lead to the switch.

All three of the connections must be pigtailed because we want the other devices in the circuit to work even if the receptacle fails for some reason.

First, feed the loose ends of the appropriate backbone wires into the receptacle box. You will need three pigtails for this task. A quick reminder about the anatomy of a receptacle, the short slot is hot and the tall slot is neutral. The screws on the corresponding sides are meant to connect to hot or neutral as is appropriate.

Take the hot (black) pigtail, and the two hot backbone leads, and twist these three wires together with your needle-nose pliers (p. 8). Cap this with a wirenut, and make sure only insulated wire is showing (bare wire could cause a short).

Repeat that step with the neutral wires, twist the three leads (two backbone leads, and one pigtail) together and cap with a wirenut.

Repeat that step again with the ground wires. Twist the leads, and cap with a wirenut.

You now have three pigtail ends, make a hook on the end of each one to screw it onto the receptacle. The ground wire can be screwed to the metal box or the receptacle. The hot wire should be connected to the hot slot on the receptacle, and the neutral wire should be connected to the neutral slot.

4: The Switch

Moving down the line, it is now time to install the switch (p. 10). Here, you will be attaching the backbone from the receptacle, the switch, and the backbone headed for the junction box. You will not use pigtailing here because the purpose of the switch is to interrupt the current, so you don't want the current to bypass the switch as a pigtail set-up does.

Feed the loose ends of the two backbone sections you mean to connect into the switch box.

Neutral Wire: Look at the schematic, and notice that the neutral wire doesn't go to the switch. This is because the switch doesn't need to be powered, its only job is to mechanically make a connection (or disconnect one). This means that the two white wires only need to be spliced together. So take needle-nose pliers or your multi-tool to grip and twist the wires together as shown in the wirenut photo in the other handout. Twist on the wirenut, and now the wires are connected and bypassing the switch.

Ground Wire: The ground requires the use of a pigtail for safety. Take the three ground ends (one pigtail and two backbone leads), and twist them together with your needle-nose pliers and twist on a wirenut. The other end of the ground pigtail must be turned into a hook and attached to the metal box, or the ground screw on the switch.

Finally we must deal with the hot leads. From the photo of the switch in the other handout, you will notice two screws on one side of the switch. These are the two connection points for each backbone hot lead. For safety, the switch controls the hot leads. Turn the hot leads into hooks and then attach them to the switch.

5: The Junction Box

Feed the sheathed backbone wire from the switch to the junction box (p. 3), and voila! You are done with assembly!

6: Testing your Connections

Attached is a schematic of all the points at which you need to test your board. Test the board with the light bulb **uninstalled** and the flip switch in the “on” position.

We can verify that the board is correctly wired by testing the resistance between various test points. You are going to test resistances on your board with a multimeter. You will do this before you connect to 120V.

What resistance readings mean:

If two points you are checking with your multi-meter probe are <u>connected</u>, then there will be almost <u>no resistance</u> between them because the current can flow freely in our low resistance wires.

If they are <u>not connected</u>, then there will be <u>“infinite” resistance</u>, and your multi-meter will read “OL”, as in overload. This is because the electrons cannot flow between disconnected points, and so there is unlimited resistance to the flow of electrons.

Examples:

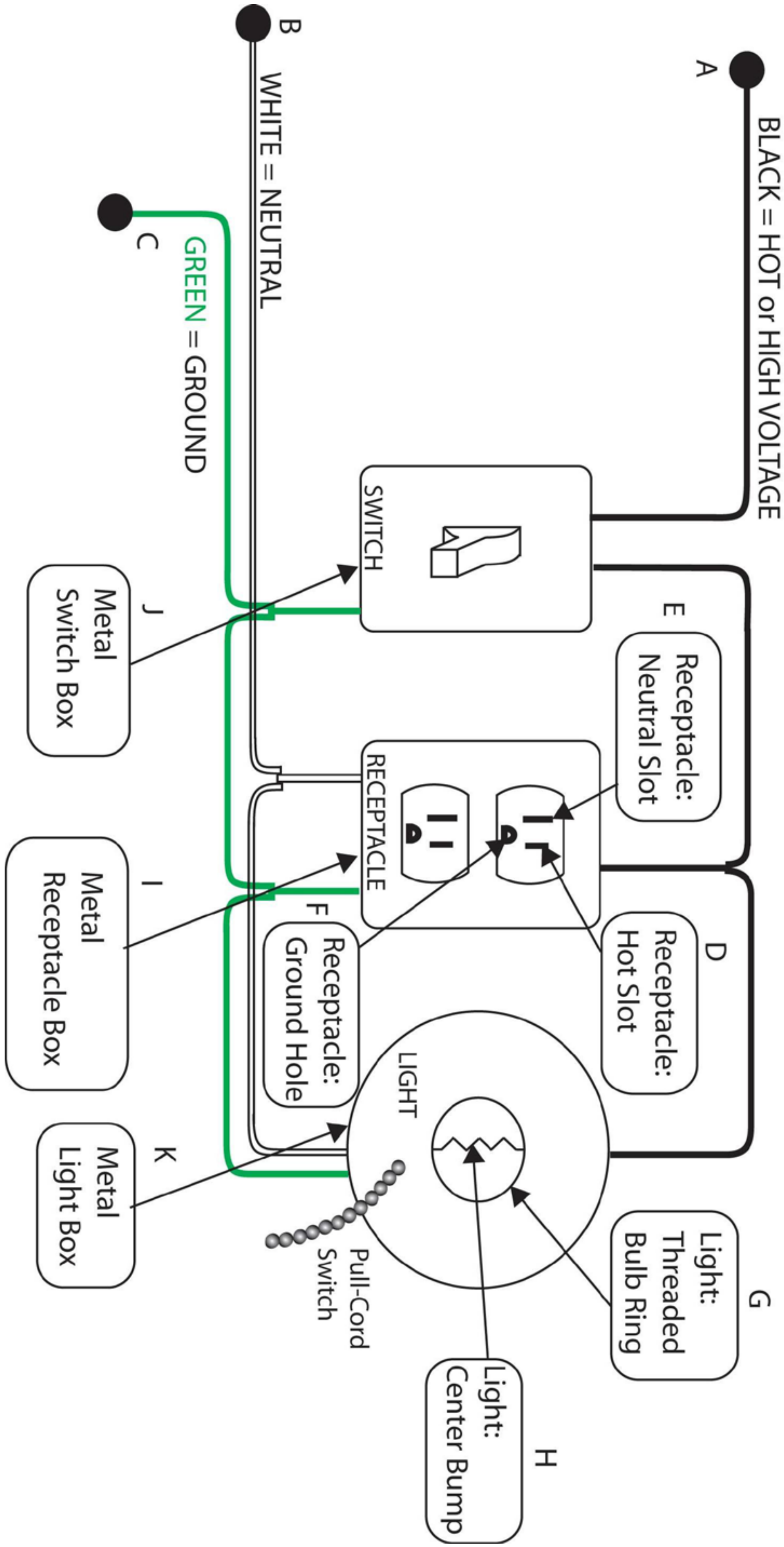
Place the multi-meter probes on points A and B of the diagram. They are not connected because nothing is plugged in the receptacle and the light bulb is not in the socket. The resistance should therefore read “OL”.

The neutral slot of the receptacle (point E) should be connected to the neutral lead (point B). Place one probe in the tall, neutral slot of the receptacle, and the other on the neutral lead. They are connected, so the resistance should read 0.

Practice:

For all of the following tests, we want the pull cord switch to be in the “on” position. If it is already in the “on” position then the center post (wired hot, point H) and the hot wire (point A) will have 0 resistance between them. Test this now. If there is ∞ resistance, then pull the cord and test again.

Fill in the following Excel chart with your **measurements** by testing the board with the multimeter. See if you observe resistances consistent with the correct resistances. If not, you have wiring problems and may need to re-work some of your connections.


A
BLACK = HOT or HIGH VOLTAGE
B
WHITE = NEUTRAL
C
GREEN = GROUND
SWITCH
RECEPTACLE
LIGHT
E
Receptacle: Neutral Slot
D
Receptacle: Hot Slot
F
Receptacle: Ground Hole
G
Light: Threaded Bulb Ring
H
Light: Center Bump
J
Metal Switch Box
I
Metal Receptacle Box
K
Metal Light Box
Pull-Cord Switch

Magnetism

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- ☐ 16 bolts
- ☐ 8 compasses
- ☐ 8 Petri dishes of paper-clips
- ☐ 8 rare earth magnets
  -STORED ON THE CABINET DOOR-

Shared/Consumable Components:

- ☐ 8 alligator leads cards
- ☐ 16 spools of copper wire
- ☐ 8 battery boards
- ☐ 1 small piece of sandpaper
- ☐ 16 ceramic Magnets
  (from Motors)
- ☐ 8 fur strips
  (from Static Electricity)

Optional:

- ☐ multimeters to check circuits

Optional demonstrations at instructor's request:

- ☐ 5H10.30 - Projection of the Fields of Permanent Magnets
- ☐ 5H15.40 - Projection of the Magnetic Field Due to a Current in a Solenoid
- ☐ 5H10.15 - Dip Needle

Other additions:

Special notes for instructor:

Instructor Outline: **Magnetism**

Lab length: 70-80 minutes
Lab objective: Instruct the students about magnetism, magnets, field lines, ferromagnetism, Earth's magnetosphere, and electromagnets.

Materials

1 battery board
1 alligator lead card
1 bolt
1 spool of copper wire
1 small piece of sandpaper
1 ceramic Magnet
1 compass
1 fur strip
1 Petri dish of paper-clips
1 rare earth magnet

Exploration stage: 30 minutes – group lab-work
The students detect the Earth's magnetic field with a compass, then detect a ceramic magnet, and compare the two fields. They then bring a ceramic magnet and a bolt near the paper clips and observe the behavior of each. Students rub the bolt to see if that makes a difference in its magnetism, and finally, they build an electromagnet and observe magnetic properties in the bolt.

Analysis stage: 15-20 minutes – lecture
The instructor analyzes with the class the findings in the exploration, and answers questions formed during that stage. Concept development is done on magnetism, field lines, ferromagnetism, electromagnets, and the Earth's magnetosphere.

Application stage: 15-20 minutes – group lab-work
The students work in groups to observe and explore the right hand rule. They observe three factors: magnetic field, electrical current, and movement.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

NOTE: Tell students to keep and label electromagnets for Relay & Buzzer lab.

Concepts developed:

1. Magnets have two poles that are always found together.
2. Magnetic fields indicate the direction of force on a magnet by another magnet.
3. The movement of a current-carrying wire depends on the direction of current **and orientation of the magnet.**

<u>Suggested Demonstrations:</u>

5H10.30 - Projection of the Fields of Permanent Magnets
5H15.40 - Projection of the Magnetic Field Due to a Current in a Solenoid
5H10.15 - Dip Needle

ANALYSIS: MAGNETISM

Every magnet has two poles: a north and a south pole. Electric charges can be found individually, as with a single proton or a single electron. Unlike electric charges, the two opposite poles of magnets are always found in pairs. Even when you induce a magnet, as with an electromagnet, two poles are formed.

In electrostatics we observed that charge could be built up from friction, rubbing materials with compatible electronegativity produced an excess of positive or negative charge. This is not the case with magnetism. Magnetic fields behave differently than electric fields.

The magnetic fields of magnets are represented by field lines. Widely spaced lines indicate a weak field; closely spaced lines indicate strong fields. If a small magnet is in a magnetic field, it will try to spin and orient itself along the field lines. This is often shown in classroom demonstrations with iron filings and a permanent bar magnet.

This is an artist's conception of Earth's magnetic fields in space. The Earth is a giant magnet whose magnetic field is observed all over the planet. This is why it is and has been used for navigation with compasses (small magnets); it provides orientation at any point on Earth. The Earth's magnetic field also extends well out into space and helps deflect charged particles from the sun called solar wind. Notice that the solar wind greatly distorts Earth's magnetic field lines.

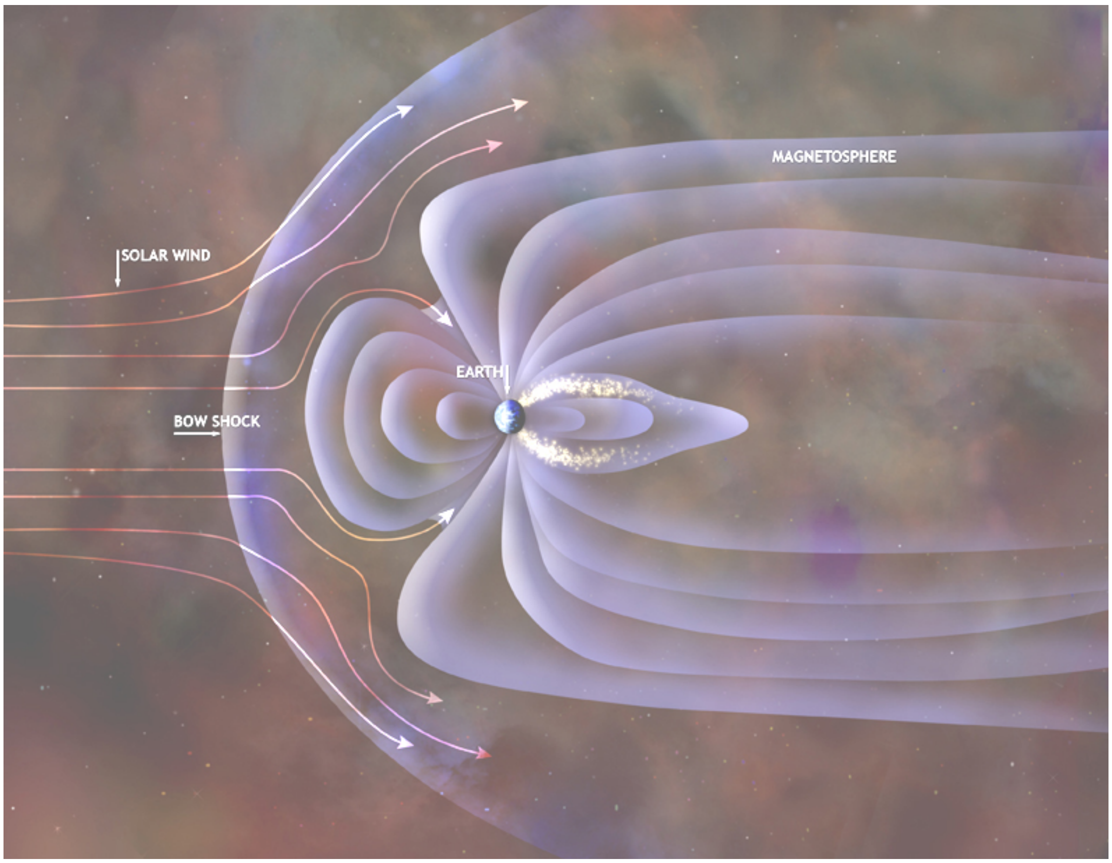


Figure 1: Earth's Magnetosphere, (NASA/CXC/SAO, 2006)

A large magnet is really just the sum of many small magnetic regions. When those regions are partially aligned then the object is considered to be a magnet.

Current passing through a wire creates a magnetic field. When a current-carrying wire is looped many times around a ferromagnetic core (a material susceptible to being magnetized), the device is an electromagnet.

MAGNETISM

Pre-Lab Question

How is magnetism different than electricity?

EXPLORATION

Materials

1 battery board
1 alligator lead card
1 bolt
1 spool of copper wire
1 ceramic Magnet
1 compass
1 fur strip
1 Petri dish of paper-clips

1. Magnetic poles are in some sense similar to electric charges. Opposites attract and likes repel. Since opposites attract, a compass' north pole will be attracted to the south pole of another compass. The north pole of a compass magnet points to the geographic north of the Earth. The Earth's magnetic field behaves like a giant internal bar magnet aligned almost along its axis.

Place the compass on the table away from any metal objects and observe how it is oriented. If you cannot escape metal objects, hold the compass in your hand. What is the orientation of the earth's magnetic field based on what you observe with a compass?

Discuss with your group and explain your conclusions.

Label the magnetic poles on the figure below.

Figure 1: Earth's geographic and magnetic poles

2. Take the ceramic magnet and bring it near the compass. Explain what happens and determine where the poles of the ceramic magnet are. Compare the ceramic magnet to the Earth's magnetic field.

3. Bring the ceramic magnet to the paper clips in the Petri dish, and then remove the magnet. Observe and explain what happens. Are the paper clips and magnet the same type of thing? Replace the paper clips to the dish.

Take the bolt and bring it near the paper clips. Compare the bolt to the ceramic magnet. Discuss with your group and explain what you've observed.

Take the strip of fur and rub the bolt. Bring the bolt near the paper clips and observe what happens. Compare to what you observed with static electricity. Discuss with you group and record your conclusions.

4. Take the spool of wire and use the wire to wind a coil around the bolt. **Leave roughly 10 cm (≈ 4 inches) of loose wire on the start and finish of your coil for making connections.** Consult the prototype at the front of the classroom for a sample if needed.

Sand 2 cm (≈ 1 inch) off the opposite ends of the wire. The copper wire is coated with insulating enamel which must be removed to reveal the bright copper color before a good electrical connection can be made.

Now that you have a 10 cm length of loose wire on each end of the bolt, with 2 cm sanded off, build a circuit with a 3V battery, a switch, and the bolt coil in series.

Close the switch and bring the rounded **head** of the bolt near the compass slowly. Open the switch. How is this different than what you observed with the bolt in step 3? Why is it different, what has changed with the bolt? Discuss with you group and record you conclusions.

Given what you've observed, is the magnetized bolt a north pole or a south pole? Explain your answer.

5. Close the switch again and bring the **tail** of the bolt near the compass. Open the switch and discuss your observations with your group. Does this agree with your north/south pole conclusion? Explain what type of magnet the bolt is.

6. With the switch open bring the magnet near the compass. Explain what you observe.

Challenge Work:

1. Touch a paper-clip to the ceramic magnet. Then bring the paperclip near the compass. What do you observe? Describe how magnets are magnetized.

Everyday Applications

- Earth's magnetosphere
- Aurora
- Car lifting magnets used at junk yards and in James Bond films
- Home alarm systems use electromagnetic contacts to see if windows or doors are opened.
- Magnetic tips are used on power drills to hold ferromagnetic screws more easily.

