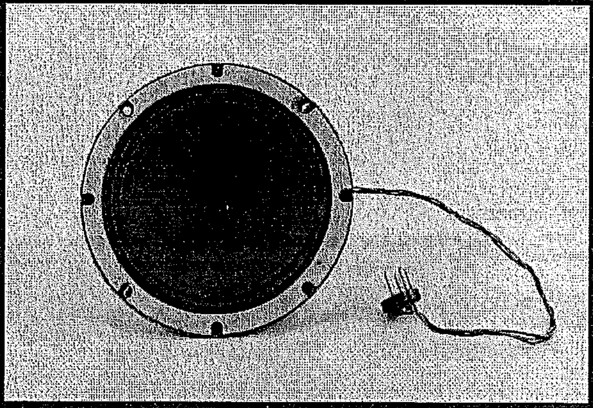
L1

Electromagnetic Forces

Daily life is subject to forces found in nature. A force is any interaction that, when unopposed, changes the motion of an object. For example, gravity is a force that keeps our feet on the ground. In order to jump into the air, your legs must overcome gravitational force. Electric and magnetic forces influence all aspects of daily life. Electromagnetism refers to the close interrelation between electricity and magnetism. Electric forces can produce magnetic forces, and magnetism can produce electric forces.

Electromagnetism is at the core of most music produced in the twenty-first century. Electromagnetism underpins how microphones, loudspeakers, and headphones work. The following activities are meant to help you discover electromagnetism.



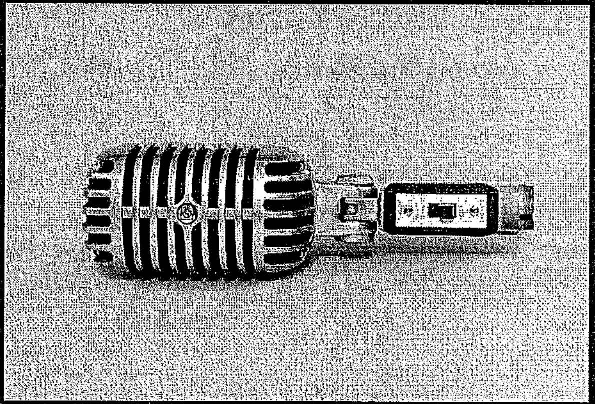


Figure 1: Loudspeakers and many microphones rely on principles of electromagnetism.

Arizona Science Standards 2018*

4.P2U1.2 Electric currents
4.P2U1.3 Magnetic forces
5.P2U1.3 Balanced and unbalanced forces
6.P2U1.4 Forces act on objects at a distance
7.P2U1.1 Electromagnetic forces can be attractive or repulsive and can vary in strength

**Arizona Department of Education. "Arizona Science Standards." 2018. www.azed.gov/standards-practices*

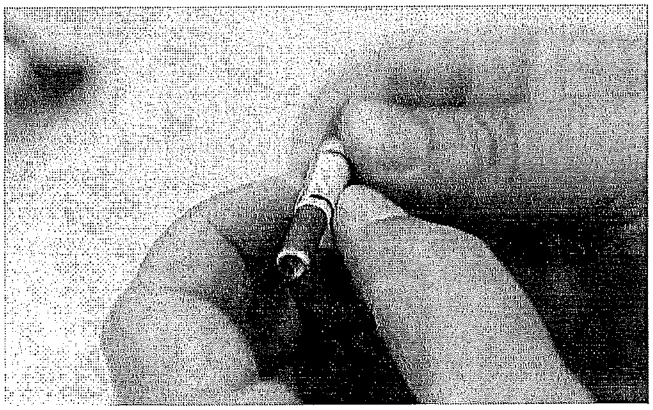
Materials

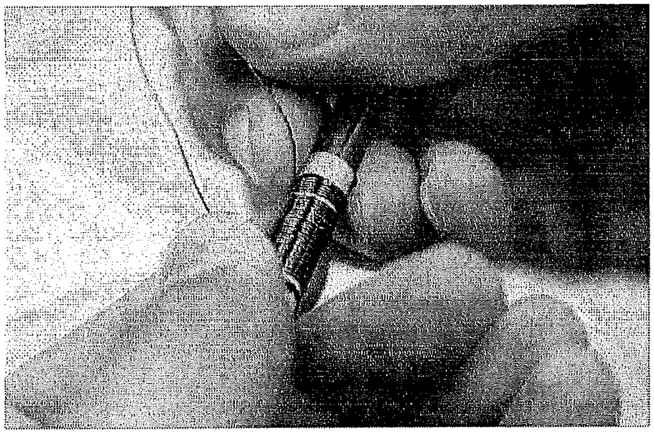
- 100 cm of very thin, **coated copper wire (28 AWG or smaller)**
  NOTE: Carefully scrape or burn the insulative coating from both ends of the wire using a lighter, sandpaper, or small razor.
- (1) **0.25 in. plain steel rod** cut into 5 cm lengths
- (6) **6 mm x 3 mm permanent magnets**
- (1) **3.5 mm mono audio plug to alligator clips** terminal adapter or 3.5 mm **audio terminal block (male)**
- (2) **Alligator clip test leads**
- (1) 9 V battery
- (1) Scissors
- (1) Tape
- (1) Paper—for both the speaker "cone"and to use when making the wire coil
- (1) Pen or Pencil
- (1) Plastic Cup
- (1) Paper Clip
- (1) Cell phone, iPod, Walkman, or other device with a 3.5 mm jack that can both play and record music/sound

Part I: Electromagnets

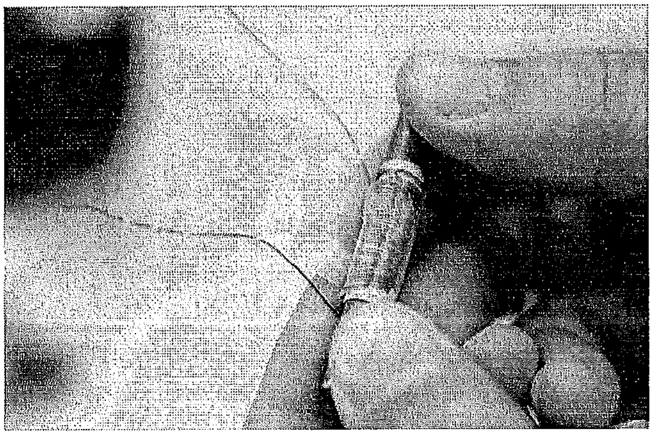
How does an electromagnet work?
How can I make one of my own?