APPLICATION: A CURRENT IN THE PROXIMITY OF A MAGNET

Materials

1 Battery Board
1 Alligator Leads
1 Rare Earth Magnet

1. Wire the circuit as shown in the diagram below.

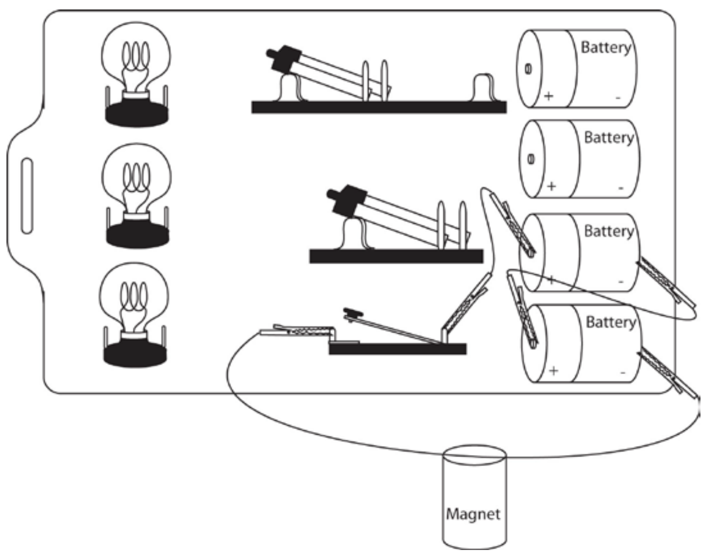


Figure 2: Battery Board wired for experiment

Make sure the circuit is wired as shown with the alligator lead wire draped lightly on top of the magnet (you can hold the wire loosely on top of the magnet if it will not stay otherwise). When this is done, press the momentary contact switch for a moment and observe very carefully what happens. Notice whether the wire moves up-and-down or side-to-side. Write your observations.

2. Flip the magnet and repeat the experiment. What is the difference, if any, depending on the side of the magnet? Record your observations.

3. Remove the magnet and repeat the experiment with the wire on the table. Does the wire behave differently than when there is a magnetic field present? Write down your observations.

4. Replace the magnet and hold the wire further away from the magnet than in previous trials. Repeat the experiment. Does the proximity of the wire to the magnet change how the wire reacts? Write down your observations.

5. Discuss in your group what factors you think contribute to the wire moving. Record your conclusions

Challenge Work:

1. Draw a diagram and explain how an electromagnet (like the one you built) works based on what you've observed with the wire.

Summary

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Return the sandpaper to the bin you took it from. **Save the bolt wound with wire, you will use it next time.** Label your bolt with masking tape.

Bibliography and recommendations for further reading:

Kurtus, Ron, "Magnetism," *School for Champions*, http://www.school-for-champions.com/science/magnetism.htm (accessed June 12, 2006).

Relay and Buzzer

Demonstration Lab Assembly

Dedicated Components
(located on shelf):

- ☐ 8 relay board

Saved Component
(from previous class):

- ☐ 8 bolts wound with wire

Shared/Consumable Components:

- ☐ 8 alligator lead card
- ☐ 8 Battery boards

Optional demonstrations at instructor's request:

- ☐ Killer Relay

Other additions:

Special notes for instructor:

Instructor Outline: **Relay and Buzzer**

Lab length: 55-70 minutes
Lab objective: Instruct the students about relays and circuitry.

Materials

1 battery board
1 alligator lead card
1 bolt wound with wire
(from previous lab)
1 relay board

Exploration stage: 20-30 minutes – group lab-work
The students observe the basic components of a relay. They attach their electromagnet and build a light bulb circuit operated by a normally open relay.

Analysis stage: 15-20 minutes – lecture
The instructor analyzes with the class the findings in the exploration, and answers questions formed during that stage. Concept development is done on electromagnets, normally open and closed relays, circuits, and the difference between and electromagnet and a permanent magnet.

Application stage: 20 minutes – group lab-work
The students build a self-frustrating relay, a buzzer.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. A current creates a magnetic field.
2. Permanent magnets are partially aligned, atomic scale magnets (having to do with spin and alignment of the material).
3. A buzzer is a negative feedback system.

Suggested Demonstrations:

Killer Relay

RELAY AND BUZZER

ANALYSIS

Relays

A relay is an electrical switch that is composed of an electromagnet and a pivoting connector. The relay can be one of two types: normally open or normally closed.

Normally open means that when the electromagnet is inactive (has no current and therefore no strong magnetic field) the switch is open. An open switch is not electrically connected, so no current can flow through the attached circuit. When the electromagnet is activated, the switch closes, completing the circuit.

Normally closed means when the electromagnet is inactive the switch is closed, so the attached circuit is completed. When the electromagnet is activated, it opens the circuit.

When the relay created its electrical connection, you heard a sound of the plate hitting the contact. Listening to the sounds from a relay just like you built is the essential technology that allowed incoming telegraph messages to be read in Morse code.

Relays are widely used. Doorbells and elevators use normally open relays. When you press the button an electromagnet is powered and a switch is closed to activate the device. Some fuses are examples of normally closed relays. They allow current to flow, but when there is too much current they open the switch.

Electromagnets and Permanent Magnets

You've seen the application of electromagnets where a current creates a magnetic field. What about permanent magnets?

It turns out on the atomic scale electrons themselves act as currents creating tiny magnetic fields. Normally, these fields are oriented randomly, but some materials allow the fields to align. Those materials are permanent magnets.

RELAY AND BUZZER

Pre-Lab Question

What is the difference between a permanent magnet and an electromagnet?

EXPLORATION

Materials

1 battery board
1 alligator lead card
1 bolt wound with wire (from previous lab)
1 relay board

1. Observe the structure of the relay board. The metal components are all aluminum except for the steel bar. Note that the connected metal components can conduct electricity.

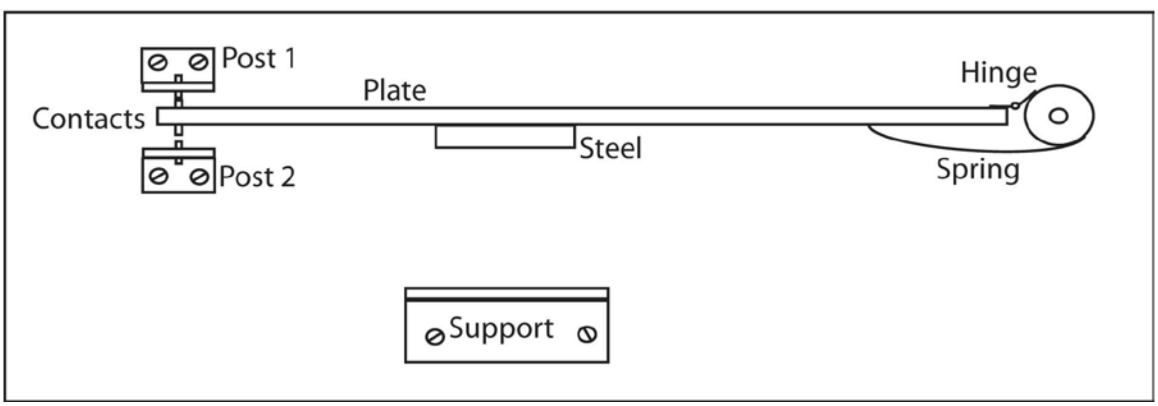


Figure 1: Bare Relay Board (top view)

Observe that the spring pushes the plate against post 1, creating a normal electrical connection between the plate and the top contact.

If a magnet is attached to the large support on the board, then it would attract the steel (just like a paper-clip). If the magnet is strong enough, then the plate will swing and connect with the bottom contact, overcoming the tension of the spring.

There are two competing forces, the magnetic field and the spring. If there is no magnetic field, then the spring pushes the plate against post 1. If there is a sufficiently strong magnetic field, then the plate swings and connects with post 2.

If an electromagnet is used, then the connection can be controlled with a switch.

Build the circuit drawn below to control the hinged plate's connections with the momentary contact switch. Use the bolt wound with wire your group built in the previous lab.

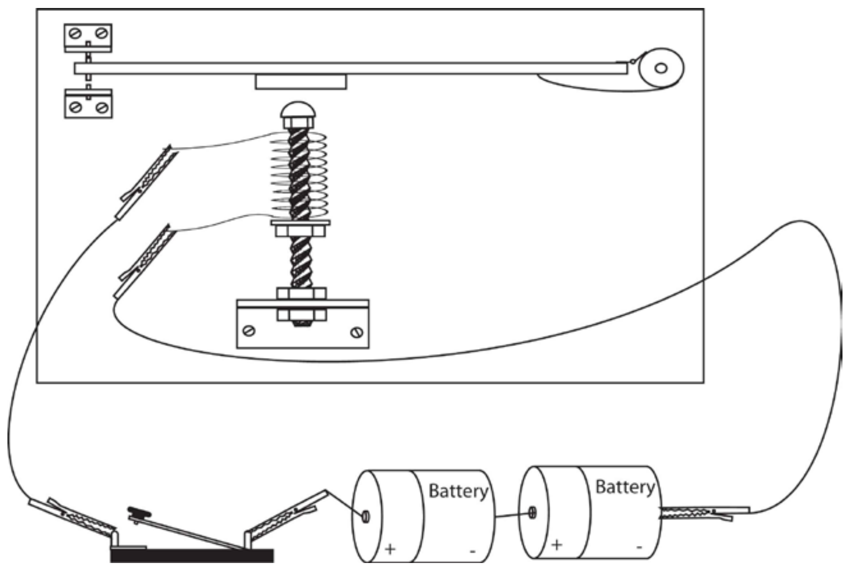


Figure 2: Wired Relay Board

Attach the bolt to the relay board with the two free-spinning nuts. Adjust the two nuts until the bolt is almost touching the hinged plate. Use the prototype in the front of the classroom for guidance if needed.

2. Press and release the momentary contact switch. Describe what happens.

3. Connect the relay board to a light and the remaining batteries on the battery board.

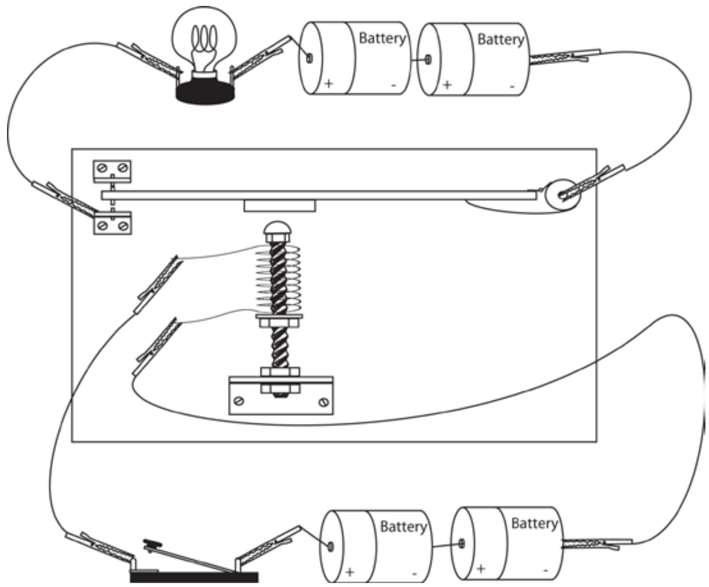


Figure 3: Relay Board with light

Notice that the two circuits are completely independent of each other.

4. Press the momentary contact switch. Observe and describe what happens.

5. Draw a schematic diagram for the circuit you just built. Try to invent a new symbol for the coil that is wound around the bolt. This coil is called a solenoid. Hint: make sure that you completely separate the two circuits.

Challenge Work:

Moving only one connection, change the board so the light goes out when you press the momentary contact switch. Doing so, you change the relay from normally open to normally closed.

Everyday Applications

- Telegraph
- Remote switches
- Elevators
- Doorbells
- Car power locks and windows
- Car turn signals

APPLICATION

Materials

1 battery board
1 alligator lead card
1 relay board with bolt

1. Build the circuit as shown below.

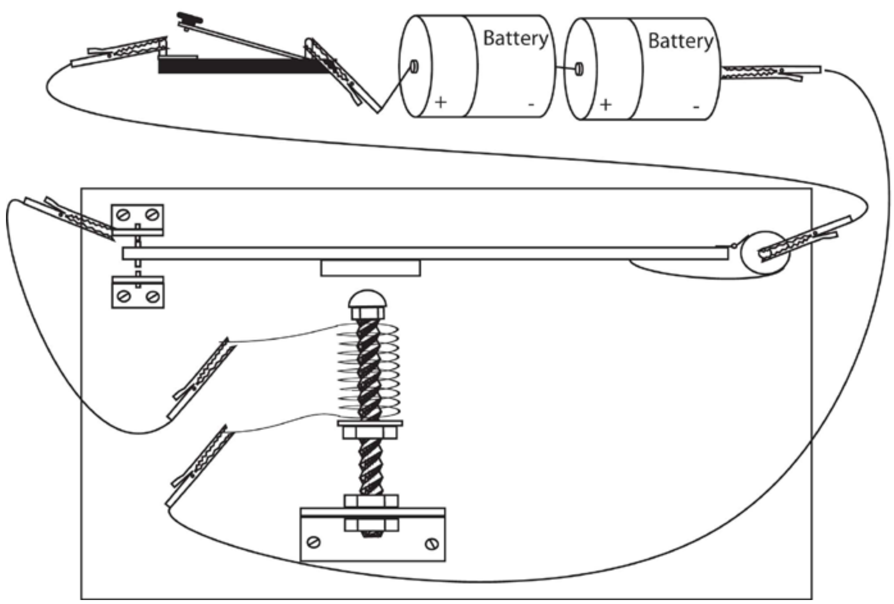


Figure 4: Battery Board with Relay Board

2. Press the momentary contact switch and observe what happens.

3. Explain how this buzzer works.

4. Draw a schematic diagram for the buzzer you just built.
Hint: make sure that you draw a single circuit now.

5. What is an application of this kind of device?

Challenge Work:

Which group can achieve the loudest buzzer? What variables can you change to make this happen? Note: Do not change or tweak the steel spring hinge!

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Remove the bolt from the relay board and replace the board to the cart. You are done with the bolt; it will be disassembled for you. Replace the battery board to the cart.

Motors and Generators

Demonstration Lab Assembly

Dedicated Components
(located on shelf):

- ☐ 8 Motor Board
- ☐ 8 Forms for Rotor
- ☐ 8 Wire spools for Rotor
- ☐ 16 Ceramic Magnets (black)
- ☐ 8 Hand Generators
- ☐ 8 Red LEDs
- ☐ 8 Capacitors

Shared/Consumable Components:

- ☐ 8 alligator lead cards
- ☐ 8 Battery boards
- ☐ 8 Multimeters
- ☐ Sand Paper
- ☐ 8 Pliers

Optional demonstrations at instructor's request:

- ☐ Torque Demo: Instruct a student to push a door open with one finger near the hinge and far from the hinge.
- ☐ 5H40.11 - Right Hand Rule
- ☐ 5H40.71 - Rolling Rod in a Magnetic Field

Other additions:

Special notes for instructor:

Instructor Outline: **Motors and Generators Lab**

Lab length: 70-80 minutes
Lab objective: Instruct the students about right hand rule, motors, generators, and torque.

Materials

Motor Board
Form for Rotor
Wire for Rotor
Sand Paper
2 Ceramic Magnets (black)
Battery Board
Alligator Leads
Rare Earth Magnet (silver)
Multimeter
Hand Generator
Red LED
Capacitor
Pliers

Analysis - motors: 10 minutes – lecture
The lecturer does concept development for motors, explains how the motor effect is defined by the right hand rule. A RHR demo may be useful here. Explain how an apparatus can be built that takes advantage of that rule and produces torque and a rotating motor. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Exploration – motors and generators: 30-40 minutes – group lab work
The students build motors according to the apparatus described in the Analysis stage. It takes them a lot of time to build a well balanced motor, but their motors will work much better. They must explore and find what features control the direction of rotation. The students unplug their motors and observe a voltage across the posts when the motor is rotating. They double up the magnets, and observe a higher voltage.

Analysis - generators: 10 minutes – lecture
The lecturer does concept development for generators. Explain how they are the inverse of a motor, and some of Faraday's law. The students can use the analysis text to follow during the lecture, read it at a later time, or use it as a reference only.

Application - generators: 15 minutes – group lab work
Students interact with a DC hand generator, measure the voltage it produces and use it to light an LED and charge a capacitor. Finally, they get a sample of current direction by reversing the leads on the LED.

Summary: 5 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts Developed:

1. Motors use the right hand rule to convert electrical energy into mechanical energy.
2. Generators convert mechanical energy into electrical energy.

<u>Suggested Demos:</u>
Torque Demo: Instruct a student to push a door open with one finger near the hinge and far from the hinge.
5H40.11 - Right Hand Rule
5H40.71 - Rolling Rod in a Magnetic Field

Motors and Generators Lab

ANALYSIS: THE MOTOR

An electrical current near a magnet undergoes a force resulting in movement. A more sophisticated way of phrasing it is that we can convert electrical energy into mechanical energy.

Motors are a specific form of converting electrical energy into **rotating** mechanical energy we are going to focus on in this lab. The characteristic feature of a motor is that it rotates. The simple function of rotating has extensive applications in our everyday lives because it is what makes garbage disposals, fans, power windows, CD players, and washing machines work. Before we go further into motors, we must first understand what happens when a magnet makes a current carrying wire move.

Force on a Wire

When a current is traveling through a magnetic field, the magnet exerts a force on that wire and moves it in a specific direction. The factors that control the direction of the wire's movement are the polarity of the magnetic field and the direction of current in the wire. The wire's movement direction can be determined using something called the right-hand rule for reasons that will be explained shortly.

Direction of Magnet:
Physicists have chosen a direction to magnetic field lines: magnetic field lines point from a north pole to a south pole.

Direction of a Current:
Physicists also have chosen a direction for current (*I*) flow in a wire. Current travels from positive voltage (+) to negative voltage (-).

Direction of wire movement:
The wire moves in a direction perpendicular to both the direction of the magnetic field and the direction of the current flow as shown in Fig. 1.

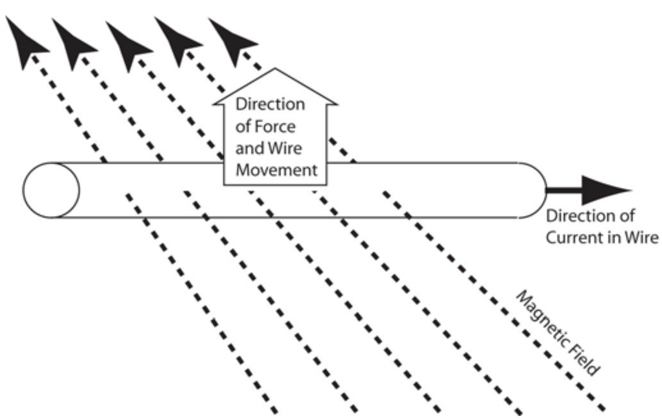


Figure 1: Direction of Magnet, Current, and Movement

The three perpendicular directions are related by the right hand rule. The right hand rule says that if the direction of the thumb is the direction of the current or charge, the direction of the first finger pointing up is the direction of the magnetic field, and the second finger pointing perpendicular from both is the direction of force. All of these directions are perpendicular from one another, which is to say that they are all at 90º angles. You can see this relationship in the photo below.

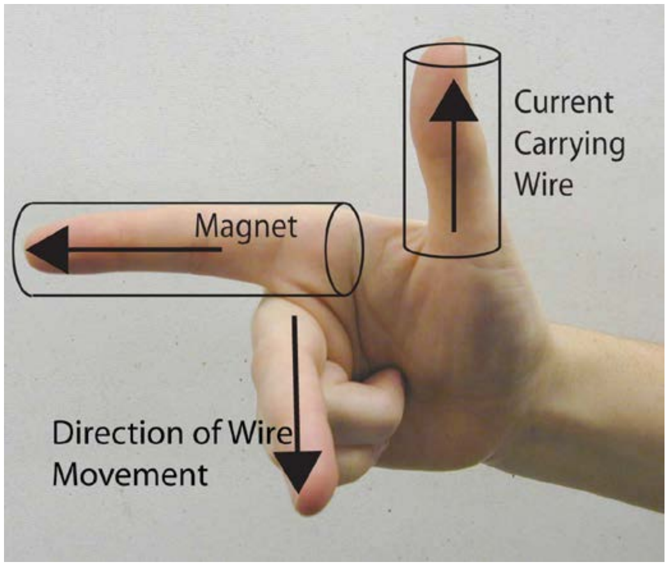


Figure 2: Right hand rule: mutually perpendicular directions

Use your right hand to visualize the diagram in Figure 2 as also an application of the right hand rule. Beware using your left hand by accident!

Rotation

How do we convert this reaction of the wire into a rotating motor device? If we pass the current in two directions, forces are created in two opposite directions.

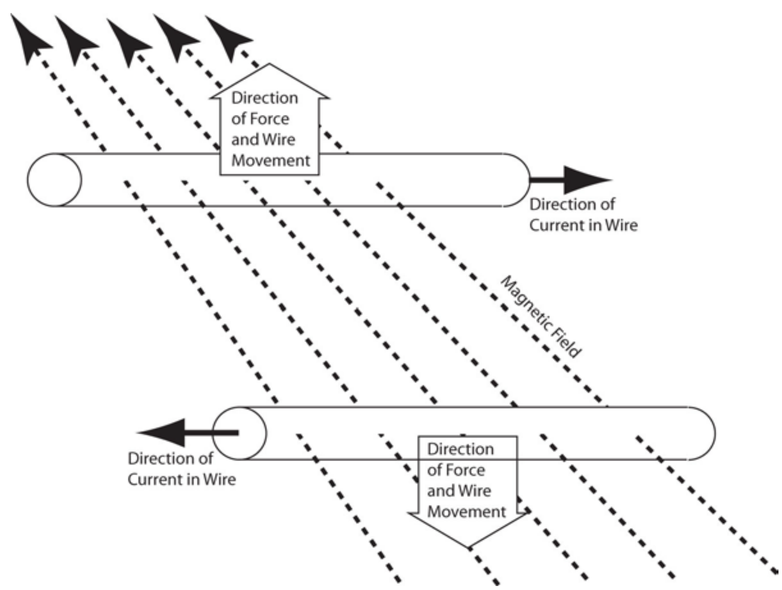


Figure 3: Rotating Apparatus

If those wires are connected on a rigid axis, then the opposite forces will cause a torque. Torque (also called leverage) is the relationship between the amount of force exerted and the distance of the force from the axis of rotation. It turns out that if you exert the force at a distance from the axis, you will exert more rotational force (torque) than if you exerted the force near the axis. This is the reason why wrenches are used to tighten and loosen bolts and why door-knobs are located on the distant side of the door from the hinges.

Now consider how these forces will make the system behave for a loop of current carrying wire on an axle. The two regions of the current carrying wire (with current in opposite direction) elicit forces in opposite directions. That kind of mechanism is similar to the velocity vectors of a wheel, and is the kind of force that can generate rotation if the device is mounted on an axle.

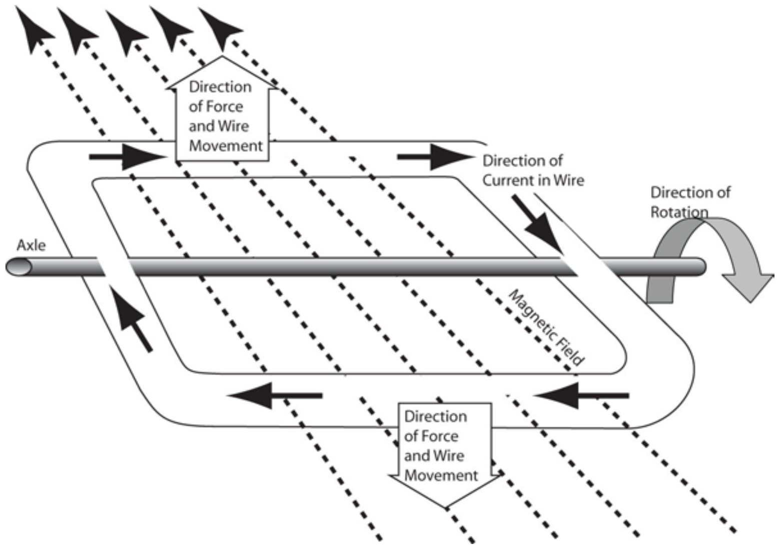


Figure 4: Rotating apparatus includes axle, magnetic field, and current carrying wire.

We can even enhance this effect by making many overlapping loops with the wire. We call this pile of loops a rotor, and the enhanced force from having many loops, high current, or a strong magnet can be powerful enough to run a blender or turn the wheels on electric vehicles.

But, there's a catch…

What is outlined above describes the initial forces that start the motor spinning in a perfectly symmetric motor. Once the system rotates 180º the force reverses itself. This means the rotor first builds angular speed and then loses it until it reverses direction. This creates a situation where the rotor is oscillating rather than spinning, and very inefficiently too.

There are two ways to solve this problem:

1. Stop the current half the time.
2. Reverse the current every half rotation.

We're only going to concern ourselves with the first case. The rotor gets current at a junction at the end of its axis which is called a commutator. The junction has to be free spinning so it doesn't bind up as the motor rotates. The motor we're building simply be rests on two conductive supports so that it can freely spin. To only allow current through half the time, the commutator can be polished so that it only makes electrical contact half the time, and is insulated the other half the time.

This is very inefficient; the motor only experiences a force compelling it to spin half the time. But, it is very easy to do and is the technique we will use in our motors. You can see how this works in the figure below.

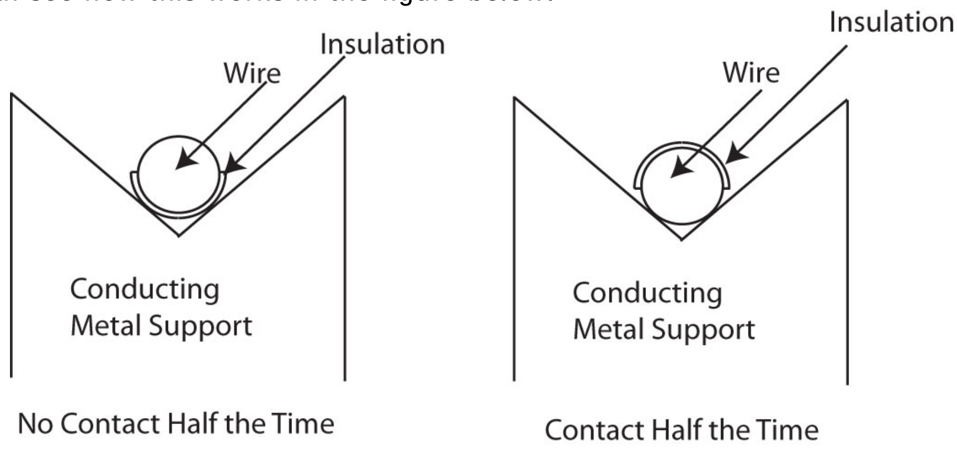


Figure 5: Half-Time Commutator

Now the rotor will only experience a force in one angular direction, and will spin successfully.

ANALYSIS: ELECTROMAGNETIC INDUCTION

Earlier you observed that a magnet and current carrying wire produce wire movement.

Now you've observed that a magnet and wire movement produces current.

The phenomenon that powers a motor works in reverse! Earlier we observed that electrical energy can be converted into mechanical energy, now we are observing that mechanical energy can be converted into electrical energy. This has many fantastic applications as far as energy production is concerned.

The phenomenon is known as electromagnetic induction and is described by Faraday's law. Faraday's law states that a voltage is induced when a conducting wire is in the presence of a changing magnetic field. When you spin the rotor in the presence of a magnetic field, a current is induced in a closed circuit.

MOTORS AND GENERATORS

EXPLORATION: Building a motor and generator

Materials

Battery Board
2 Ceramic Magnets
Motor Board (with conductive supports)
Form for Rotor
Wire for Rotor
Sand paper
Pliers
Multimeter

You are going to build a motor. There are four components to this motor: a rotor, a conductive support, a power supply, and a magnet.

Motor:

1. Wind the Rotor

A rotor is basically a stack of loops mounted on an axle. To build one you must turn the provided copper wire around the wooden form as many times as possible (more loops = more force). You must also leave 4 inches on either end to shape your axle. Figure 6 shows a sample rotor and axle. Make sure your axle is long enough to balance the rotor on the conductive supports.

Optimize the rotor:
An evenly balanced rotor will be a better motor (you will get more revolutions using less power)! Balanced means the motor doesn't have a preferred (heavy) side that falls down when placed on the Motor Board posts.

If the coils are tightly wound the motor will be more balanced, so wind tightly!
Make the axle perfectly balanced. The axle should be centered on the rotor both from top-to-bottom and side-to-side. Side-to-side is achieved by threading the axle through the rotor loops using a pair of pliers. Take the opportunity to inspect the model in the front of the classroom.

The rotor is to be balanced on the motor board with the ceramic magnet as shown below.

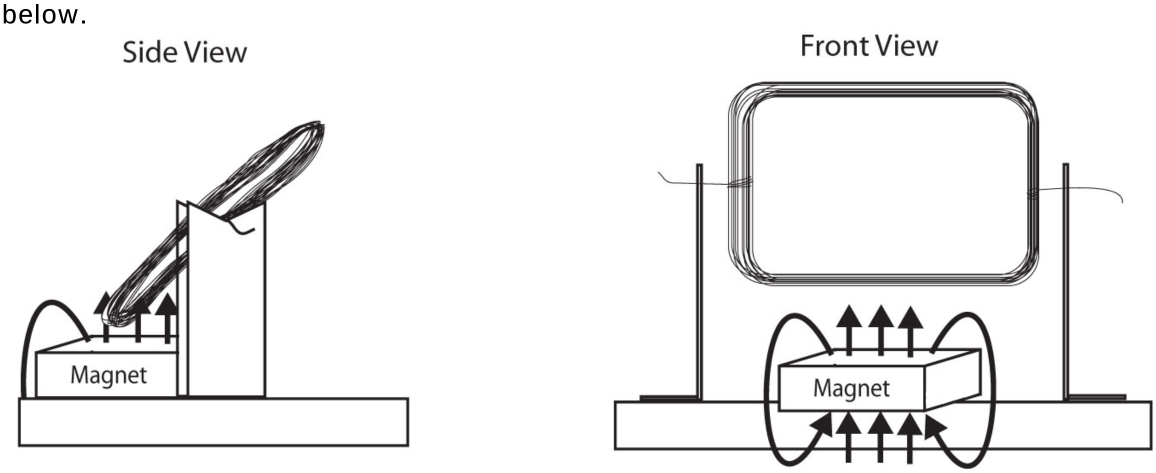


Figure 1: Motor Set-up

2. Sand the ends of the axle

The rotor needs one final refinement to be functional; the commutator must be built. The copper wire comes already insulated with a layer of enamel. If you remove the insulation from a portion of the wire ends then they will permit current to flow half the time. These points on the axle are the commutators. The two ends must be symmetrical for the device to work. The easiest way to sand the device is when it is laying flat on the table. **Sand the same half on each end.**

3. Assemble the rotor board

Mount the rotor on the motor board according to the diagram in figure 1. Include the magnet.

4. Add power

Wire the battery board to produce 3V and wire it to an open switch. Connect the power across the motor board. Clip the alligator leads to the support posts, not directly to the axle so the axle can spin freely. There will be electrical contact between the supports and the sanded portion of the wire.

You are now ready to test your motor. Close the switch. You may have to bump start the motor with your finger. Observe what happens, and record your observations below.

You can optimize your rotor by adjusting the position of the magnet. Move the magnet around to see which locations produce the most revolutions per minute. Draw a diagram of the optimal magnet placement.

There are variables in the set-up you just built that control which direction the motor spins (clockwise or counter-clockwise). Explore the components of this set-up and find two different ways of changing the direction of rotation. Record your findings below.

Generator

1. Start with your assembled motor. **You will not be powering the motor with batteries**, so disconnect the power leads so the motor is without power and stationary. Set the multimeter to V_{DC} (DC voltage reader) and have one group member measure the voltage across the motor supports, one lead on each post. Record the voltage of the stationary coil first. While the multimeter is on the posts, have another group member spin the motor by flicking it with their finger; the faster the spin, the better. Observe the voltage of the spinning motor and record.

Stationary Coil Voltage: ________________.

Rotating Coil Voltage: __________________.

Discuss in your group what you have observed and repeat the experiment if desired. Record and explain your observations below.

2. Two Magnets

As with the motor, there are variables you can change. Stack a second magnet onto the first one.

Offset the magnets slightly so the rotor doesn't hit them. Measure the stationary and rotating voltages again.

Stationary Coil Voltage: ______________.

Rotating Coil Voltage: _______________.

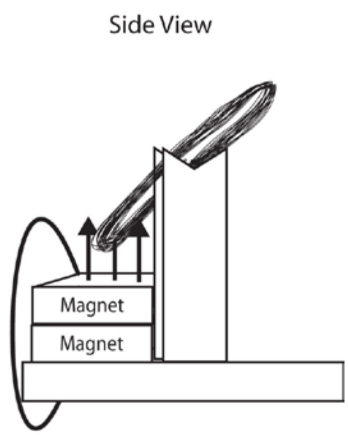
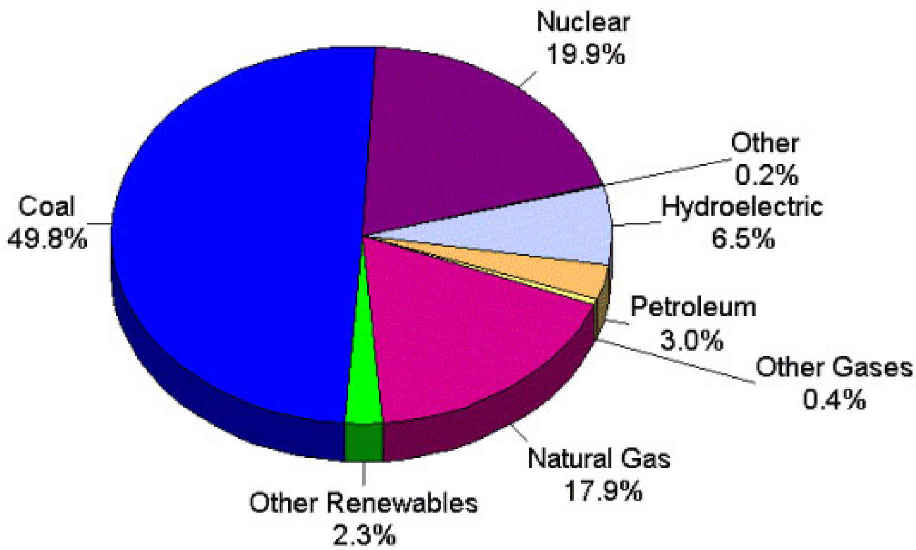


Figure 2: Two magnet set-up

Discuss in your group what you have observed and repeat the experiment if desired. Record your observations below.

Everyday Applications

- Motors are used everywhere! If it spins electronically (and often if it just moves) a motor is behind it: Blenders, electric screwdrivers, fans, power windows, hard drives, CD players (twice, to spin the disc and to open the tray), food processors, garbage disposal, garage door opener, electric golf cart wheels, vacuum cleaner, washing machine, and more.
- Almost ALL the electrical power that we use every day is derived from energy sources with the use of a generator. The graph below shows electrical energy sources of the U.S. for the year 2004.[1] The only exception is solar energy (under "Other Renewables") which constitutes less than 2.3%. That means more than 97.7% of energy we use is produced by generators.



[1] DOE, "U.S. Electric Power Industry Net Generation," *Energy Information Administration,* http://www.eia.doe.gov/cneaf/electricity/epa/figes2.html (accessed May 10, 2006).

APPLICATION: GENERATORS

Materials

Hand Generator
Red LED
Capacitor
Multimeter
Battery board

The hand generator is an engineered version of the motor/generator you built. It also has a commutator, magnet, and coil. When it is rotated, a current is sent through the two leads. Make sure the generator leads are attached correctly (as labeled with a red paint pen).

1. Attach the hand generator to the multimeter and set the multimeter to V_{DC}. Rotate the generator in the direction of the arrow drawn on the generator. First, rotate the generator quickly and record the voltage you observe below. Second, rotate the generator slowly and record the voltage below.

Hand Generator Voltage – Fast Rotation: ______________.

Hand Generator Voltage – Slow Rotation: _______________.

Discuss in your group your findings in terms of what you have learned about generators and record your conclusions below.

2. Attach the leads of the generator to the red LED. Attach the painted red lead to the painted red contact on the LED. Rotate the generator in the direction of the arrow, record your observations below.

3. Attach the leads of the generator to the capacitor. Attach the painted red lead to the painted red contact on the capacitor. Rotate the generator twenty times in the direction of the arrow. Stop rotating the generator, release the handle and count the number of rotations. Did you recover all your rotations? Record your observations.

4. Attach the leads to the LED again, but this time in reverse. Rotate the generator in the direction of the arrow. Discuss your observations with your group and record your conclusions.

5. Attach the generator leads to a light bulb on the battery board. Rotate the generator. Reverse the leads and rotate the generator again. Discuss your observations with your group. Does the behavior of the incandescent bulb agree with your conclusions about the LED?

Summary

Final Clean-up
Please disconnect all alligator leads and reattach them to the clip card. Return all equipment to the carts.