1. Cut a 2 cm strip of paper.
2. Draw two parallel lines approximately 1.5 cm apart lengthwise along it.
3. Wrap the strip of paper around the metal rod two times with the parallel lines showing. Cut off excess.
4. Tightly coil the wire around the rod at one of the two parallel lines, coiling in the direction of the other line. Keep each wrapping of the coil as close to the previous one as possible. Continue this process until you have a coil that is at least 1.5 cm wide. Leave approximately 5 cm of wire free on either side of the wire coil.



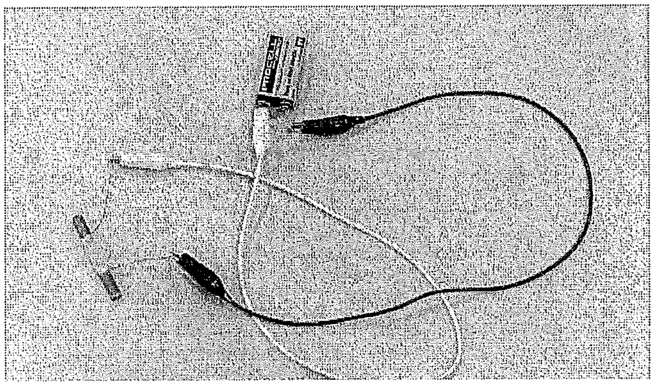


5. Wrap scotch tape around the circumference of the wire coil to keep it from unraveling.

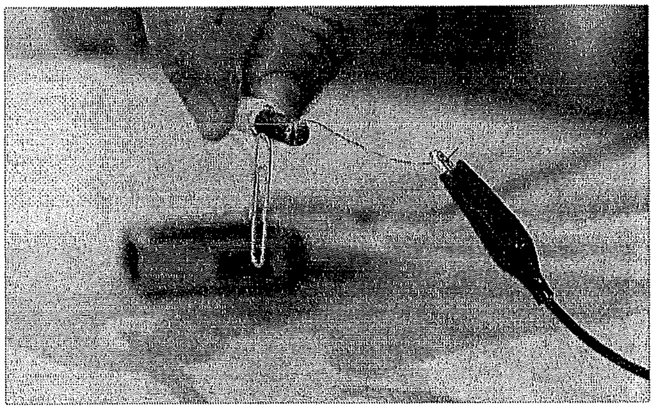


6. Connect each end of the wire coil to a different test lead. Then, connect the negative (-) terminal of the battery to one of the test leads. When ready, connect the positive (+) terminal of the battery to a test lead.

WARNING: Do not leave the battery connected to the electromagnet for more than a few seconds at a time. Always disconnect the battery immediately after use. The electromagnet and battery may become extremely hot if left connected for extended periods.



7. Try to pick up the paper clip with one end of the wire coil.



8. Disconnect the battery. Try to pick up the paper clip again.

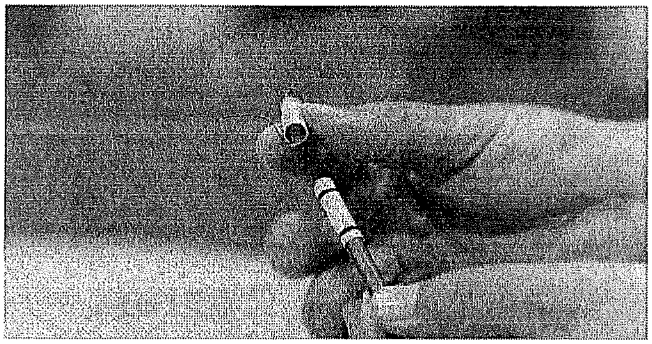
Why does the paper clip stick to one end of the wire coil when the battery is attached?

Connecting a battery to both ends of a wire creates a path or circuit along which an electric current can flow. A magnetic field is generated as electric current flows through a wire. The greater the current and the tighter that a wire is wrapped into a coil shape, the stronger the magnetic field that is produced.

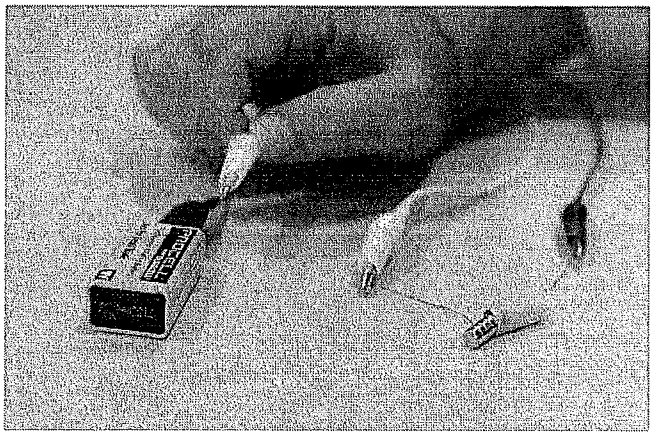
Part II: Electric Motors

How does an electric motor work?
How can I make one?

1. Carefully slide the wire coil off of the metal rod. Remove the paper tube.



2. Place three of the 6 mm x 3 mm magnets in one end of the wire coil; the other three magnets should be visible outside of the coil.



3. Reattach the battery.
4. Disconnect the battery.

Why does the magnet move (either inward or outward) when the battery is attached to the coil?

5. Place the magnet into one end of the wire coil facing the opposite direction.
6. Reattach the battery.
7. Disconnect the battery.

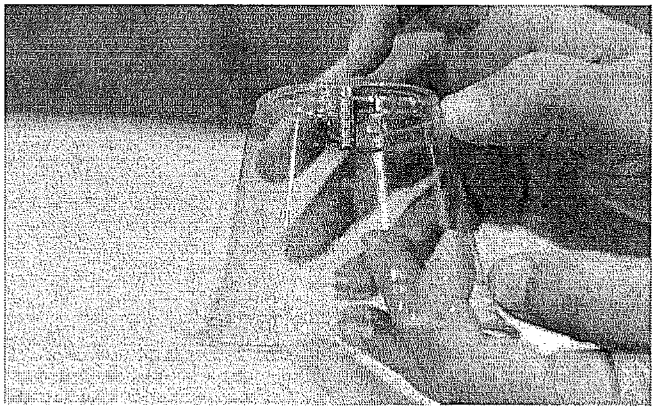
Why does the magnet change directions depending on which direction it is placed into the wire coil?

Magnetic forces have polarity, north to south, or negative to positive. Opposite polarities attract one another while similar polarities repel one another. The permanent magnet will either be shot from the end of the wire coil or sucked further inside, depending on which of its poles is facing into the electromagnet, as well as the polarity of the electromagnet. Remember, opposite polarities attract, and similar polarities repel. Electric motors rely on this same principle. An electromagnetic coil arranged around a central axis creates an oppositional force with the permanent magnets that surround it. This causes the motor to spin on its axis.