Shaker Flashlight

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- ☐ 8 Shaker flashlight boards
- ☐ 8 Magnet tubes
- ☐ 8 coils w/ leads

Shared/Consumable Components:

- ☐ 8 Multimeters
- ☐ 8 Rare earth magnets
(on inside door of magnetism lab)
- ☐ Alligator leads

Optional demonstrations at instructor's request:

- ☐ Oscilloscope and AC source
- ☐ 5L30.10 - Diode Rectifier Display Board
- ☐ 5K10.21 - Electromagnetic Induction Projectual
- ☐ Commercial Shaker Flashlight

Other additions:

Special notes for instructor:

Instructor Outline: **Shaker Flashlight**

Lab length: 75-85 minutes
Lab objective: Instructs students about diodes and applies a number of other circuit and electronic components the students have learned about (capacitors, generators, and relays).

Materials

Shaker Flashlight board
Hand generator components
Alligator leads
Rare earth magnet
Multimeter

Exploration stage: 15 minutes – group lab-work
The students explore how a diode behaves in a circuit (with a simple diode and an LED) and the type of current a hand generator produces.

Analysis stage: 20 minutes – lecture
The instructor analyzes the findings in the exploration stage, and answers questions formed during that stage. Concept development is done on diodes, AC, DC, and full-wave bridge rectifiers. Use of an oscilloscope with an AC and DC source is strongly recommended.

Application stage: 30-40 minutes – group lab-work
The students build a full-wave bridge rectifier. The student's goal is to repair the flashlight "flaws:" flickering, shaking, and inefficient use of energy. The rectifier repairs the efficiency (let them notice the double flashing of the diodes as the magnet enters and leaves the solenoid); the capacitor repairs both the strobe effect and the shaking problem by providing a steady voltage source and a storage device.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to formalize the series and parallel observations that were just made.

Concepts developed:

1. Diodes only allow current to flow in one direction (up to a designated voltage)
2. DC flows in only one direction is either positive or negative voltage.
3. AC flows in both directions, and represents both positive and negative voltage.
4. Full-wave bridge rectifiers rectify AC into DC by routing current flow from an AC source.

<u>Suggested Demonstrations:</u>

5K10.21 - Electromagnetic Induction Projectual
Oscilloscope w/ AC and DC sources
Commercial Shaker Flashlight

SHAKER FLASHLIGHT

ANALYSIS

To build an optimized shaker flashlight, you must use the diodes to route the current produced by the hand generator into a constant source that can power the LED continuously.

DC and AC

There are two types of current: DC and AC. These acronyms stand for direct current and alternating current.

Simple Definitions:
Batteries and capacitors are examples of **direct current** sources; they produce voltage with constant sign as time goes on (either positive or negative).

AC generators produce the power that we use from wall sockets and are examples of **alternating current** sources; they produce a voltage with alternating sign that changes from positive to negative voltage.

A positive or negative voltage merely denotes the direction of current flow in a circuit. If you measure from upstream to downstream, the voltage is positive. If you measure from downstream to upstream, the voltage is negative.

Positive and Negative Voltage

A positive voltage denotes current flow in a certain direction (from positive to negative). A negative voltage denotes current flow in the opposite direction (from negative to positive).

Look at the diagrams below to understand a positive direct current.

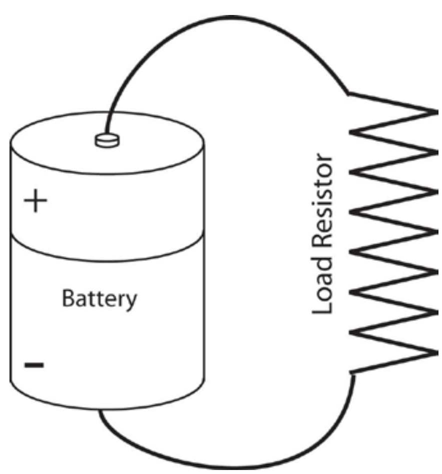


Figure 1: A simple circuit of a battery and resistor.

We cannot measure the voltage with a multimeter; we need another device that is more precise called an oscilloscope. It responds very quickly to voltage changes in contrast to a multimeter, which averages voltage over several seconds. An oscilloscope measures voltage versus time. We connect the positive and negative leads from the oscilloscope to the circuit as shown and measure the voltage. The signal will be green; the zero line will be drawn in black.

Positive Voltage

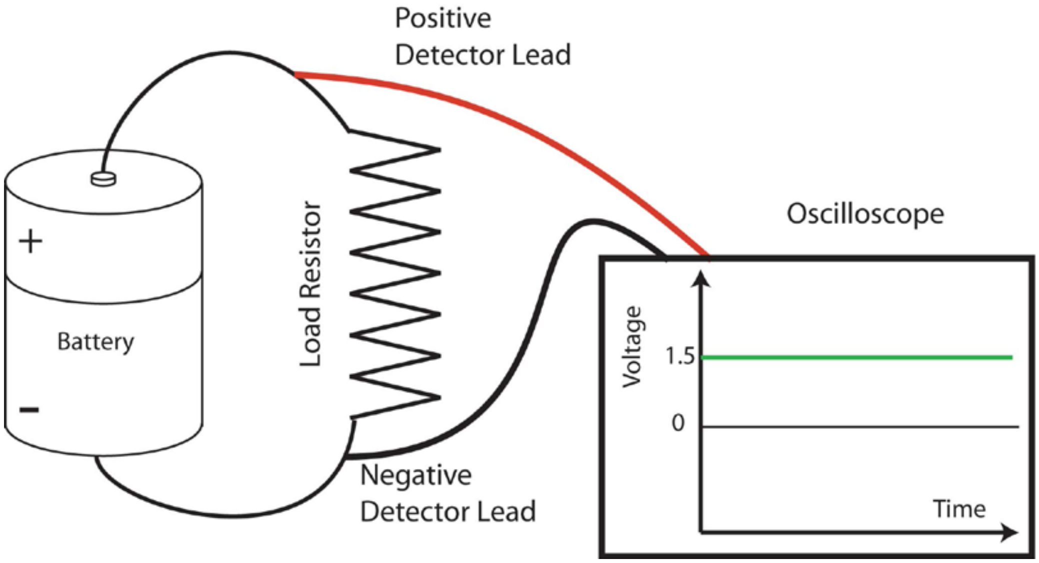


Figure 2: Measuring the voltage of the simple circuit.

If we look at the oscilloscope, we will see the green signal is at 1.5V the whole time. A constant sign means that the current is flowing in the same direction the whole time, in this case in the clockwise direction from our point of view. Since the current is flowing only in the clockwise direction, the battery is a direct current source. In the real world, the battery will eventually die and the voltage will reduce to zero, but it will always be positive in this system. The oscilloscope is a tool that measures the voltage with time and the direction of the current giving a positive or negative signal.

To observe a system with **negative voltage** is very simple: reverse the battery.

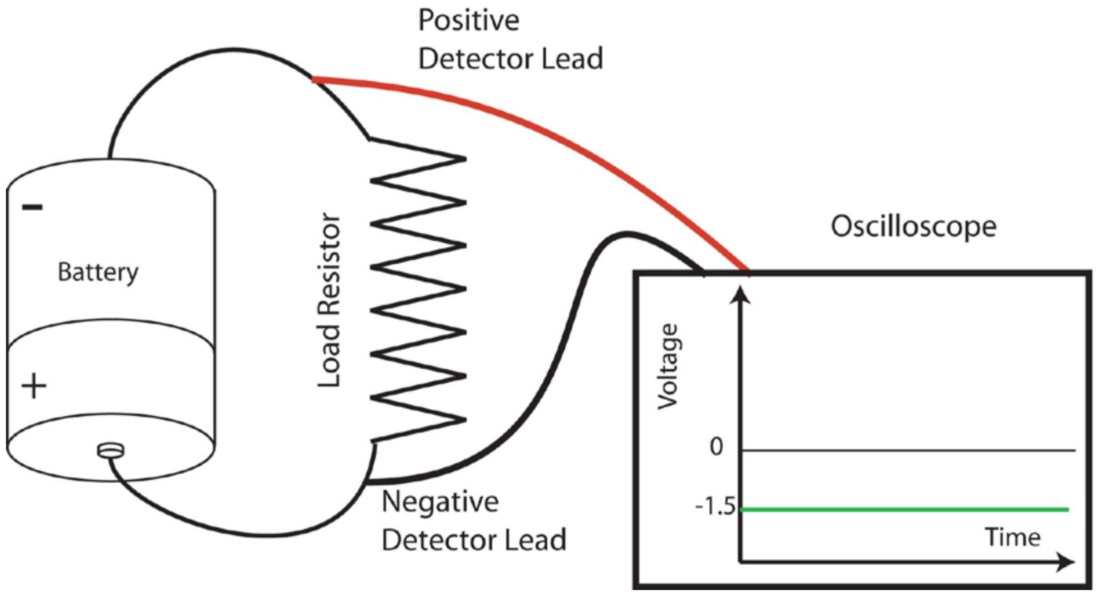


Figure 3: Measuring the voltage of the simple circuit with current reversed.

When we flip the battery, we change the direction of current flow from clockwise to counter-clockwise. Now, when the oscilloscope reads the voltage it still observes that there is a constant voltage with time (because this is still a direct current source), but that the voltage is negative. This time the current is flowing in the reverse direction.
We know what positive and negative voltages look like; they simply reflect the direction of current flow from a source. We've also seen the direct current example: a source with constant voltage that can be either positive or negative.

Alternating Current

Alternating current is a very different case from direct current. Below is an example of what an alternating current source looks like to an oscilloscope.

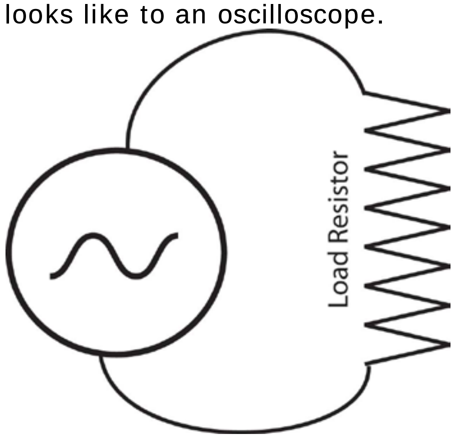


Figure 4: This is a simple AC circuit. The squiggly symbol is for an AC source, and we are using the same basic load resistor as in the direct current circuit to measure voltage.

Now we're going to measure the voltage across the resistor with the oscilloscope that measures voltage with time.

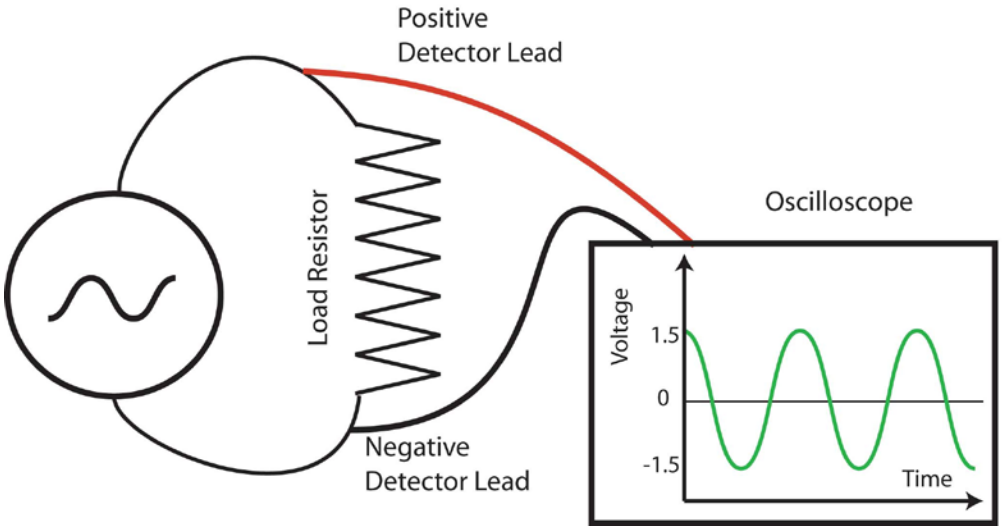


Figure 5: Measuring the voltage of the AC circuit

The signal is green, and we see that the voltage is alternating between positive and negative as a sine wave. It spends half the time positive, and half the time negative. This means that the current flows in one direction, slows down, flows in the other direction, slows down again, and then repeats this pattern as time goes on.

A negative voltage is not the same thing as zero voltage. Most devices don't care which way the potential is oriented when they are working. A light bulb is an example: the filament lights up all the time it is plugged into the AC power of the wall. It is not lit only half the time because it doesn't care which way the electrons are flowing, it lights up because electrons are flowing. It doesn't bother the filament that the electrons change their mind; it stays lit the whole time because there is always movement.

But some devices (diodes) do care which direction the electrons are flowing, and so we use diode rectifiers to redirect the current flow.

Diodes

Diodes are the electronic version of a turnstile. The turnstile only allows people to pass in the one direction. Diodes only allow current to flow in one direction. Otherwise current is not permitted to flow in the circuit. Let's see what happens when one diode is added to an AC circuit.

The symbol for a diode is:  The arrow points in the direction the current is allowed to flow (from + to -).

Figure 6: Turnstile

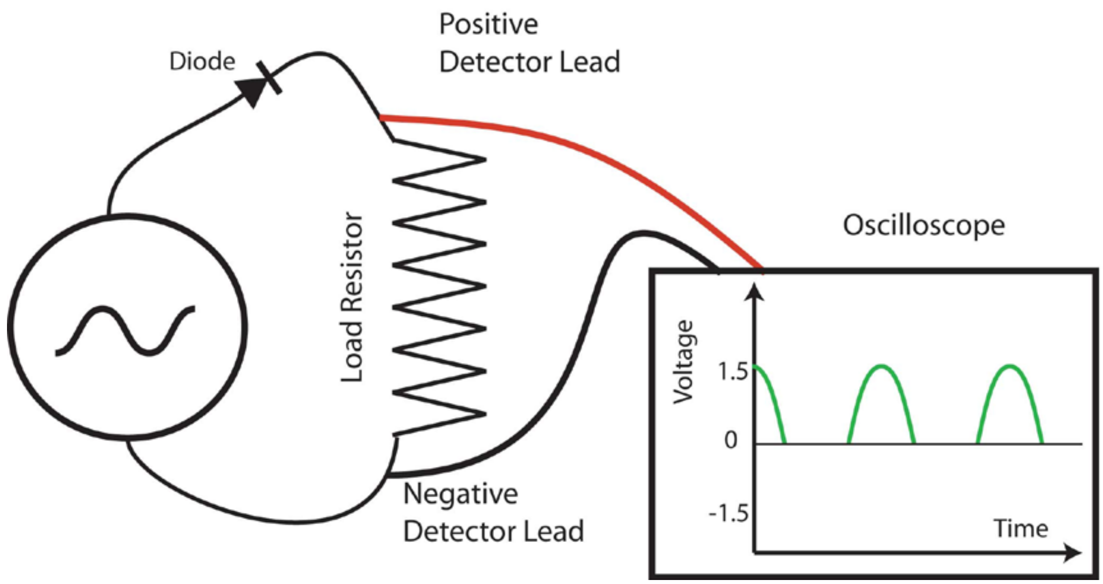


Figure 7: AC source with diode

Notice that in this circuit, we only observe the positive voltage. The diode stopped the flow of current when the AC source reversed the direction of its flow. This produces a positive voltage, but only half the time. This is now a pulsed DC source. What would happen if we reversed the diode?

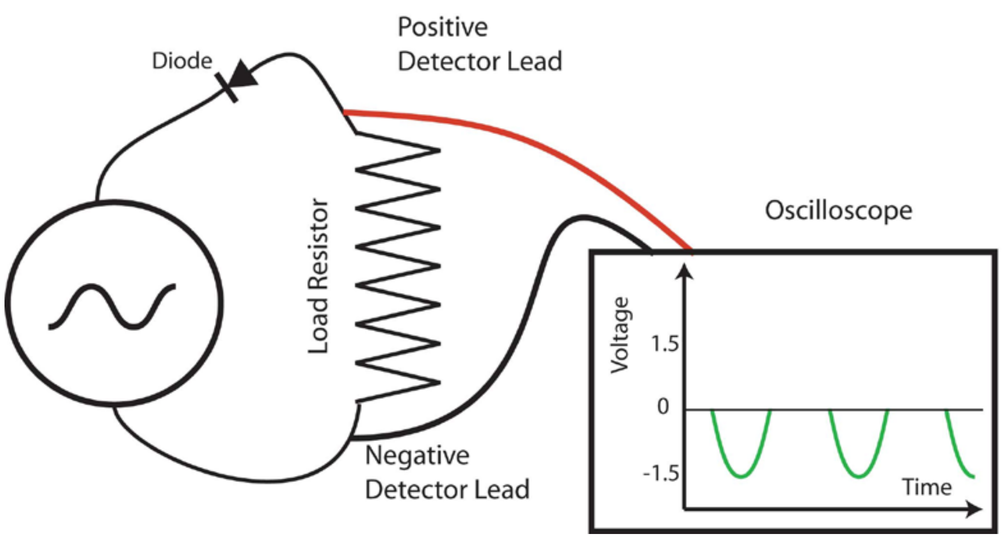


Figure 8: Same AC source with reversed diode

This time, the current flows only in the opposite direction, a negative voltage. This is now a pulsed DC system with a negative voltage.

If we were to use one diode in a circuit, we would lose half of the energy produced by the AC source. That is why a combination of diodes is commonly used to redirect (also called rectify) the current flow efficiently. This combination is called a full-wave bridge rectifier.

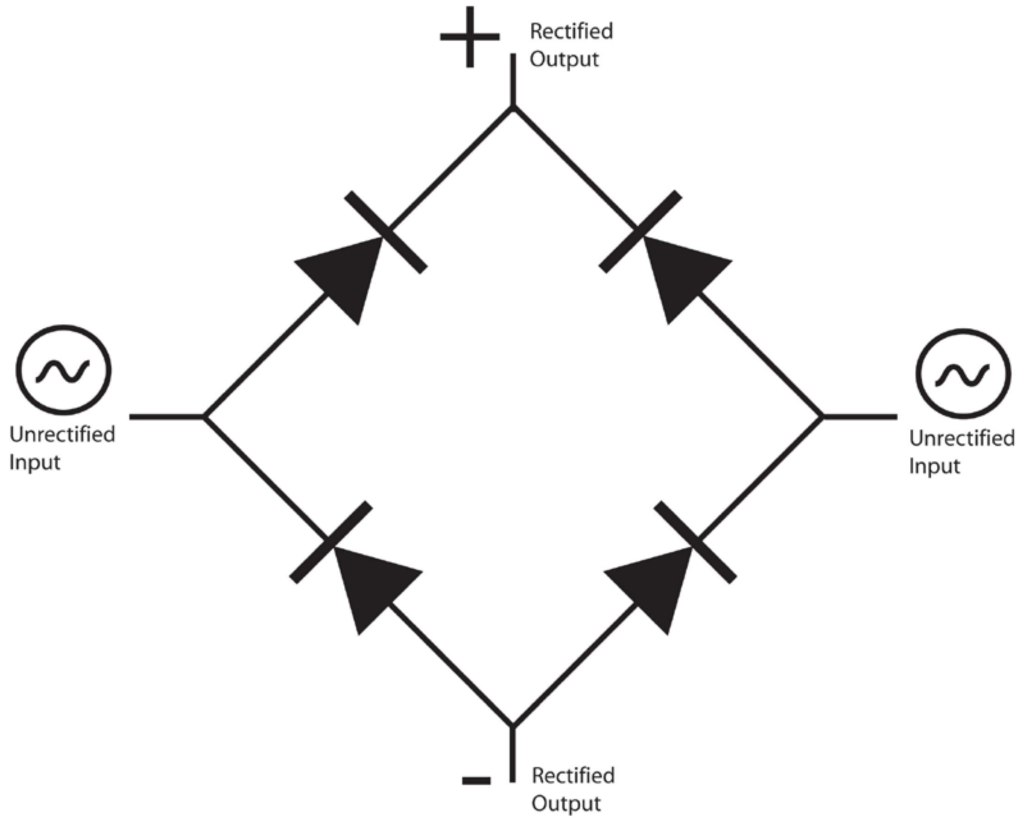


Figure 9: Full-wave Bridge Rectifier

This diagram shows the schematic for a full-wave bridge rectifier. When you attach the two inputs for the rectifier to the two outputs of an AC source, it rectifies the current and produces a direct current output. In short, a diode rectifier converts an AC source into a DC source. The **positive and negative outputs are connected** via the electronic device you are powering, which for our purposes can be a simple resistor again.

This is a very complicated schematic, but the principle is simple. The current flows in the direction of the arrows. Let's say the first direction of flow from the AC source is from left to right. Here is what the path will look like:

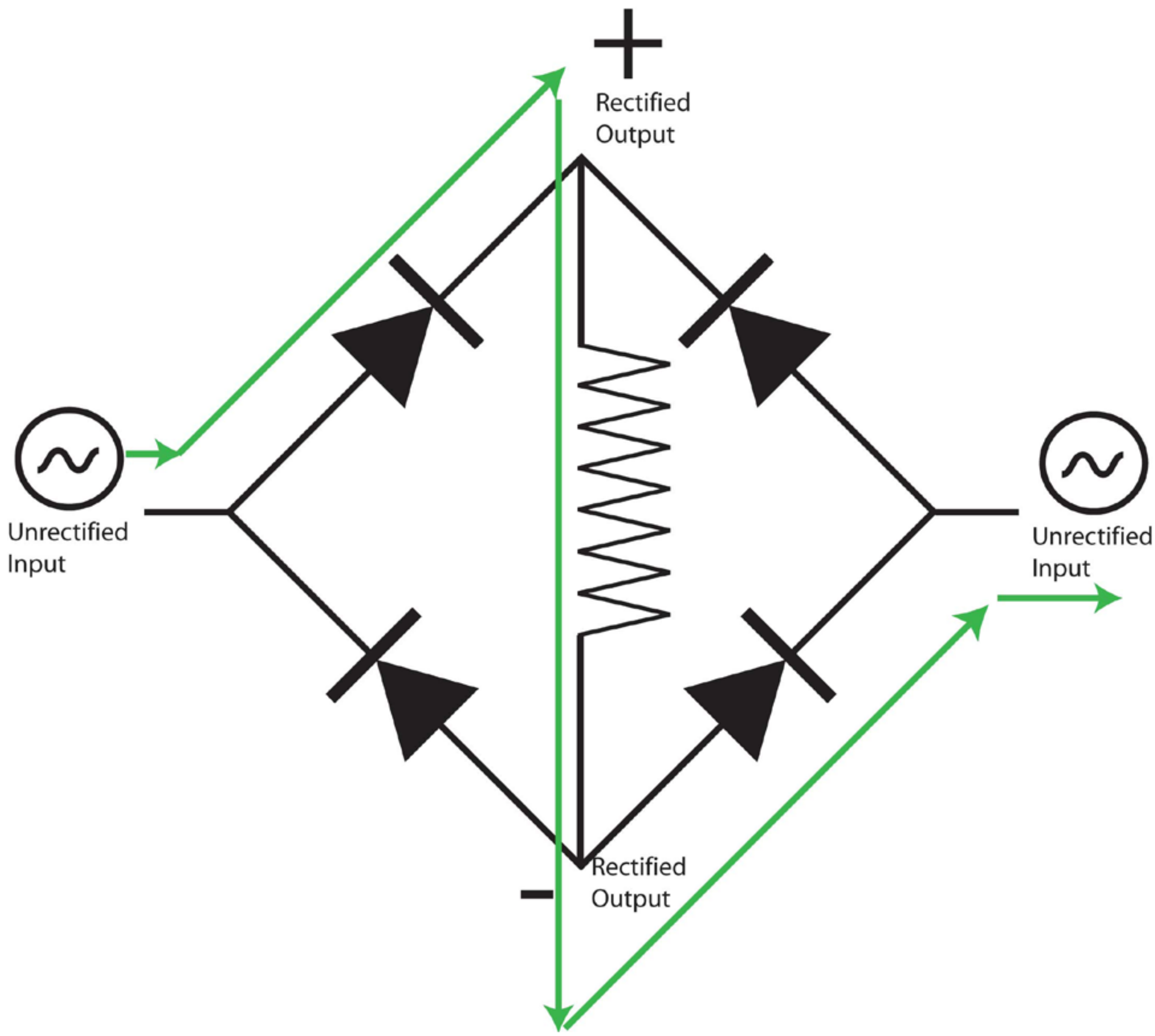


Figure 10: Rectifying a left-to-right current flow.

If the current is flowing from left-to-right then the only path for the current is along the green line from positive to negative outputs.

Let's look at a right-to-left current.

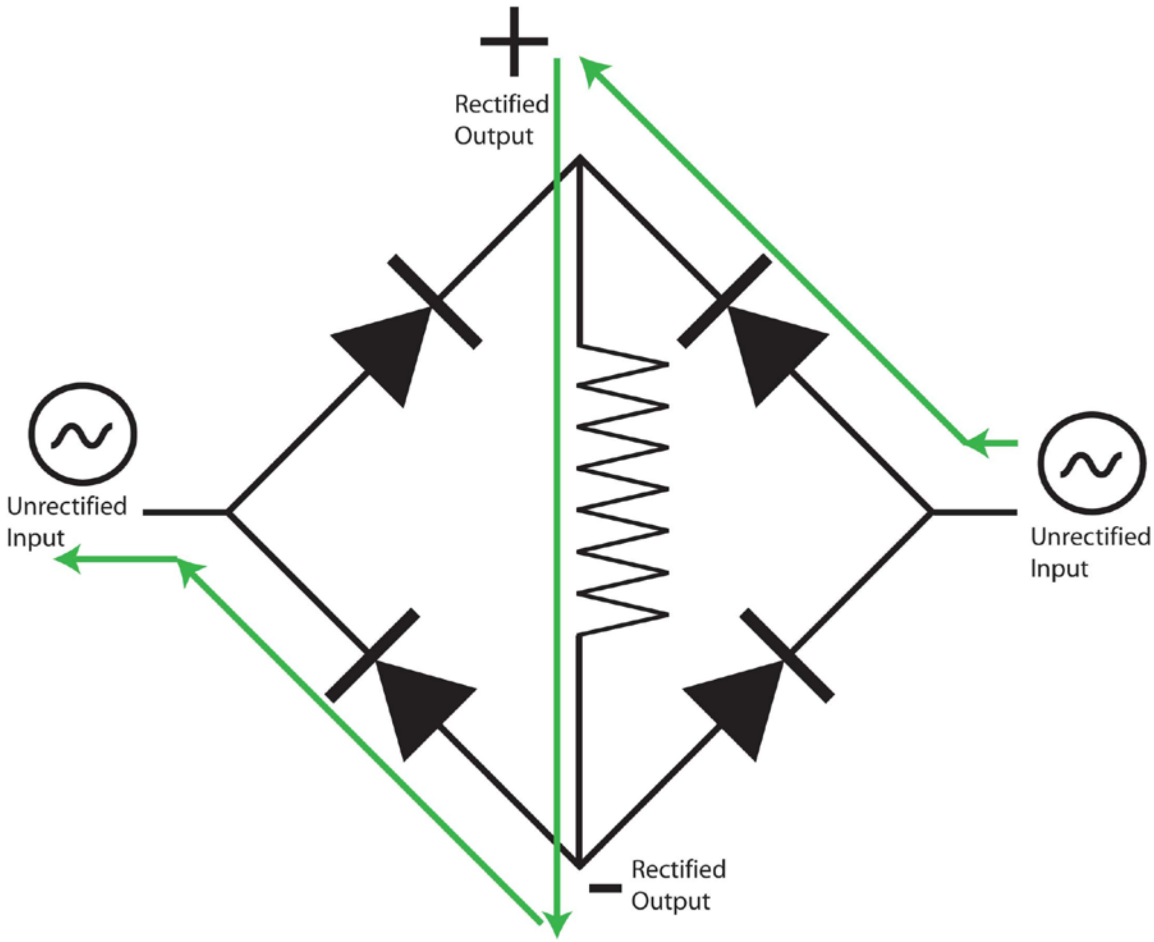


Figure 11: Rectifying a right-to-left current

The only path open to the current is the path from the positive output to the negative output again! No matter what direction of current goes into the rectifier, it only sends current in one direction across the device AND it sends all the current across the device instead of wasting half of it like only using one diode does.

Concept Questions:

1. What kind of voltage output does a direct current source produce?
2. Can a direct current source be negative?
3. What kind of voltage output does an alternating current source produce?
4. Can an alternating current source be negative?
5. What does a diode do?
6. Can a single diode use all the voltage produced by an AC source?

SHAKER FLASHLIGHT

EXPLORATION

Materials

Shaker Flashlight board	Alligator leads
Hand generator	Tape

The shaker flashlight set-up contains all the electronic components included in a commercially sold shaker flashlight. There are only 5 components in the set-up:

- 1 hand generator: converts mechanical energy into electrical energy

<u>On the Board:</u>

- 1 LED (light-emitting diode): generates light
- 1 capacitor: stores electrical energy
- 1 magnetic reed switch: switch to control current flow to LED
- 4 diodes

The electrical energy that powers the flashlight is not going to be converted from chemical energy (as it is in battery flashlights). It is instead going to be converted from the mechanical energy of shaking the flashlight. The advantage of this is it will work without batteries even after a long period in storage.

<u>Magnetic Reed Switch</u>

While you may not have heard of a magnetic reed switch, you are familiar with its essential function: it is a normally open relay. When a magnet is brought near the switch, it closes the switch, as shown in Fig. 1.

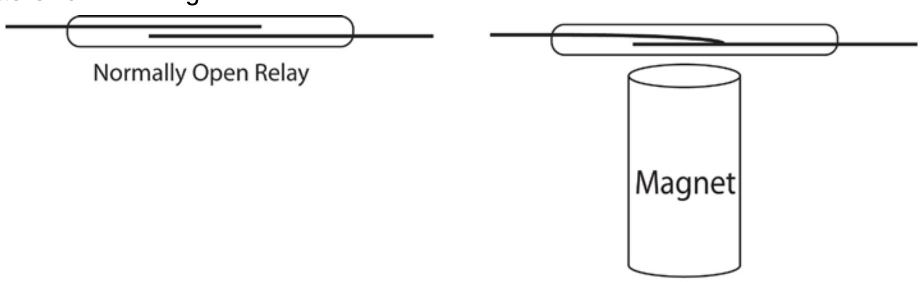


Figure 1: Magnetic Reed Switch. Left: open switch. Right: closed switch in presence of magnet.

<u>Diodes</u>

You already know about four of the five components: the diodes are a new component that has not yet been discussed. In this section you will experiment with how a diode behaves in a circuit and eventually use diodes to optimize the current generated by the hand generator.

1. Build the hand generator by mounting the coil on center of the magnet tube. Secure the coil with the tape.

Connect the hand generator's alligator leads across the LED. Shake the flashlight and observe. Discuss with your group and record an explanation of the LED's behavior.

2. Now connect the LED, one of the four plain diodes, and the hand generator in series as shown in the diagram below. Shake the hand generator and observe.

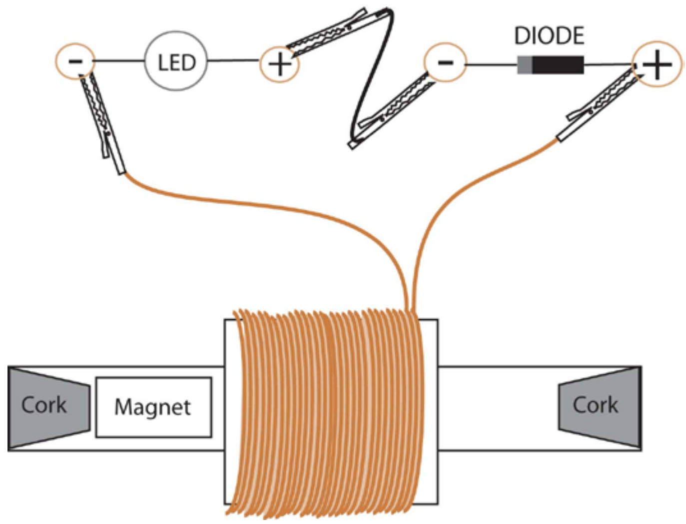
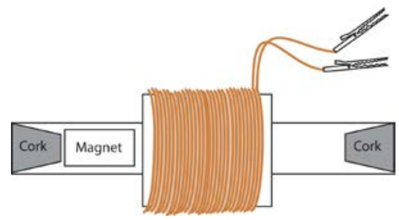


Figure 2: LED and diode circuit, version 1.
NOTE: Direction of current is important!

Shake the flashlight. Compare what you observe to the original circuit.

3. Reverse the direction of the diode in the circuit (switch + to – and vice versa). Shake the hand generator again and observe what happens. Compare what you observe to the original circuit.

4. Describe the current produced by just the hand generator. Draw a current vs. time diagram.



Describe the behavior of the diodes (LED and diode) on the circuit.

Everyday Applications

- AC adapters for electronics (almost all include a full-wave bridge rectifier to convert AC to DC).

APPLICATION

Materials

Shaker Flashlight board
Hand generator components
Alligator leads
Rare earth magnet
Multimeter

We can optimize the flashlight to improve on the first circuit you built in the exploration phase. The original circuit has three main flaws: it strobes, it wastes energy, and the operator must be shaking it while it is operating. Flickering, shaking light would be aggravating to anyone trying to use the flashlight as a tool. Wasting energy happened because only using one diode (the LED) blocks half of the generated current (from the AC source). Wasted energy in this design will exhaust the flashlight user because of all the work the user must do to shake the flashlight.

1. Build a full-wave bridge rectifier with the 4 diodes that are provided. This will convert an AC signal into a DC signal. Present your rectifier to the GSI or instructor before moving forward. Tip: number the diagram and your board, and then match the numbers to get the correct connections.

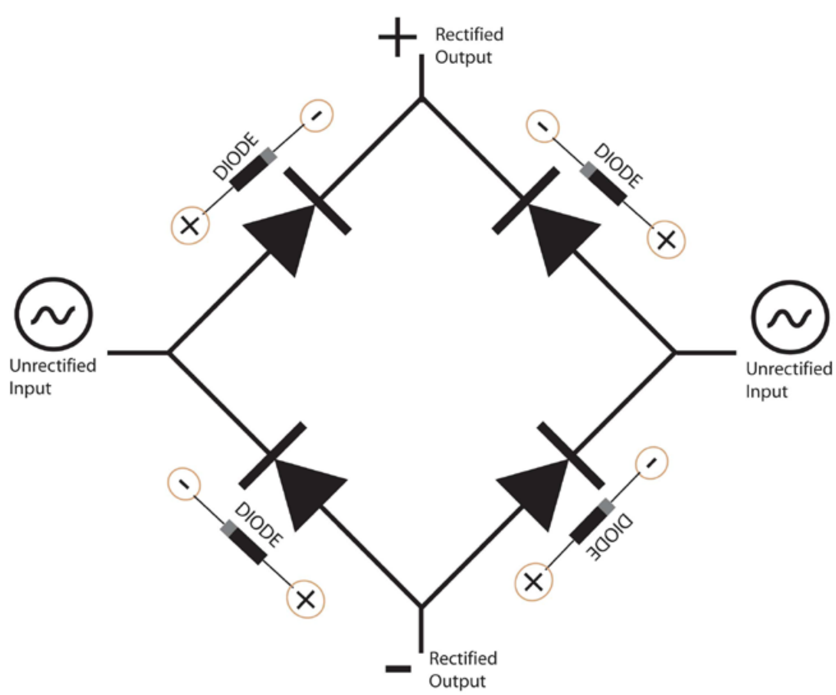
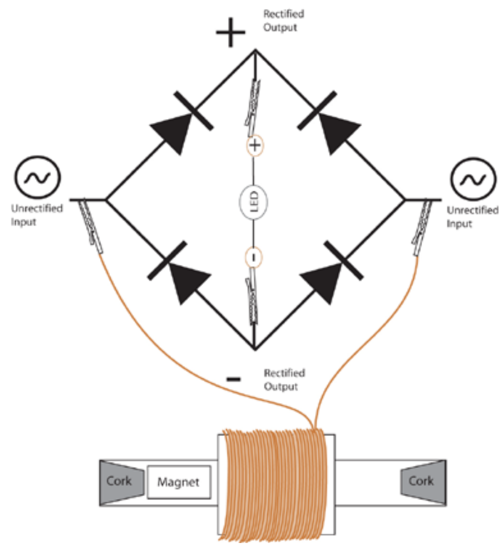


Figure 3: Full-wave bridge rectifier

2. Use the rectifier to optimize the current produced by the hand generator. Connect the hand generator across the LED directly. Note: current direction matters! Make sure the rectified output is correctly attached to the LED.



First predict which, if any, of the flaws using the rectifier will solve?

Shake the hand generator and observe: were any of the flaws solved? Explain.

Using the rectifier protected us from wasting energy; all of the energy we produced on the hand generator with our mechanical energy is going into the circuit. However, the flashlight still flickers and shakes while operating. We've only solved 1 of the 3 flaws.
Instead of using the rectified generator to directly power the LED, we will use it to charge the capacitor. The rectified generator is an unsteady source; it oscillates from 0 to a high voltage frequently, which leads to a strobe effect. A charged capacitor is a steady source once charged to a certain voltage. The capacitor discharges in a non-oscillating stream, even if it was charge by an oscillating source (like our hand generator). Capacitors will also store charge for a reasonable length of time.