Part III: Loudspeaker

How does a loudspeaker rely on electromagnetism to create sound?

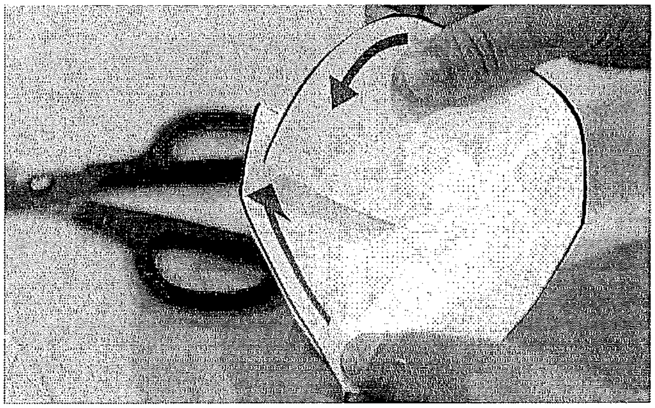
1. Speaker Chassis
   a. Make a single cut in the plastic cup from rim to base.
   b. Affix a stack of five magnets to the inside-center of the cup's base using a sixth magnet on the outside.



3. Speaker Cone
   a. Trace and cut a circle with a 12–16 cm diameter on a piece of paper.
   b. Find the center of the circle by folding it in half along its diameter in one place, opening it back up, and then folding it half again along its diameter in another place. The center of the circle is where the two folds meet.
   c. Cut a straight line along the radius of that

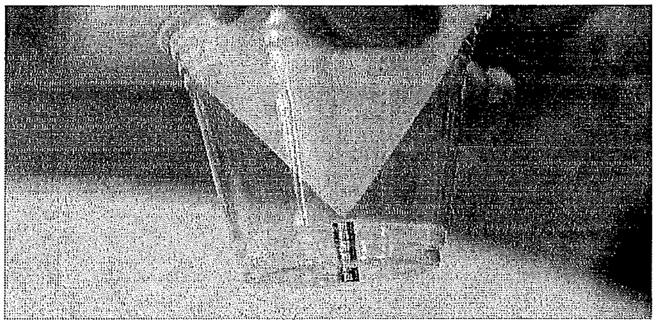
circle (i.e., from the edge to the circle's center).

d. Make a cone by sliding one side of the cut radius over the other.

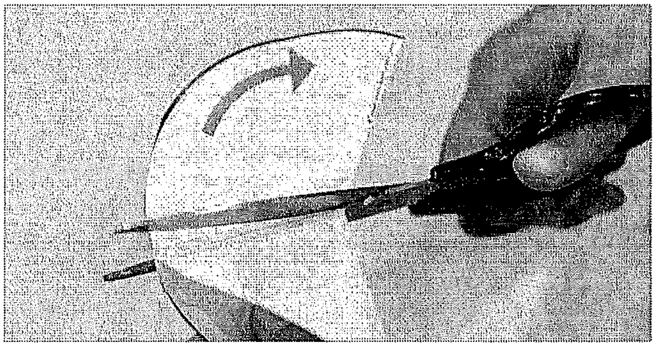


e. Place the cone inside the cup with its vertex facing downwards.

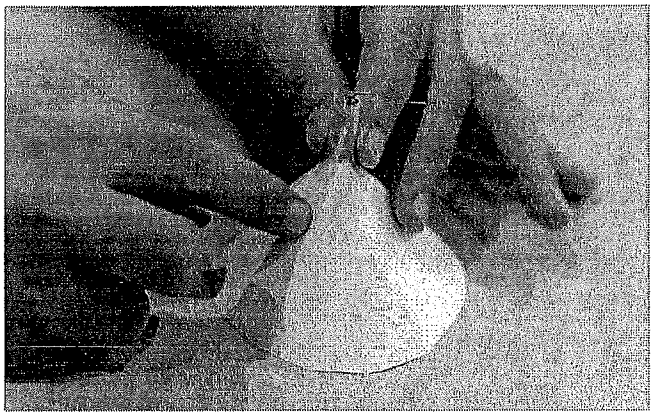
f. Adjust the height of the cone so that its vertex rests gently on the stack of magnets and its circumference rests on the rim of the cup. Depending on the diameter of the cup you use, the slant height of the cone may need to be more or less steep.



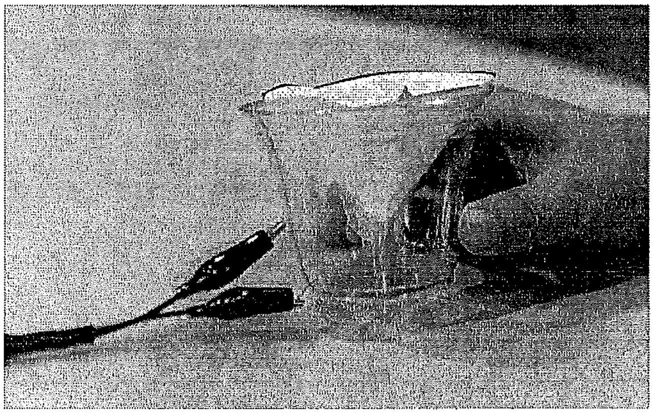
g. Place a small piece of tape on the inside of the cone to hold everything in place. Cut and remove the excess flap of paper formed on the outside of the cone.



8. Voice Coil
   a. Tape the wire coil to the outside vertex of the cone. Ensure that the bottom of the coil remains unobstructed.



2. Assemble the Loudspeaker
   a. Place the cone inside the cup so that the stack of magnets slides freely into the wire coil.
   b. Route the wire-ends of the voice coil through the cut in the side of the cup.
   c. Attach the wire-ends of the voice coil to the 3.5 mm audio adapter (alligator clips or terminal block).



   d. Insert the 3.5 mm jack into your audio player.
   e. Press play.

The electric current of an audio signal fluctuates rapidly, causing corresponding fluctuations in the magnetic field being generated in the wire coil. As in the electric motor, when the polarity of the magnetic field in the wire coil is the same as the polarity of the stack of magnets, an oppositional

L5

force is created. As this oppositional force begins and ends so quickly, it can be felt as vibrations. These vibrations are transferred to the speaker cone and then to the surrounding air. The vibrating air causes our ear drum to vibrate, which our brain is then able to interpret as sound.

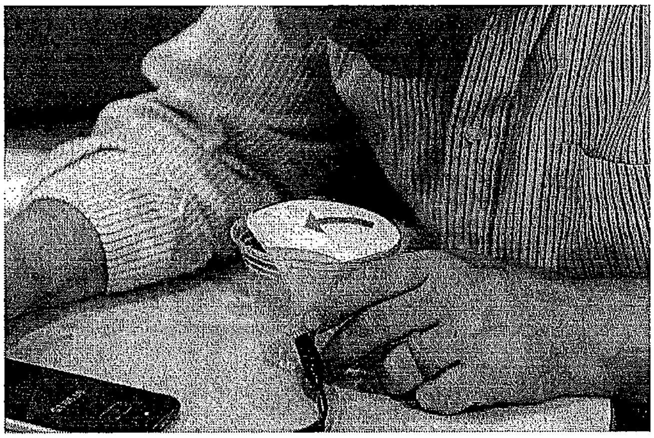
Troubleshoot:

- Tightly wound coils produce a more focused, stronger magnetic force than loosely wound coils. If the wires of your coil have large spaces between them, dismantle the coil and rewind per Part I.
- A secure connection between the voice coil and speaker cone will more effectively transmit the sound vibrations generated by the audio signal.
- Ensure the insulative coating has been scraped or burned off the ends of the copper wire. This coating does not conduct electricity.

Part IV: Microphone

How are microphones and loudspeakers related?

1. Connect the 3.5 mm jack to an audio recording device. On a cell phone, simply open a voice recording app or start a phone call with a friend in another room.
2. Speak LOUDLY into the speaker you have just made from very close proximity. Your recording device should pick up a faint signal as if from a microphone.
3. Play back the recording you just made with your homemade microphone on your homemade loudspeaker.



Microphones work similarly to loudspeakers, only in reverse—they take sound vibrations in air and convert them into fluctuating electric signals. While there are many different types of microphones, so-called "dynamic" microphones function identically to an electromagnetic speaker in that they have a small coil of wire suspended in a magnetic field. When sound vibrations cause that coil of wire to vibrate, it generates small amounts of fluctuating electric current. This electric current is then directed to an amplifier and then a loudspeaker, or into one of many technologies that "record" the fluctuations of this current for later use.

L6

A van der Graf attracts a tin plate with a force equivalent to the weight of a .02 kg weight. The distance R between the charge on the van der Graf and the charge induced in the tin plate is R = 1 inch. Imagine this as two equal charges, one +Q and one -Q, causing the attraction according to Coulomb's Law.

What is the size of Q?

L7

Electrostatic Interactions

Name:

Charge Diagrams

Introduction One of the important issues in constructing a charge diagram is knowing the excess charge on an object.

Questions 1-2

Suppose an object has 7 positive charges and 3 negative charges. What is the excess charge of the object? (Q1)

Recall that an object with no excess charge is called a neutral object. Suppose that an object is neutral. Does this mean that the object contains no charges at all? If not, what does neutral mean? (Q2)

You have seen that strips of tape prepared in a particular way attract and repel one another. We postulated that objects that interact this way have a property called charge. That is, objects that are charged will exert forces on one another electrically in a manner that is analogous to how objects with mass exert forces on one another gravitationally. Mass and electric charge are two *different* properties of an object and they lead to *different* kinds of interactions. The most important difference is that gravitation is always attractive; whereas interactions between charges can be either attractive or repulsive.

Objects are made of atoms and atoms consist of three different subatomic particles: protons, neutrons, and electrons. Protons carry a type of charge referred to as *positive* and neutrons carry no charge. These two particles are contained within a very small volume of the atom called the nucleus. Electrons carry a type of charge referred to as *negative.* They exist outside the nucleus and make up most of the volume of an atom. It is quite fortuitous that protons and electrons seem to have *exactly* the same amount of positive and negative charge respectively. Otherwise, stable objects such as tables, chairs, or human bodies would be extremely unlikely!

Definitions A ***conducting*** material is a material on which charge moves easily. Metals are examples of conducting materials. An ***insulating*** material is a material on which charge does not move much at all. Rubber and plastic are examples of insulating materials.

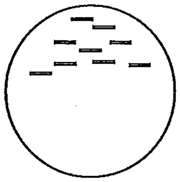
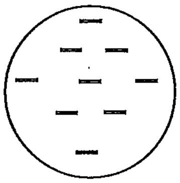
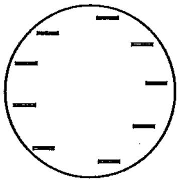
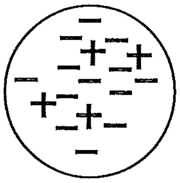
Charge Diagrams The following lists steps to follow when creating a charge diagram:

- If there are any surface charges, draw them very near the object's boundary.
- If there are any interior charges, draw them within the interior of the object.
- Typically, only excess charge is drawn on or in an object. The only exception to this is if the neutral charge of an object is distributed in a manner other than random due to interactions with something nearby. Such a distribution of charge within an object that deviates from the usual randomly distributed arrangement is called *unbalanced* charge. Thus, unbalanced and excess charges are included in charge diagrams.
- If you use a series of diagrams to explain a process, make sure you have the <u>same</u> excess charge from one diagram to the next.

Question 3 Objects are made up of many (10^{23}) atoms, each of which consists of multiple individual positively charged (protons) and negatively charged (electrons) particles. In a charge diagram, would it be practical to draw *all* of the individual charges within an object? (Q3)

Question 4 The table below shows four students discussing how to illustrate the charge diagram of a charged, solid metal sphere.

Group Discussion Of Charge Diagram Of Same Object

	*Student A*: Well, the charges have to be inside the sphere. So, my diagram shows all 9 negative charges in the sphere.
	*Student B*: The negatives in your picture are all in the top half of the sphere. My diagram shows that they are evenly spread out inside the sphere.
	*Student C*: The charges should be spread around the outside of the sphere to get as far apart as possible. My diagram shows the negatives on the surface.
	*Student D*: The sphere is made of protons and electrons so it has some positive charges too. My diagram shows this.

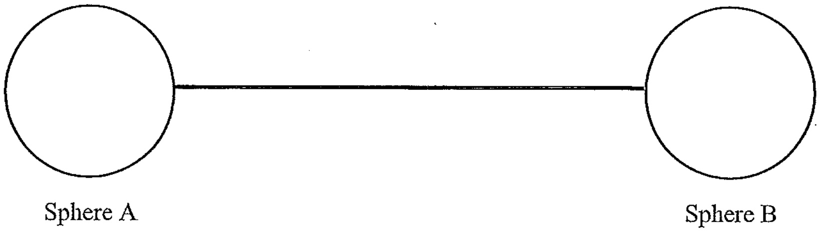
Which diagram(s) best illustrates how the charges on a conductor are actually arranged, and why? (Q4)

Problem 5: Charge equalization on identical conducting spheres:

Suppose you have two metal spheres that are exactly the same size, separated by a very large distance. Sphere A carries an excess of eight negative charges while sphere B carries an excess of two positive charges. Sphere A is momentarily connected to Sphere B using a metal wire and then the wire is removed. Draw charge diagrams of the two spheres for the two cases below before and after the connecting wire is used. (Q7)

- Before the spheres are connected using the wire

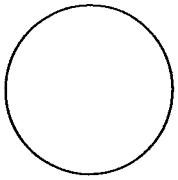
The wire is connected to the spheres (Do NOT draw a charge diagram here!)