3. Which flaws will be solved (and why) if we use a capacitor in the circuit?

4. Measure the voltage of the capacitor with the multimeter set to V_{DC}. It should read nearly 0 volts. If not, short out the capacitor with an alligator lead until the voltage reads 0.

Build the circuit shown in figure 3. Charge the capacitor with the rectified hand generator to 3V (when the generator is at rest). Use the multimeter set to V_{DC} across the capacitor. It should read 3V when the generator is at rest.

Note: Orientation matters! The capacitor must be charged in the correct current direction shown below. Take turns charging the capacitor, it takes time.

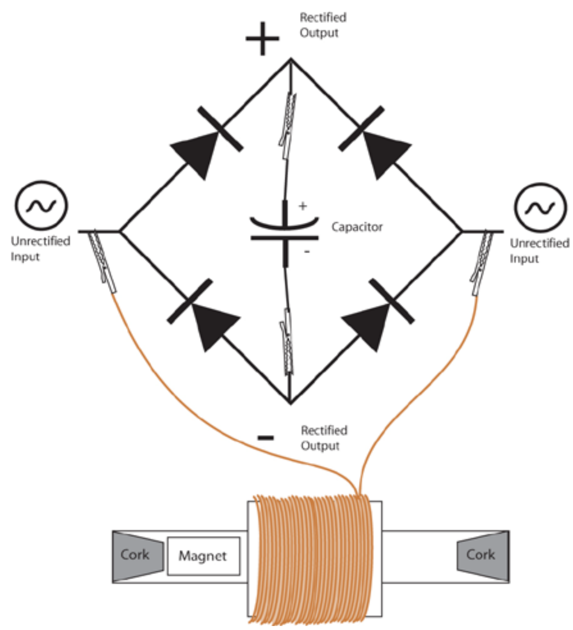


Figure 3: Capacitor charging circuit

5. Once the capacitor is charged, build the circuit shown below (leave the rectifier circuit intact). Notice the orientation of the capacitor and the LED. Bring the rare earth magnet near the reed switch. Recharge the flashlight as needed.

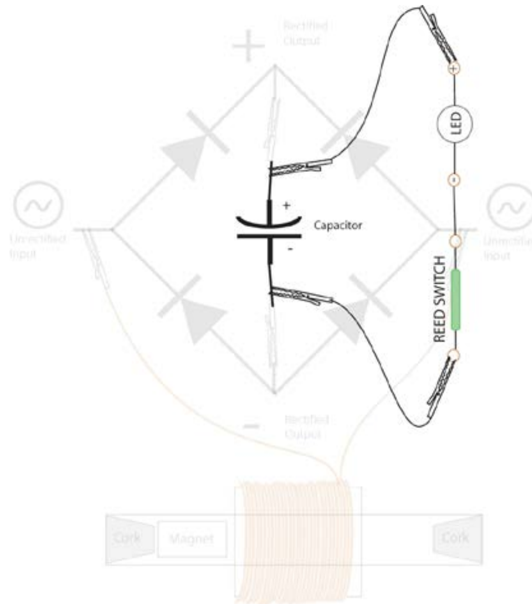


Figure 4: Flashlight circuit.

6. If you were engineering this flashlight for retail, describe other improvements you would make to the design and why.

Challenge Work:

1. Describe in your own words the type of current that the hand generator produces.

2. Describe in your own words what the diode rectifier does to the current produced by the hand generator.

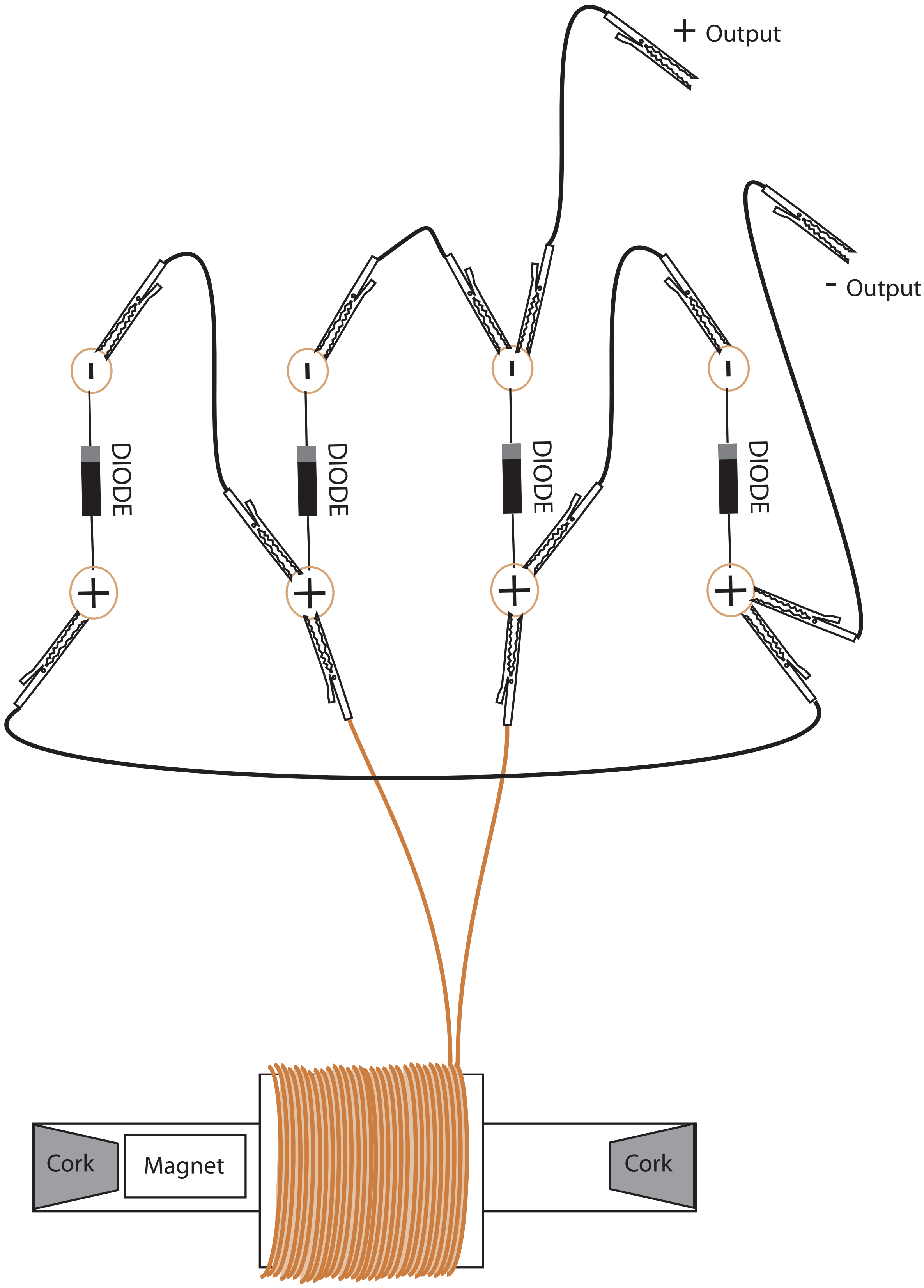
3. The time you spend charging the capacitor is always less than the time the LED is lit with this arrangement. What components would you optimize to yield a more efficient charging to running ratio?

Summary

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Return all equipment to the carts.

Full-Wave Bridge Rectifier Wiring Directions



Loudspeaker and Microphone

Demonstration Lab Assembly

Dedicated Components (located in boxes):

- ☐ 8 plastic spools
- ☐ 8 amplifiers
- ☐ 8 walkman radios w/ audio tape
- ☐ 8 mini-magnets
- ☐ Krazy glue

Shared/Consumable Components:

- ☐ Sand paper strip
- ☐ 8 - 32 gauge wire on spool
- ☐ 8 etched Petri dishes (top and bottom)
- ☐ 16 alligator leads
- ☐ 8 1/8th inch pin plug-1/8th inch pin plug wire
- ☐ 8 1/8th inch pin plug-double bare ends wire

Optional demonstrations at instructor's request:

- ☐ Show and Tell Speakers
- ☐ 2 – 25' wires for telephones
- ☐ Prototype
- ☐ 3B70.10 - Sympathetic Oscillation between Two Tuning Forks
- ☐ 5K10.48 - Current-Coupled Oscillators
- ☐ 5K10.21 - Electromagnetic Induction Projectual
- ☐ 5K40.u1 - Moving Magnet Generator

Other additions:

Special notes for instructor:

Instructor Outline: **Loudspeaker and Microphone**

Lab length: 75-80 minutes
Lab objective: Instruct the students about speakers, microphones, induction, amplification, recording and transmission of sound, and electromagnetism.

Materials

1 plastic spool
1 sand paper strip
32 gauge wire on spool
1 Petri dish (top and bottom)
1 amplifier
1 1/8th inch pin plug-double bare ends wire
1 1/8th inch pin plug-1/8th inch pin plug wire
2 alligator leads
1 walkman w/ audio tape
1 mini-magnet
Gluing template

Exploration stage: 30 minutes - group lab work

The students work in groups to build a speaker using Petri dishes and a cassette player. They introduce an amplifier and observe how the signal changes.

Analysis stages: 15 minutes – lecture

The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on speaker, microphones, and the transmission of signals with currents.

Application stage: 20-25 minutes – group lab work

The students use their Petri speakers as microphones. They build a one-way telephone. Then they work with another group to produce a two-way telephone.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. The students learn how audio signals are transmitted electronically in wire.
2. Microphones use electromagnet induction to convert vibrations into electrical signals.
3. Speakers use electromagnetic induction to convert electrical signals into vibrations.

Suggested Demos:

3B70.10 - Sympathetic Oscillation between Two Tuning Forks
5K10.48 - Current-Coupled Oscillators
5K10.21 - Electromagnetic Induction Projectual
5K40.u1 - Moving Magnet Generator

LOUDSPEAKER AND MICROPHONE

ANALYSIS

Current Signal

With the relay and buzzer lab, you observed that connecting and disconnecting a circuit can relay a message. This is how telegraphs work, a pattern of on and off signals translated into an alphabetic Morse code.

A more sophisticated relationship guides the transmission of sound. Instead of two options (on or off) there are many signals related to the magnitude of current generated by the magnet and coil. Each of those signals corresponds to a sound.

Microphones

Alexander Graham Bell was instrumental in the transition from telegraph technology to the transmission of sound we still use for phones and sound recordings. What you've constructed is precisely the method he refined.

Sound sources produce vibrations in the air. When those vibrations reach surfaces, they cause those surfaces to vibrate. The Petri dish is a decent surface for recording because it is rigid and thin. When the dish surface vibrates, it oscillates the magnet. These oscillations are tiny, but they are enough to induce a current in the coil. That current carries the induced signal to the amplifier.

Speakers

The amplifier also contains a speaker, and it decodes the current from the microphone or a recording back into sound by reversing the microphone process. A current passes through a coil near a magnet attached to the speaker surface. The current creates a magnetic field that attracts and repels the magnet, and the small oscillations of the magnet in turn vibrate the speaker panel (called the diaphragm), which shakes the air in the pattern identical to the sound of the signal.

LOUDSPEAKER AND MICROPHONE

Pre-Lab Question

How is sound recorded?

EXPLORATION

Materials

1 plastic spool
1 sand paper strip
32 gauge wire on spool
1 Petri dish (top and bottom)
1 walkman w/ audio tape
1 amplifier
1 1/8th inch pin plug-double bare wire
1 alligator lead card
1 mini-magnet
1 gluing template

1. In the motors and generators lab you saw that when you pass a current in a wire near a magnet there is a force that moves the wire. You also saw that when a wire moves near a magnet, a current is created. This reciprocal relationship is how speakers and microphones work.

When a sound is created, a vibration causes the propagation of vibrating air molecules and when they reach a detector (such as an ear drum) that surface vibrates too. If a magnet is attached to that surface near a coil, then that vibration will be recorded as tiny currents in the wire. This is what a microphone does; it converts the vibrations of a sound wave into oscillations of current that are sent to a speaker. These oscillations can also be recorded as with a tape, CD, or digital music file to be played back later.

Build a microphone with the Petri dish as your vibrating surface. The thin plastic is ideal for vibrations, and will be effective as a microphone surface.

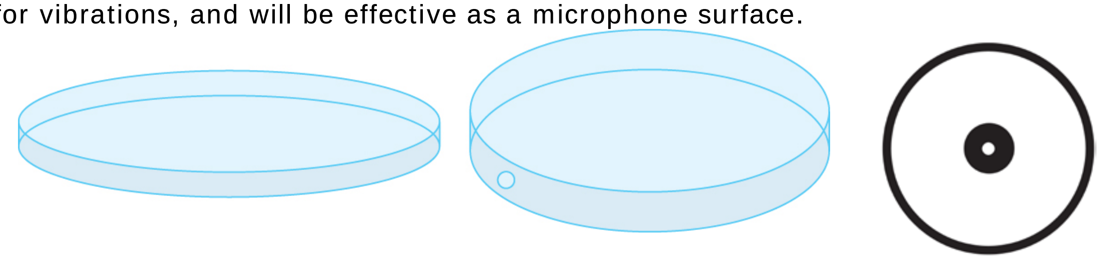


Figure 1: Petri dish and template

Center the large top on the template, and glue the magnet to the inside center of the top of the Petri dish with superglue according to the template with a magnet sized ring as a guide for the center of the dish. The glue is at the back of the classroom.

2. Use all the provided wire to wind a coil on the plastic spool. The more windings you add, the more current will be induced providing a better signal. Wrap neatly and leave 4 inches on both ends to allow for connections. Strip about ½ inch of insulation off the ends of the wire with the sandpaper.

3. Glue the spool to the Petri bottom, using the template as a guide for where to glue the spool so it is centered. Before you glue, make sure that the spool seats nicely with the glued magnet in the Petri top.

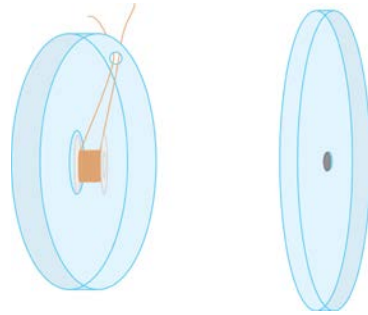


Figure 2: Petri dish with glued components

4. Route the wire ends through the hole in the bottom Petri dish. Close the Petri dish. Connect the Petri dish to a tape player with the 1/8th inch pin plug-double bare wire and alligator leads. Plug the 1/8th inch pin plug end into the "phones" slot in the tape player.

Figure 3: Petri with tape cassette

5. Press play on the tape deck. What happens? Explain what you observe.

6. Include an amplifier in the arrangement. Connect the 1/8th inch pin plug-bare wire between the Petri and the amp OUTPUT plug. Connect the 1/8th inch pin plug-1/8th inch pin plug wire between the cassette player and the amp INPUT plug.

Figure 4: Cassette player, amplifier, and Petri device

Turn on the amplifier and the tape deck. What do you observe, how is this different than without the amplifier. Explain why the amplifier is used.

Challenge Work:

Place a finger on the surface with the magnet and listen to a transmission. Is the quality as good as when nothing is pressing the surface? Explain what you observe.

Everyday Applications

- Telephones
- Sound recordings
- PA systems
- Music Radio transmission
- Mp3 players, such as iPods
- Stereo systems

APPLICATION

Materials

1 assembled Petri speaker
1 amplifier
2 alligator leads
1 1/8th inch pin plug-double bare ends wire
1 1/8th inch pin plug-1/8th inch pin plug wire

1. Now remove the tape player and plug the speaker into the amplifier input slot.

Figure 5: Petri microphone and amp

Turn on the amplifier by rotating the dial on the right side. Speak into the Petri dish, and observe what happens. Do not put your thumb on the surface with the magnet glued to it or you may "damp" the signal. Record your observations.

How are microphones and speakers similar?

2. Build a one-way telephone by using a long wire to connect the devices. Place the microphone and speaker on opposite ends of the room and see if you can transmit a sound.

3. Work with another group to build a two-way telephone. Each groups Petri device will serve as the microphone, but on opposite ends of the room connected by a long wire.

Challenge Work:

1. Stay in groups. The transmission of sound in a current can easily work between two Petri dishes alone. Connect a microphone dish and speaker dish with alligator leads. Can you hear a transmission? Why do you think that telephone companies use amplifiers?

Summary:

Final Clean-up

Keep your microphone **intact** and label it with masking tape from the front of the classroom. You will need it for making electric guitars in 2 weeks. Please disconnect all other components and replace them to the carts neatly.

Musical Instruments

Demonstration Lab Assembly

Dedicated Components
(located in boxes):

- ☐ 8 large straws
- ☐ 8 wooden rods
- ☐ 8 plastic mouthpieces
- ☐ 8 wooden rods
- ☐ 8 plastic mouthpieces
- ☐ 8 corks
- ☐ 8 Electric Guitar boards

Shared/Consumable Components:

- ☐ 8 amplifiers
(from Loudspeaker lab)
- ☐ 8 1/8th inch-double bare ends wire
- ☐ 16 drinking straws (small)
- ☐ Alligator leads
- ☐ Scissors

Saved Components:

- ☐ Pre-assembled Petri microphones

Optional demonstrations at instructor's request:

- ☐ Spectrum analyzer laptop
- ☐ 3C10.10 - Model of the Ear
- ☐ 3C20.10 - Range of Hearing
- ☐ 3D46.15 - Tuning Forks (industrial)
- ☐ 3D32.10 - Organ Pipes

Other additions:

Special notes for instructor:

Instructor Outline: **Musical Instruments**

Lab length: 65-90 minutes
Lab objective: Instruct the students about sound, frequency, instruments, and overtones.

Materials

1 pre-assembled Petri microphone
1 amplifier
1 1/8th inch-double bare ends wire
1 alligator lead card
1 cork
2 drinking straws (1 large, 2 small)
1 PVC tube
Scissors
1 guitar apparatus
1 wood rod
1 plastic mouth-piece

Exploration stage: 20-30 minutes - group lab work

The students work in groups to build a slide flute and an oboe. They play the instruments and observe pitch changes in the flute and potentially octave changes in the oboe.

Analysis stages: 20-30 minutes – lecture

The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on sound, frequency, instruments, and overtones. The instructor can use a laptop driven spectrum analyzer and a microphone to analyze the tones of the student's oboes contrasted with a tuning fork's pure tone. Overtones are shown in the analyzer, and the software shows the waveform from the speaker.