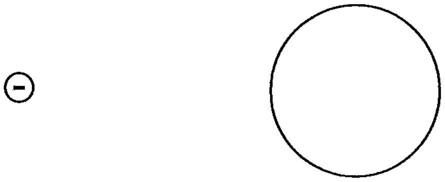
- After the wire has been removed

Problem 6: How a point charge attracts a neutral metal sphere.

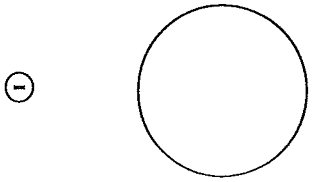
Now, draw the charge diagram of an isolated solid metal object



Now, draw the charge diagram of the same solid metal object when a negative point charge is brought near.



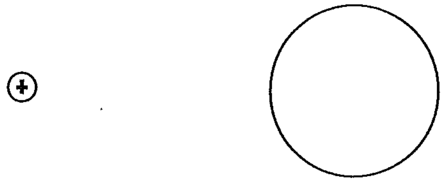
The point charge is brought closer still. Show how the charge diagram of the solid metal object changes for this situation.



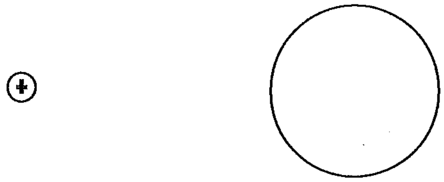
Problem 7: Forces - Now show the forces on each of the above charges or groups of charges.

Problem 8

Suppose that instead of the above, a positive point charge is brought near the solid metal object. Draw the charge diagram of the solid metal object in this case.



Draw the forces on both the point charge and the solid metal object. (Note: Each object should have more than one force vector included on it.)



Is the net force on the solid metal sphere directed to the left, directed to the right, or is it zero? Explain.

Name: **Date:**
Lab Partners: **Effective Resistance Lab**

Three resistors are combined in various ways, resulting in different effective resistances. Use the voltmeter and the Labpro ammeter to find the R_{equiv}

Part I: Series

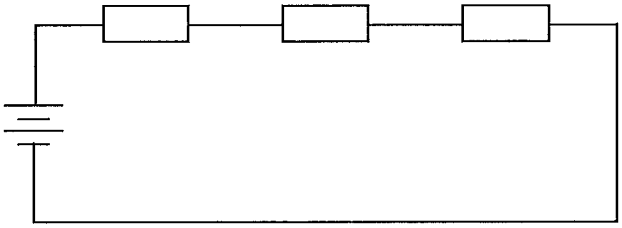
a. Get three resistors. Be sure thy all have different values. Measure the values of the three resistors.

R_1 = ____________ Ω R_2 = ____________ Ω R_3 = ____________ Ω

b. Measure the voltage of the battery.

V = ____________

c. Construct the following circuit – label the boxes R_1, R_2 and R_3



d. Calculate the equivalent resistance of the circuit and *predict* the current.

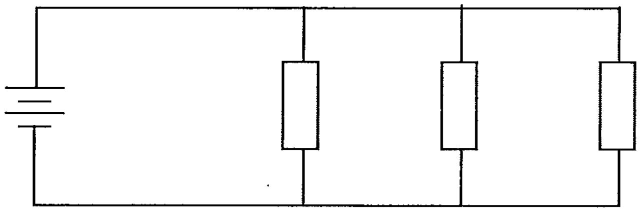
$\mathbf{R_{equiv}}$ =

I_{pred} =

e. Measure the current. What is the percent difference between the predicted and measured currents?

Part II: Parallel

Construct the following circuit using the same three resistors – label the boxes R_1, R_2 and R_3:



a. Find the equivalent resistance of the parallel combination:

R_{equiv} =

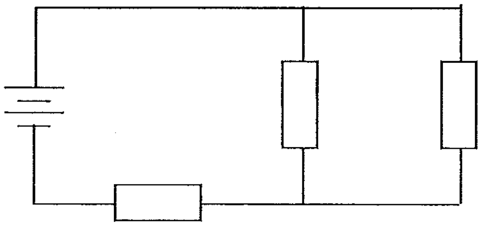
b. Predict the current through the battery using the battery voltage and equivalent resistance:

I_{pred} =

c. Measure the total current through the battery. What is the percent difference between the predicted and measured currents?

Part III: Combination Series-Parallel

Arrange the resistors – label the boxes R_1, R_2 and R_3:



a. Predict the current through the battery
b. Measure the current through the battery
c. What is the percent difference between the predicted and measured values?

Name: **Date:**
Lab Partners: **RC Time Constant**

Overview: When a charged capacitor C drains through a resistor R, the time constant for the charge to decay away is τ = RC. If you know the resistor value R, and time the decay, you can solve for the value of the capacitance. You will use this method to determine the capacitance of two capacitors in series, and two capacitors in parallel.

Setup

Materials: 6 Volt battery, two 1 farad capacitors, an approximately 20-50 ohm resistor

A. Set up the data collection device, the Vernier LabPro / LoggerPro System

Attach the Voltage probe to the LabPro. You are now ready to begin recording voltage data as a function of time.

B. Set up a circuit for RC measurements

The RC circuit is set up as in the following diagram. The arrow indicates a switch, which can be performed simply by removing the top capacitor wire from the battery and moving it over to the resistor.

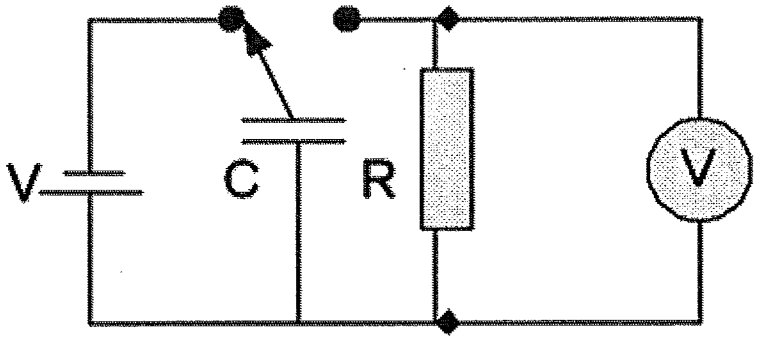


Figure shows switch in the charging position. When moved to the right, the capacitor starts to discharge.

Data collection

A. Log voltage data for the RC circuit with a 1.0 F capacitor and 10 ohm resistor.

1. Predict the time constant from your resistor and capacitor:

   Predicted time constant = R*C = ____________________

2. Data collection setup
   - **a.** Zero the voltage probe using the software.
   - **b.** First try collecting data using default graph and settings. Start with the battery connected to the capacitor. Observe the correct

polarity of the capacitor: the electrode attached to the outside metal case of the capacitor should be attached to the positive terminal of the battery. Switch the capacitor over to the resistor R with Logger Voltage probe attached.

c. Immediately press the start button in the software with the mouse to start logging data.

d. Choose from the Experiment Menu pulldown the Data Collection dialog, and set the length of data collection to 2 x R x C. Collect about 2 samples per second.

e. Properly scale the axes, so the graph fills up the screen.

<u>Data collection</u>

1. When you have a good graph, determine the time constant τ as follows: For each reading, select a starting voltage on the graph, V1. Then find V2 so the voltage ratio is V2/V1 = 0.37. Then find the time difference, T2 – T1, between those two points. Fill in the following table:

R = ___________

Volts (V)	Time (s)
V1 =	T1 =
V2 =	T2 =
V2/V1 =	τ = T2 – T1 =

τ = ___________

Question: Does the value of the time constant, τ, obtained in #A1 (above, your prediction), agree with the value of τ obtained from this LabPro data analysis?

B. **Try different resistance in the RC – Try another value of R, larger or smaller, in** your time constant circuit to verify that the time constant varies in proportion to R.

R = ___________

Volts (V)	Time (s)
V1 =	T1 =
V2 =	T2 =
V2/V1 =	τ = T2 – T1 =

τ = ___________

RC = ___________

Question: Comment on whether or not the values of the time constant, τ, change appropriately when you try different values of R?

C. **Capacitors in Series** – This time change the capacitance by using two 1.0 F capacitors in series. Predict the effective capacitance of these two capacitors in series:

Prediction of series capacitance: C series,predicted = __________________.

Now use the time constant to find the actual capacitance:

Volts (V)	Time (s)
V1 =	T1 =
V2 =	T2 =
V2/V1 =	τ = T2 – T1 =

τ = ____________

R = ____________

Cseries, actual = ____________

Did your prediction for the series capacitance agree with the actual, and can you now give the correct equation for C_1 and C_2 in series?

D. **Capacitors in Parallel** – This time change the capacitance by using two 1.0 F capacitors in parallel. Predict the effective capacitance of parallel capacitors:

C parallel,predicted = __________________.

Now use the time constant to find the actual capacitance:

Volts (V)	Time (s)
V1 =	T1 =
V2 =	T2 =
V2/V1 =	τ = T2 – T1 =

τ = ____________

R = ____________

Cparallel, actual = ____________

Did your prediction for the parallel capacitance agree with the actual, and can you now give the correct equation for C_1 and C_2 in parallel?

Question: Assume $\tau = 10$ seconds and $V_o = 1$ Volt. If $V = V_o e^{-t/\tau}$ calculate V for t = 0, t = 10, and t = 20 seconds. Do you find that each time t increases by one time constant, V is reduced by another factor of .37?

t = 0, V =

t = 10, V =

t = 20, V =

1. **What is the relationship between** 0.37 and e = 2.71828…?

L20

Name: **Date:**

Lab Partners: **Magnetic Forces Lab**

Materials: batteries, wire, paper clips, Ammeter to measure current

1. Electromagnet strength depends on N_{TPM}

N_{TPM} = the number of **turns per meter** (TPM). The idea is to try the formula for a solenoid's magnetic field $B = \mu_0 N_{TPM} I = 1.26 \times 10^{-6} N_{TPM} I$; To give a rough idea of the strength of B, count the number of paper clips that can be lifted by various configurations of solenoids and currents and TPM.

a. Try winding 50 or so turns of double wire around a rebar made of mild steel. The mild steel acts as a multiplier for the magnetic field produced by the solenoid. The multiplier with iron is anywhere from 10 to 1000 times the magnetic field with air. For ordinary rebar steel in this lab, assume the multiplier is 10x, ie, $B = \mu \mu_0 N_{TPM} I = 1.26 \times 10^{-5} N_{TPM} I$. (We will come back and investigate these constants further).

1. Attach the battery to an ammeter and switch in series with a solenoid and determine the number of paper clips lifted. Leave the battery on briefly, since the current drain is large, and the wire can get hot. We want to try for the battery to remain strong and consistent throughout the experiment.
2. Since the wire is doubled, you can use a single wire (O), a parallel configuration (P), or a series configuration (S) for the two wires.
3. Unwind half the number of turns and measure the paper clips lifted.
4. Try a different number of turns and measure.
5. Try bunching the turns to get a larger N_{TPM} near one end, and measure the clips at each end.
6. Take the same number of turns as in (4) above and spread it out along the entire length of the rebar to get a different N_{TPM}.

Create the following table:

Sample description	N_{TPM}	One wire, Series, or Parallel	I (ammeter reading)	Number of Paper Clips	compute B

b. Describe the trend for number of paper clips versus N_{TPM}, with different numbers of turns per meter.

2. <u>Magnetic Strength in various locations around a single magnet</u>.
Wind 50 or so turns near the end of the rebar to get a medium strong magnet. Characterize the field strength by the number of clips lifted in various parts of the magnet.

a. At the coil end of the rebar

b. In the middle of the windings along the side

c. At the end of the rebar where there is no wire.

Questions:
Use the right hand rule and a compass to determine, does the B-field point in the right direction? (Note: the north end of the compass points in the direction of the B vector.

Why does the magnet pick up the clips (which are not magnets to begin with)?

Why do some clips hang from other clips?

What is the expected field outside the solenoid along the side and why?

What is the reason the field is much smaller at the end of the rebar farther from the coil?

Why do some clips remain attached to the magnet after the current is turned off?

3. Dependence on current. For this part, try to verify the current dependence of the solenoid field formula. Try 1, 2, and 3 D-batteries in series on the same coil. Use a single strand in the magnet.

Trial #	N_{TPM}	V across coil	I through coil	One wire, Series, or Parallel	Number of Paper Clips	compute B

Question: Does the strength of the magnet increase linearly with the current applied and why or why not?