We recommend using the oboes and the tuning fork. The oboe produces nice overtones with a higher frequency. If time permits, the slide flute may produce fewer overtones than the oboe (less rich sound). A xylophone also produces pure tones.

Application stage: 15-20 minutes – group lab work

The students play with the "guitar." They observe how forcing a node change the fundamental frequency of the instrument. They use their microphones as pickups on their electric guitars.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Sound is pressure oscillations in a medium.
2. Vibrations are detected by ears, and generated by vibrations.
3. Frequency (Pitch) is how notes are distinguished.
4. Overtones are pleasing and multiples of the fundamental frequency.
5. The length of a cavity determines the frequency of the cavity.

Suggested Demos:

Spectrum analyzer laptop
3C10.10 - Model of the Ear
3C20.10 - Range of Hearing
3D46.15 - Tuning Forks (industrial)
3D32.10 - Organ Pipes

MUSICAL INSTRUMENTS

ANALYSIS

Sound

Sound is the transmission of pressure waves of a certain frequency through a medium.

Musical instruments are characterized by two main features:

1) Vibration
Vibrating objects (such as guitar strings and human voice boxes) initiate the pressure waves that propagate sound.

2) Amplification
The shape and size of an instrument contributes to how it amplifies and shapes a sound.

Frequency

One characteristic that makes a sound unique is the pitch or frequency of the note. The frequency is the number of oscillations a pressure wave makes in a second. The human ear can hear between 20 and 20,000 oscillations per second, also called Hertz (Hz). However, human's hearing diminishes with age and most adults can't hear above 15,000 Hz.

For reference, dogs can hear up to 45,000 Hz and bats can hear up to 100,000 Hz.

Musical notes represent specific frequencies, for example concert A is 440 Hz. If the note is "flat" then the frequency is lower than the ideal frequency. If the note is "sharp" then the frequency is higher than the ideal frequency.

If a singer is flat when recorded digitally, the producer can tighten up the track and shift the song into the correct pitch.

Musical Instruments

Musical instruments are tools that create vibrations that humans find pleasing. The vibrations depend on the shape and size of the instrument as well as the technique used to start the vibration.

The cavity of the instrument (such as the tubes of the flute and oboe you built) helps define what note will be produced.

With the oboe you may have noticed that your embouchure (mouth positioning) would produce either a high or low frequency note. What you heard was the same note in a different octave. That is one way in which how you start the vibration (how you blow on the reed) contributes to the final note.

Why is music pleasing?

There is no definitive answer to this question, but Physicists have proffered a few observations about pleasing sounds. Oftentimes instruments and voices with a pleasing quality are able to create overtones in their cavities. This means that not only do they achieve the pure tone of the note (such as 440 Hz for a concert A), but they generate overtones which are multiples of the pure note (such as 880, 1320, and 1760 Hz for A).

In these cases the cavity is resonating at multiple frequencies, which can be observed with a spectrum analyzer. From an aesthetic point of view, people find notes with overtones more pleasing than pure notes (notes that only produce the fundamental frequency).

It is not simply overtones on a note that produce pleasing sounds. Musicians have an unquantifiable technique for navigating between notes in a pleasing fashion that is not achieved by current electronic music generators.

APPLICATION

Materials

1 pre-assembled Petri microphone
1 amplifier
1 1/8th inch-double bare ends wire
1 alligator lead card
1 guitar apparatus

1.

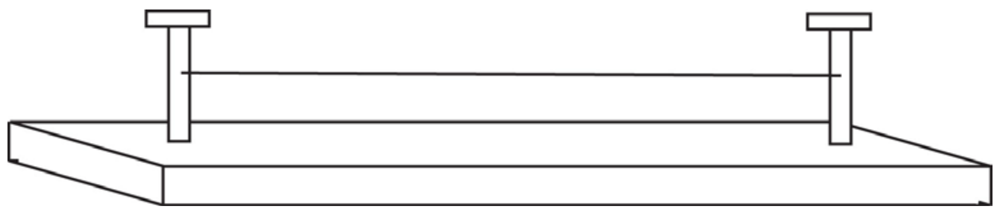


Figure 1: Electric Guitar

Pluck your “guitar.” What causes the sound you hear?

Press down on the guitar string firmly with a pencil and pluck again. This is called “forcing a node.” How did the sound change and why? Explain. Is this similar to the flute and oboe?

2. Assemble your Petri device so it is a microphone attached to the amplifier as shown below.

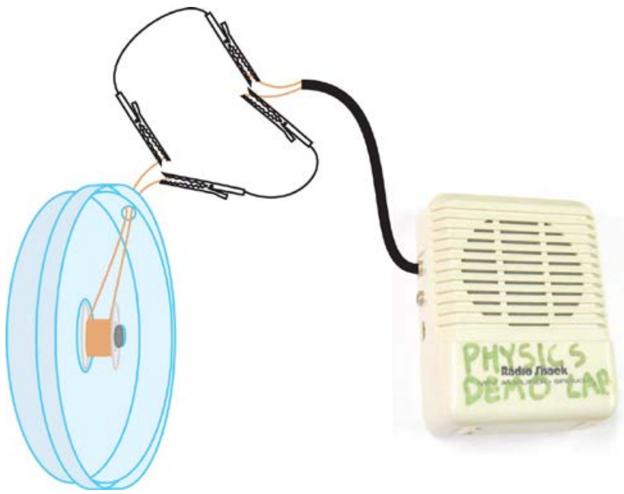


Figure 2: Petri microphone

Place the Petri microphone under the guitar string, with the magnet-side nearest to the string. Get some cellophane tape and tape the microphone to the base (this will prevent the magnet from being attracted to the string).

Turn on the amplifier and pluck the guitar again. How does adding the microphone change the sound of the guitar?

Challenge Work:

1. What is the general relationship between the size of an instrument and the pitch of the sound that it produces?

2. How do you make instruments start vibrating? List at least four ways.

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. You are finished with the microphone and loudspeaker, but some parts are re-used so please return the device to the cart. Return all equipment to the carts.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Pitch (music)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Pitch_%28music%29&oldid=60691898 (accessed July 7, 2006).

MUSICAL INSTRUMENTS

Pre-Lab Question

What is a note? What is pitch?

EXPLORATION

Exploration Materials

1 cork
2 drinking straws (1 large, 2 small)
1 PVC tube
Scissors
1 wood rod
1 plastic mouth-piece

1. Build a slide flute with the large straw, the plastic mouth-piece, and the wooden rod, as shown below.

Take the mouth-piece and the straw, and cut a small triangle in the straw a mouth-piece length from the end.

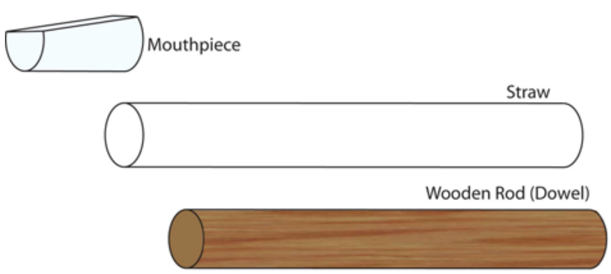


Figure 1: Slide Flute parts

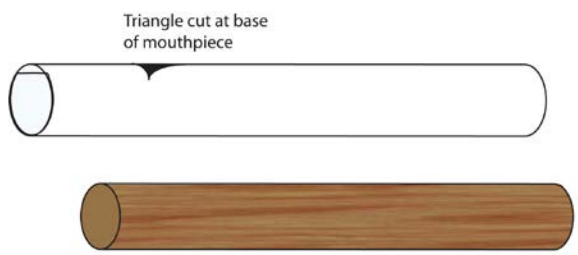


Figure 2: Mouthpiece inserted with triangle cut at base

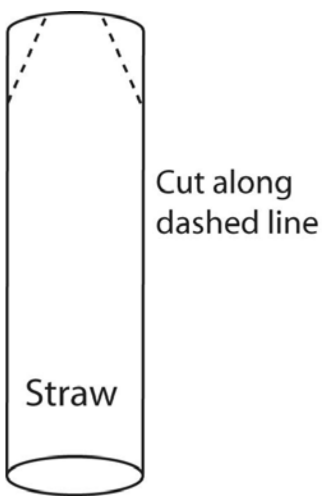
Insert the mouthpiece so the angle rises as it approaches the triangle cut. To optimize the flute, pinch and distort the straw at the triangle cut. You want the diameter of the straw at the triangle cut to be less than at the mouth piece.

Insert the wooden rod into the straw's base. This can slide up and down the flute while it is being played.

2. What do you observe when you slide the wooden rod up and down while blowing on the flute? Describe how and why the sound is different.

Have one team member play the flute. Have them play a piece of music, see if you can recognize it.

3. Build an oboe
Take the small straws and cut them in half, distribute one piece to each group member. These pieces will be your reeds. Cut ½ an inch off the end of the straw in a triangle pattern.



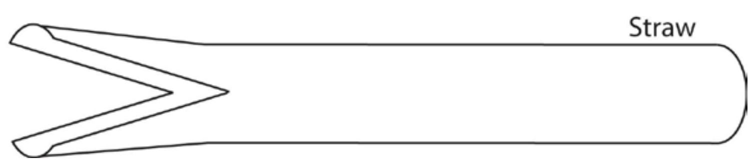


Figure 3: Straw cut into a reed

Flatten the two straw pieces together, and cut into a triangular shape leaving the tip at your mouth (don't make it too sharp).

Insert the unfinished end of the straw all the way into the rubber cork. Plug the cork into the PVC pipe.

Prepare to the play the "oboe." It will take some practice to get a sound. It is helpful to pinch the reed together gently with your lips or teeth while blowing.

Play the oboe. Try to get different sounds. What do you change to achieve different sounds?

Each person has a reed; each person should try to play the oboe. Do you notice a difference with different reeds and players? Explain what you observe.

Compare what you observe with the oboe with what you observed in the slide flute. Does one instrument have a better or richer sound quality?

Challenge Work:

Are the different sounds you hear on the slide flute due to changes in loudness (volume)? Explain.

Why do different instruments playing the same note sound unique? Explain.

Everyday Applications

- All Musical Instruments
- Music production software
- Dog whistles

APPLICATION

Materials

1 pre-assembled Petri microphone
1 amplifier
1 1/8th inch-double bare ends wire
1 alligator lead card
1 guitar apparatus

1.

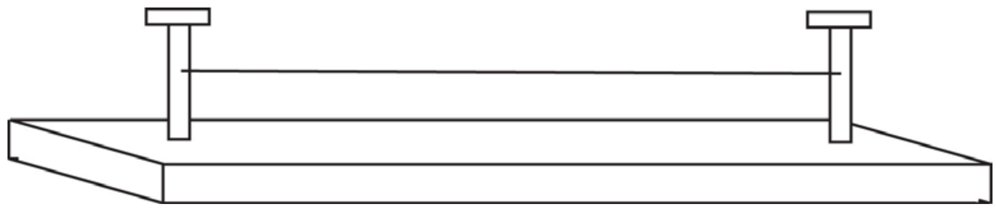


Figure 4: Electric Guitar

Pluck your “guitar.” What causes the sound you hear?

Press down on the guitar string firmly with a pencil and pluck again. This is called “forcing a node.” How did the sound change and why? Explain. Is this similar to the flute and oboe?

2. Assemble your Petri device so it is a microphone attached to the amplifier as shown below.

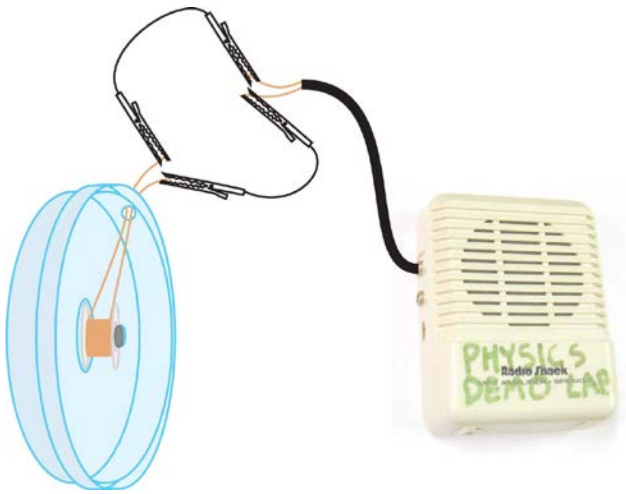


Figure 5: Petri microphone

Place the Petri microphone under the guitar string, with the magnet-side nearest to the string. Get some cellophane tape and tape the microphone to the base (this will prevent the magnet from being attracted to the string).

Turn on the amplifier and pluck the guitar again. How does adding the microphone change the sound of the guitar?

Challenge Work:

1. What is the general relationship between the size of an instrument and the pitch of the sound that it produces?

2. How do you make instruments start vibrating? List at least four ways.

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. You are finished with the microphone and loudspeaker, but some parts are re-used so please return the device to the cart. Return all equipment to the carts.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Pitch (music)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Pitch_%28music%29&oldid=60691898 (accessed July 7, 2006).

Instructor Outline: **Waves**

Lab length: 75-100 minutes
Lab objective: Instruct the students about amplitude, standing waves, and overtones.

Materials

1 wave-motor apparatus
1 battery board
1 card alligator leads
2 squeeze clamps

Exploration stage: 15-20 minutes - group lab work

The students work observe standing waves. They test which variables contribute to the number of nodes and antinodes.

Analysis stages: 20-30 minutes – lecture

The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on nodes, antinodes, and driven waves.

Application stage: 15-20 minutes – group lab work

The students fill out chamber with forced nodes and anti-nodes. This builds an understanding of overtones.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Nodes are forced a fixed and antinodes are forced a open ends.
2. Amplitude is the magnitude of the oscillation and is independent of the frequency.

<u>Suggested Demos:</u>

None

WAVES

ANALYSIS

Waves

Standing waves are excellent representations of wave behavior. In a medium, waves have node and anti-nodes, points of low and high excitement. With the standing wave apparatus you can see these points. The fixed ends are nodes; the wide sweeping regions are anti-nodes. When the elastic is excited at a high frequency, additional nodes appear along the length of the rope.

WAVES

EXPLORATION

Exploration Materials

1 wave-motor apparatus
1 battery board
1 card alligator leads

1.

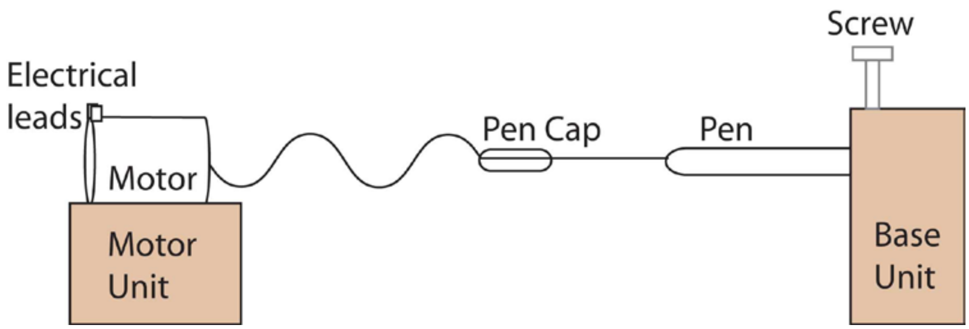


Figure 1: Standing Wave Unit

1. Observe standing waves on a string. The standing wave apparatus has two parts: a motor-elastic-pen unit, and a base unit with a plastic screw. Slip the bottom of the pen into the base unit and tighten the screw. Clamp the motor mount to the table so you can stretch the base unit away from it.

Wire a 1.5V battery with a switch and connect it across the motor. Have one group member close the switch, and another move the base unit. Try to find the fundamental wave which looks just like a jump rope: the ends are fixed and the center swings up and down. Draw your observation below. Clamp the base unit down.

2. Add another battery, increasing the voltage to 3V and close the switch. You can move the base unit a small amount to rectify the wave if it is not smooth. What happens to the wave? Draw below.

3. What does adding batteries do to the wave? Explain and predict what will happen when you add a 3rd battery and increase the voltage to 4.5V.

Add a 3rd battery to the set-up and observe what happens to the wave. Again, you can slide the base unit slightly to clean up the wave if it is not smooth. What happens to the wave? Does this agree with your prediction? Draw the wave you observe below.

Challenge Work:

Slide the pen cap while the motor is running. How does this change the number of antinodes?

Everyday Applications

- Musical Instruments

APPLICATION

<u>Overtone Diagrams</u>

1. Draw a diagram of an open tube's fundamental frequency. This length is equal to 1/2 of the fundamental wavelength.

Draw a diagram of an open tube's first overtone. This length is equal to 1 of the overtone's wavelengths.

Draw a diagram of an open tube's second overtone. This length is equal to 1.5 of the overtones wavelengths.

2. Draw a diagram of a closed tube's fundamental frequency. This length is equal to 1/2 of the fundamental wavelength.

Draw a diagram of a closed tube's first overtone. This length is equal to 1 of the overtone's wavelengths.

Draw a diagram of a closed tube's second overtone. This length is equal to 1.5 of the overtones wavelengths.

3. Draw a diagram of an open-closed tube's fundamental frequency. This length is equal to 1/4 of the fundamental wavelength.

Draw a diagram of an open-closed tube's first overtone. This length is equal to 3/4 of the overtone's wavelengths.

Draw a diagram of an open-closed tube's second overtone. This length is equal to 5/4 of the overtones wavelengths.

Summary:

Final Clean-up

Please disconnect all alligator leads and reattach them to the clip card. Replace all equipment to the carts.

Instructor Outline: **Resonance**

Lab length: 75-100 minutes
Lab objective: Instruct the students about period, frequency, amplitude, wave velocity, resonance, pendulums, standing waves, and chambers.

Materials

1 length of string
2 masses
1 ring stand
1 stopwatch
1 piston assembly
2 tuning forks
1 measuring tape
1 ruler
1 digital scale

Exploration stage: 20-30 minutes - group lab work

The students work in groups to build pendulums. They test which variables contribute to period.

Analysis stages: 20-30 minutes – lecture

The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on period, frequency, and pendulums.

Application stage: 15-20 minutes – group lab work

The students observe resonance with resonance chambers. They calculate the speed of sound with a known frequency tuning fork, and then calculate the frequency of an unknown fork. The instructor will have to lecture on wave diagrams, nodes, and anti-nodes.

Summary: 10 minutes – lecture

This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. Period and frequency describe the behavior of oscillating systems.
2. Amplitude is the magnitude of the oscillation and is independent of the frequency.
3. Resonance is when the driving frequency and the natural frequency match. That creates large amplitudes.
4. One can calculate the speed of sound with a known frequency tuning fork and a chamber.