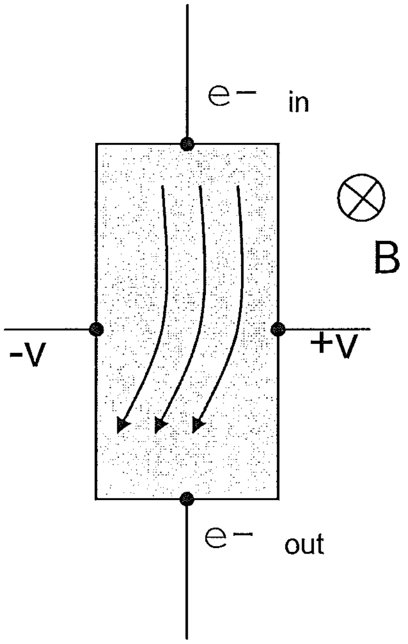
Name:
Lab Partners:

Date:
Slinky Solenoid B-field

Materials: 4 batteries, battery holder, slinky, LabPro setup, LabPro Hall Probe, wire to make our own coil, clip-on meter to measure current.

<u>Introduction – What is a Hall Probe?</u>

The Hall probe is a small and simple device for measuring magnetic fields. Basically, the device consists of a small rectangular piece of conducting material with electrical contacts on each of the four sides.



If a current of electrons passes into a conducting rectangle (e- in) and then out of the rectangle (e- out), there is normally no voltage difference created between the left side and the right side of the rectangle. However, if a magnetic field is present (shown directed into the paper), the electrons experience a force directed toward the left. The electrons, however, can not actually move left -- they bump into the edge of the rectangle. Therefore, the left edge becomes negatively charged, and the right hand side of the rectangle becomes positively charged. This charge is detectable as a voltage difference between the right and left edges in the presence of the field. The force on the electrons, and thus the size of the voltage, 2V, is proportional to the magnetic field, B. Therefore this arrangement, called a Hall probe, can measure magnetic fields.

The Labpro has a Hall Probe attachment which you will use in this experiment to measure the magnetic field in a variety of magnetic situations.

Magnetic field of a slinky as Solenoid

A slinky is a solenoid with an adjustable N_{TPM}. Hold a length of the solenoid down with two rulers and two bricks and measure the N_{TPM}. In order to avoid a magnetic contribution from the Earth's field affecting the magnetic field inside the solenoid, orient the solenoid perpendicular to the Earth's field – that is, the Hall probe when aligned to the solenoid will have the Earth's field at right angles, so it won't register much of a field component from the Earth.

Now attach battery leads to the slinky and apply enough voltage to get a field in the range of the Hall probe – it has two ranges and cannot read higher than a certain maximum value for each range. Use the clip-on meter to measure the current going through the slinky at the same time you measure the magnetic field. Insert the Hall probe at right angles into the coil from above, and align the white dot in the direction of the long axis of the slinky. Use this to find the magnetic field B.

If you flip the current, the B-field should also flip. Take the difference between the two readings – straight and flipped. Then the difference between the two, divided by 2, is a good measurement of the B-field. This technique eliminates any zeroing errors in the probe as well as any stray fields – the stray fields from other sources won't flip when the curren is flipped, so they cancel when 'flipped' and 'straight' are subtracted.

1. What is the formula for the magnetic field in a solenoid ?

$B_{solenoid}$ =

____

In the following table, enter the measurements and calculations for a range of different N_{TPM} by stretching and compressing the slinky.

#	Ntpm	V volts	I amperes	B (formula)	B (probe)
1					
2					
3					

Questions and Additional measurements:

2. The Hall probe, if it is perfectly aligned with the B-field direction, should give the exact negative reading when rotated 180 ° around its long axis. Try it. Why?

3. Measure the field at the end of the solenoid where the current is connected, and compare this with a measurement in the middle of the solenoid. Explain.

4. Measure the field outside the solenoid, keeping the orientation of the Hall probe exactly the same for both inside and outside measurements. What do you expect, why, and what did you actually get?

L27

Name:
Lab Partners:

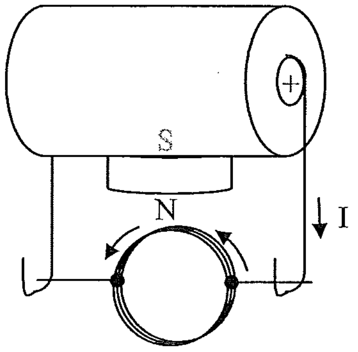
Date:
Electric Motors Lab

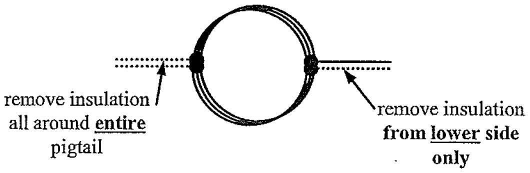
You can make electric motors using a powerful permanent magnet to create a constant magnetic field, and copper wire to carry current perpendicular to the magnetic field.

Preliminary Question 1
Explain the difference in magnetism between an ordinary piece of metal, such as zinc or copper, and a piece of iron.

Preliminary Question 2.
Explain the difference in magnetism between an ordinary piece of iron and a strong, permanent magnet.

Motor #1
Materials: Wire, scalpel, Neodymium magnet, D-cell battery, 2 large paper clips





Wind approximately 110 cm of #18 gauge copper wire into a conducting coil using a suitable form, and secure the coil with the two ends of the wire. The wire should stick out from the coil in a pigtail about 3 cm on each side. Twiddle the coil using each pigtail to make sure the coil is balanced and turns symmetrically around the pigtail.

On one pigtail, remove insulation on one side of the wire but not the other side of the wire, using the scalpel to scrape it off. The other pigtail should be stripped all sides.

Determine the north pole of the magnet, and mount the magnet as shown on the side of the battery.

Questions:

Case 1. Configuring the battery as shown in the drawing, predict the motion of the coil (ie, which will turn toward you – the top of the coil or the bottom of the coil?

Prediction:

Is reality according to prediction?

Case 2. In Case 1 above, the battery has the (+) terminal to the right. If everything is kept the same but the battery is flipped so the (+) terminal is to the left, predict the motion.

Predict turning direction, relative to Case 1: same opposite (circle one)

Is reality according to prediction?

Case 3. If the magnet and battery are unchanged from Case 1, but if the coil is turned around, predict the motion.

Predict turning direction, relative to Case 1: same opposite (circle one)

Is reality according to prediction?

4. Explain the basic ingredients of a motor and how does an electric motor work?

a)

b)

c)

d)

5. How is a **very powerful** electric motor designed?

6. Any other variations you want to try – more magnets, more wire, different scraping of the loop, hold the magnet in your hand, etc. Try to achieve higher speeds?