Suggested Demos:

3D40.55 - Shattering the Wine Glass
3A60.10 - Tacoma Narrows Video Clip

RESONANCE

ANALYSIS

Natural frequency

Objects have a preferred oscillation frequency dictated by features such as shape and material. When the wine glass is flicked by a finger, it hums at its natural frequency. When a bell is rung, it reverberates at its natural frequency. When a pendulum is released from a height, it oscillates at its natural frequency. When you accidentally drop a pan and it rings for a moment until you touch it (damping it), it is oscillating at its natural frequency. The natural frequency is a characteristic of the object.

Amplitude

The amplitude of a system's oscillations depends on the impulse that drives them into motion. The pendulum will swing higher (have a higher amplitude) if released from a greater height. A bell will ring quietly or loudly depending upon how hard it is hit. There are other ways to control (and enhance) the amplitude of an oscillation.

Amplitude can also be increased by **driving** a system. A common example of a driven pendulum is a swing. If you release a swing from a height, it will swing high for a time but quickly lose amplitude until it comes to a stop at its equilibrium point. This is fun, but I'm sure you've all learned that you can keep the amplitude of the swing high for a long time if you push it at the correct frequency. This is an example of a driven oscillator.

Anytime a system is driven in such a way that gives the oscillator large and sustained amplitude it is called **resonance**. When an oscillator is driven at resonance, the achieved amplitude can cause dramatic reactions. Rigid bells can crack, bridges can collapse, and wine glasses can shatter. Rigid systems with weaknesses tear apart with dramatic flair when the amplitude of the oscillation exceeds the system's ability to stay intact.

RESONANCE

Pre-Lab Question

How does the size of a chamber determine the frequency of the sound it resonates?

EXPLORATION

Exploration Materials

1 length of string	1 stopwatch
2 nuts	1 ruler
1 ring stand	1 digital scale

<u>Pendulum</u>

1. Build a pendulum. Use the ring stand, the length of string, and a nut to build your pendulum. Tie the nut onto the string, and tie a loop on the other end so it can be suspended on the ring stand. You are going to measure the frequency of the pendulum for a given length of string and mass (the nut).

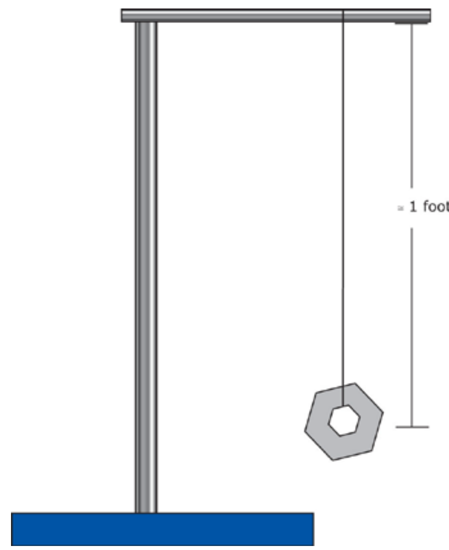


Figure 1: Pendulum

Just as with musical instruments and sound, the frequency is the number of oscillations per second. The oscillations in this case are not the vibrations of air molecules; they are instead the complete swings of the pendulum.

You are now ready to observe the period of the pendulum. Release the pendulum and estimate the time period required for the pendulum to oscillate through one full motion.

Period of 1 oscillation	

<u>Period</u>
The period is the length of time it takes for a complete oscillation to take place. If the period is short (on the order of a second) one can find a more precise figure by measuring the time for a given the number of oscillations, in our case we will measure 10. Divide the time by the number of oscillations to calculate the period with more precision.

<u>Frequency</u>
Once you have observed the period of the pendulum, you will convert that figure into frequency, a more common description of oscillations (in physics and music). Frequency is the number of oscillations per second, so is simply the inverse of the period. The units of period are seconds; the units of frequency are 1/seconds called Hertz (Hz).

There are some constants you need to measure: the length of the string, and the mass of the nut. Measure the mass with the digital scale. Record those values on the table below.

Prepare to start the stopwatch and pull the pendulum up by about 20-30º. Start the stopwatch when you release the pendulum, count 10 full swings of the pendulum, then stop the stopwatch. Record the full time of the ten swings, and then calculate the period and frequency. Repeat for 3 trials then calculate the average frequency.

Pendulum Length (cm) ___________ Mass (grams) _________

Trial #	**# of Cycles**	**Time (seconds)**	**Period (T) (seconds/cycle)**	**Frequency (*f*) (cycles/second) (Hz)**
1	10			
2	10			
3	10			
Average Frequency				

2. For the second experiment, you will double the weight of the pendulum. Predict how doubling the weight will change the period of the pendulum.

Double the weight on the pendulum, but keep the length the same. Slip the pendulum off the stand, and thread the second nut onto the pendulum. Hang the pendulum on the stand again.

Measure the new mass with the digital scale. Record the mass and length of string on the table below.

Repeat the measurements with double the mass.

Pendulum Length (cm) ___________ Mass (grams) _________

Trial #	**# of Cycles**	**Time (seconds)**	**Period (T) (seconds/cycle)**	**Frequency (*f*) (cycles/second) (Hz)**
1	10			
2	10			
3	10			
Average Frequency				

Does your measurement agree with your prediction? Explain.

3. For the third experiment, you will shorten the length of the string. Predict how shortening the length by half will change the period of the pendulum.

Halve the length of the pendulum. Record the mass and length of string on the table below.

Repeat the measurements with half the length.

Pendulum Length (cm) ___________ Mass (grams) _________

Trial #	**# of Cycles**	**Time (seconds)**	**Period (T) (seconds/cycle)**	**Frequency (*f*) (cycles/second) (Hz)**
1	10			
2	10			
3	10			
Average Frequency				

Does your measurement agree with your prediction? Explain.

4. Which features of the pendulum did you vary that control the period of the oscillation? Which features do not impact the period of the pendulum?

Challenge Work:
1. Does extra length increase or decrease the period of the pendulum?

Everyday Applications

- Musical Instruments

APPLICATION

Materials

1 piston assembly
2 tuning forks
1 measuring tape

1. You can blow on a partially filled soda bottle, and occasionally you will hit a tone that is amplified by the bottle. That tone is a resonant frequency of the bottle. Just like the pendulum, cavities have natural frequencies at which they resonate.

A closed tube has one stopped end, and one open end. Your resonant chamber is variable; its resonant frequency depends on where the plunger is.

Make the resonant chamber resonate with a tuning fork. Ping the tuning fork on a surface and place it near the opening of the tube. You will need three group members to operate this device. One holds the tube in place, another member slides the plunger, and the third pings the tuning fork and holds it in front of the chamber. Start with the plunger level with the tube’s opening, and slowly make the chamber larger.

Do you observe anything? Describe.

Search for other resonance lengths. Ping the same tuning fork while slowly pulling the plunger back farther. Are there any other resonant lengths? How many? Explain why there are multiple resonant lengths.

The shallowest resonant cavity represents the fundamental frequency of the wave. The second resonance represents the first overtone; the third resonance represents the second overtone.

Measure the distance from the tube opening to the plunger for the first three resonances. Start with the shallowest fundamental frequency.

	Length (in cm)
First Resonance	
Second Resonance	
Third Resonance	

2. Draw a diagram of the closed-open tube's first resonance. This length is equal to 1/4 of the wavelength.

Draw the closed-open tubes second resonance. This length is equal to 3/4 of the wavelength.

Draw the closed-open tubes third resonance. This length is equal to 5/4 of the wavelength.

3.
Length: The tube diameter shifts the true wavelength. For these tubes, we must add 2 cm to the plunger depth to correct for the shift. Add the open end diameter correction to each depth you measured and record in the table below.

Wavelength (λ): The wavelength is the same in all resonances you observed; the different lengths are simply different multiples of fractions of the wavelength. The fundamental frequency is 1/4 of the wavelength, the first overtone is 3/4 of the wavelength, and the second overtone is 5/4 of the wavelength. Find the value of the wavelength from each length you measured and record below.

Frequency (f): The frequency is given by the tuning fork and is the same for all three tones. Fill in the value written on the tuning fork in this field of the table below.

Wave Velocity: Given the wavelength (how long it is) and the frequency (how long it take to oscillate) we can calculate the wave velocity. In other words, we can calculate the speed of sound with these measurements.

The wave velocity is the wavelength multiplied by the frequency of the wave. Calculate the speed of sound from the wavelength and frequency you found.

$$v = \lambda \times f$$

	Length + 2 (cm)	λ **(cm)**	**Frequency (** f **) of tuning fork**	**Speed of Sound (cm/s)**
Fundamental Frequency				
First Overtone				
Second Overtone				
			Average Speed of Sound	

4. You are going to find the frequency of an unknown tuning fork using the wave velocity equation above and the speed of sound in air you just derived.

Measure the length of the fundamental frequency and the first and second overtones in the resonant chamber. Make the length correction and fill in the values below.

Calculate the wavelength of this tuning fork using the same ratios as in step 3. Fill in those values below.

The speed of sound in air is known now. Fill in the table below with the value you found above.

Finally, calculate the frequency of the tuning fork using the wave velocity equation again:

$$v = \lambda \times f$$

	Length + 2 (cm)	λ **(cm)**	**Speed of Sound (cm/s)**	**Frequency (** f **) of tuning fork**
First Resonance				
Second Resonance				
Third Resonance				
			Average Frequency	

Challenge Work:

1. Sometimes when you fill a bottle in a sink you can hear that it is almost full even though you can't see it. Explain this.

Summary:

Final Clean-up
Please disconnect all alligator leads and reattach them to the clip card. Replace all equipment to the carts.

Bibliography and recommendations for further reading:

Wikipedia contributors, "Pitch (music)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Pitch_%28music%29&oldid=60691898 (accessed July 7, 2006).

Instructor Outline: **Optics**

Lab length: 75-100 minutes
Lab objective: Instruct the students about geometrical optics, reflection, and refraction.

Materials

1 ray box
1 box optical materials
-slit screen
-mirrors: flat, concave, and convex
-lenses: shallow and deep concave, convex, prism, trapezoid, hollow concave and square

Exploration stage: 25-35 minutes - group lab work
The students work in groups to observe reflection. They test various curvatures and observe converging and diverging beams. They define the "Law of Reflection."

Analysis stages: 15-20 minutes – lecture
The instructor analyzes with the class the findings from the exploration, and answers questions formed during that stage. Concept development is done on reflection, converging and diverging beams.

Application stage: 25-35 minutes – group lab work
The students observe refraction through plastic. The observe dispersion and chromatic aberration. They compare concave and convex lens and mirrors. They make observations about focal points.

Summary: 10 minutes – lecture
This is a final opportunity for questions to be addressed. This is time to re-iterate the core concepts and principles.

Concepts developed:

1. The law of reflection states that the angle of reflection is equal to the angle of incidence.
2. Concave mirrors produce converging beams, convex mirrors produce diverging beams.
3. Concave lenses produce diverging beams, convex lenses produce converging beams.
4. A concave and convex lens pair can cancel and produce parallel beams.

Suggested Demos:
None

LIGHT: Optics

ANALYSIS

<u>Reflection</u>

A wave is reflected when it is incident upon a material that redirects it outward. Reflected waves are redirected according to the law of reflection: the angle of incidence is equal to the angle of reflection. With curved mirrors, the angle of incidence is with respect to the tangent of the curve and the point of incidence.

The law of reflection holds for each of type of mirror, but the result it produces is different for each. The plane mirror reflects a plane wave back along the same path it came from which creates an actual-size virtual image in the reflecting material. Concave mirrors make incident plane waves diverge, and convex mirrors cause incident plane waves to converge. Both of these contribute to the funny faces and bodies you see in carnival mirrors.

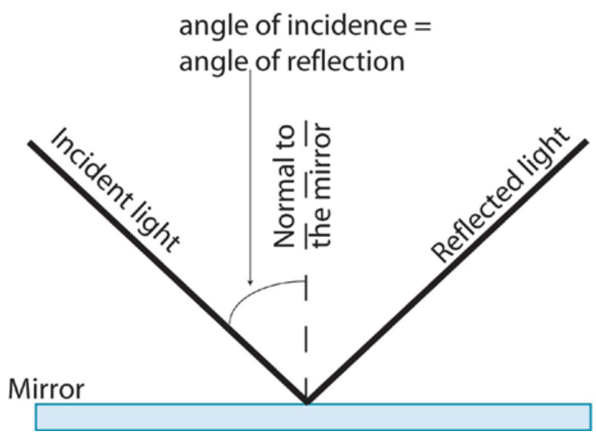


Figure 1: Plane mirror

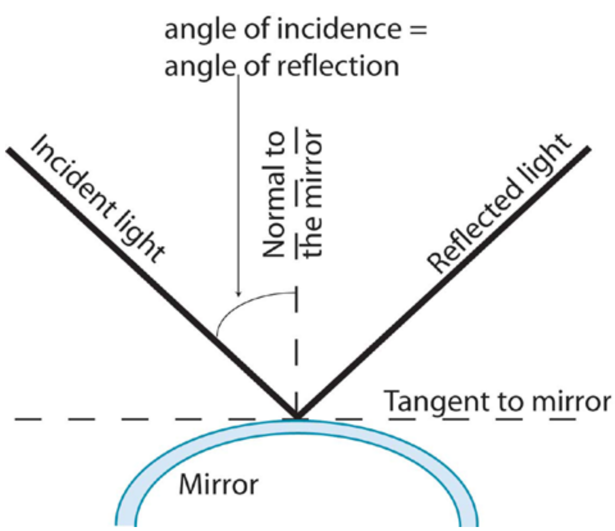


Figure 2: Convex mirror

LIGHT: Optics

Pre-Lab Question

Why can you see your reflection in the mirror?

EXPLORATION

Exploration Materials

1 ray box
1 box optical materials
-slit screen
-flat/concave/convex mirror

1. Plug in the ray box and insert the slit screen into the front of it so that only one narrow beam is emitted. Place a piece of white paper beneath the emitted light from the ray box to more easily see the beams of light. Predict and observe what happens when you place differently shaped mirrors in front of the beam.

You are going to derive to "Law of Reflection" from your observations of ray reflection off different types of mirrors. Keep that in mind while you make your observations.

Place the flat mirror in the path and observe what happens. Rotate the flat mirror slightly and see what different angles of incidence do to the reflection. Draw a few diagrams to represent different angles you tried with the mirror.

2. Insert the concave mirror and observe what happens. Rotate the concave mirror slightly and see what different angles of incidence do to the reflection. Draw a few ray diagrams to represent how light reflects off a concave mirror.

3. Insert the convex mirror and observe what happens. Rotate the convex mirror slightly and see what different angles of incidence do to the reflection. Draw a few diagrams.

4. How are the different mirrors similar? Define the "Law of Reflection." What happens when light is reflected on a surface from what you've observed? Does this depend on how the mirror is oriented? Is it the same law for flat and curved mirrors?

5. Rotate the slit screen so you have 5 narrow beams. Before placing the mirror back in the path, look at the imaging paper under the beam. The 5 beams should be parallel, but they may be diverging (spreading out) or converging (narrowing together). If the beams are not parallel, slide the ray box casing until they are.

Place the flat mirror in the path and observe what happens. Rotate the flat mirror slightly and see what different angles of incidence do to the reflection. Draw a ray diagram. Does this agree with your law of reflection? Explain.

6. Place the concave mirror in the path and observe what happens. Rotate the mirror slightly and see what different angles of incidence do to the reflection. Draw a diagram. Does this agree with your law of reflection? Explain.

7. Place the convex mirror in the path and observe what happens. Rotate the mirror slightly and see what different angles of incidence do to the reflection. Draw a diagram. Does this agree with your law of reflection? Explain.

Challenge Work:

1. Sometimes a watch can reflect light onto other people's faces? What is happening, and what is usually the source?

2. If you owned a fashionable boutique, would you install slightly concave or convex mirrors to make your customers think they were skinnier? Explain.

Everyday Applications

- Mirrors
- Lighthouses
- Indoor lighting
- Art
- Optical illusions

APPLICATION

Materials

1 ray box
Optical materials
-slit screen
-lenses: shallow and deep concave,
convex, prism, trapezoid,
hollow concave and square

1. You've observed reflection, but there is another optical phenomenon that is noteworthy: refraction. When light passes through a material, the direction of its beam can be altered depending on the material it is passing through.

Start with the rectangular part of the trapezoid. Place the rectangle, clear side up, in the path of 5 parallel beams so the length of the rectangle is perfectly perpendicular to the incoming beams. Draw the incoming and outgoing beams.

What does plastic do to light beams?

2. Rotate the rectangle slightly (about 5º). Observe what happens. Draw a diagram of the incoming and outgoing beams as well as the beams refracted inside the rectangle.

Is your description of plastics impact on light beams still valid? Why or why not, expand upon how light is refracted by materials.

3. Place the prism in the path of the ray box as shown below. Make the prism perfectly perpendicular to the beam path. Hint: look at the reflected beam.

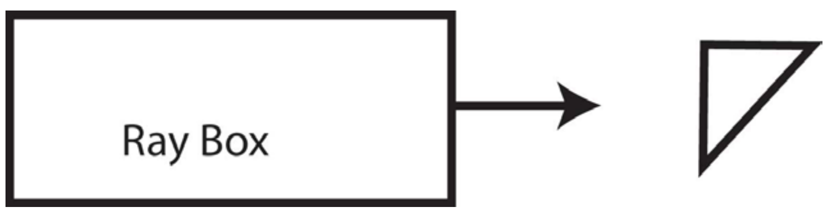


Figure 1: Ray box and Prism

What do you observe? Draw a diagram and explain your observations. Compare this result to a mirror.

4. Rotate the prism clockwise slightly.

5. Place a concave lens in the path of 3 parallel beams. Make the flat face perfectly perpendicular to the beam paths. Mark with a pencil where the three beams focus, and do not disturb the lens or ray box position.

Insert between the slit card and the ray box two color filters, one for each outside beam leaving the center beam as white light. Observe and draw where and if the beams converge. Explain this effect.

6. Shape

Does shape impact refraction? Use the larger concave lens to see how a concave lens interacts with the beams. How does it compare to the concave mirror? Draw a diagram, including the path of the beams inside the concave lens.

Record how far away the focal point is from the lens.

Focal Point (in cm)	

7. How will the shallow concave lens compare to the deeper concave lens?

Insert the shallow concave lens and record how it is different. Record how far away the focal point is from the lens.

Focal Point (in cm)	

Compare the shallow and deep concave lenses. Compare the refraction of the lenses to what you observed with concave and convex mirrors.

Challenge Work:

1. How does a convex lens interact with the beams? Draw a ray diagram of the convex lens in the beam path.

2. Where is the focal point of the convex lens?

Summary:

Final Clean-up

Please replace all optical materials in their boxes. Return materials and boxes to carts.