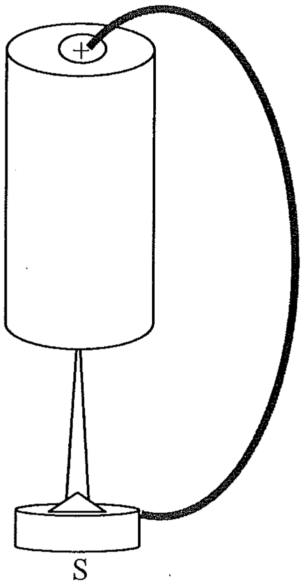
Video of electric motor with split ring commutator:

http://www.youtube.com/watch?v=yPeKC9a3WzE&NR=1

Motor #2
Materials: Wire, Neodymium magnet, pointy steel screw

Make the motor with the South end of the magnet pointed downward as shown.

7. Predict the direction of the rotation: The right side of the magnet will turn toward or away from you?



8. Draw a current arrow I to show where the current is interacting with the magnetic field.

9. How does this motor work?

L30

L31

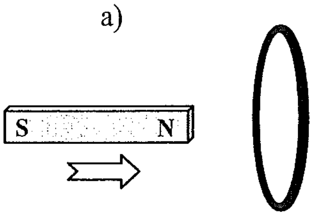
Name: **Date:**
Lab Partners: **Faraday's Law Lab**

When you move a magnet rapidly through a coil of wire, a voltage is generated in the wire. Measuring the voltage and using the Faraday's Law formula allows you to work backwards and figure out what must have been the magnetic field in the magnet.

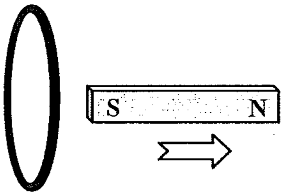
Preliminary Questions:

a. In the drawing at left, the north end of a magnet approaches a coil of wire. According to Faraday's Law, a current is induced in the coil. Draw in a N and S pole on the coil, as well as an arrow indicating the direction of current flow in the coil, due to Lenz's Law.

a)

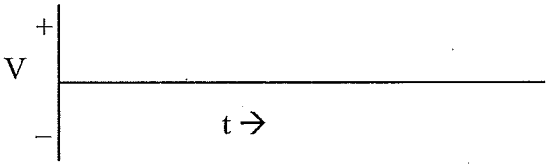


b)



b. Above right. The S pole of the bar magnet leaves the coil. Show the induced magnetic poles in the coil, as well as an arrow indicating the direction of current flow in the coil, due to Lenz's Law.

c. Based on a) and b) above, predict the voltage vs time curve for a voltmeter connected to the coil while the magnet approaches, and passes completely through the coil.



Procedure

Materials: Coil of Wire, computer w/ Labpro, voltage probe, Nd magnet, Dry-erase marker, compass. Set the Labpro 'Experiment' up for a few seconds, measurements every .002 seconds, and voltage scale ± 0.1 V. Tape the Neodymium magnet to a marker. Count the number of turns on the coil. Check the North pole of the magnet with a compass. Pull the marker rapidly one direction through the coil, and record the voltage.

Analysis:

1. Confirm the voltage waveform produced by the movement of the magnet. Does it agree with the prediction? Why or why not? If not, redraw here:

2. Confirm the direction of the voltage when the North end of the magnet enters the coil. A positive current entering the red lead of the voltage probe will produce a + reading in the Labpro. Is Lenz's Law confirmed? Why or why not?

Write the Faraday formula for the induced voltage V in terms of the number of turns N, the change in flux, $\Delta\Phi$, and the time interval Δt.

$V =$

Number of turns
$N =$

From the plot find the average voltage produced when one end of the magnet rapidly enters the coil (You can take $V_{avg} = V_{peak}/2$.)

$V_{avg} =$

From the above formula and values, solve for the change in flux,

$\Delta\Phi =$

Now use the area A of the magnet to determine the B-field coming out of the magnet:

$A =$

$B =$

Does the value of magnetic field from the Nd magnet as measured here agree with the value obtained in your previous magnetic force experiment using the current in the wire and the balance? Why or why not?

Name:
Lab Partners:

Date:
Transformer Lab

Materials: Transformer, heavy alligator leads, clip-on ammeter, hair dryer or lights for load, household AC socket.

Introduction – the Step-down Transformer

The step-down transformer has a heavy iron core, wound with copper wire primary and secondary coils. It is used for low-voltage lighting, for firing the tungsten filament-cathode of cathode ray tubes (CRTs), and for many household devices containing low voltage circuits. In power distribution, the voltage is usually stepped up at the power plant to several hundred thousand volts. Then at various sub-stations near the point of use, the voltage is stepped down by a transformer before distributing electricity to users.

CAUTIONs: The transformers used in this experiment present the ordinary danger as far as high voltage is concerned: the primary operates at 110 VAC house voltage, so the usual care must be taken to avoid wet workplaces, e.g., no drinks are allowed in the lab during this experiment.

But be very careful to **avoid shorting the secondary with copper jumpers, etc.**, because the secondary is capable of putting very large currents into a wire. This could result in melting of the wire, and the flash can cause a burn to the skin. Use only the special heavy jumper wires supplied for this experiment.

- **Be prepared to pull the plug out of, or turn off the circuit breaker on the house power strip if you detect overheating, sparks, or smoke in your experiment.**
- The lights and heaters used for loading the transformers will get hot, even at the reduced secondary voltage of the step-down transformer. **Therefore wait a minute after removing power from these devices before gripping them,** and touch them gingerly until you are sure they are cool enough.

C. Basic circuit

The purpose of this experiment is to exercise your knowledge of transformers. As you recall, the transformer can step up or step down the voltage, according to the primary: secondary turns ratio. At the same time, due to conservation of energy, the current must be in the primary and secondary must be in the opposite ratio. Therefore the primary circuit resistance : secondary circuit resistance should be according to the square of the turns ratio. Of course this assumes there is no loss of energy.

The transformer is designed to minimize losses, but it is not perfectly efficient.
Set up the circuit, using a hair dryer or some low voltage lamps (normally used for Low Voltage lighting and for automobile lights) as the load. Ask the instructor to check wiring before turning on power.
You can assume the house current is 110 VAC. You can measure the primary current and secondary current with the clip-on ammeter. You can measure the secondary voltage

with a lab multimeter. You can vary the load by changing the number of lights or changing the hair dryer from high to low, etc.

#	Load	Vpri	Vsec	I pri	I sec	Power pri	Power sec	Effic - iency %
1								
2								
3								
4								

Questions:

5. Calculate the efficiency of your transformer as a % by considering the power input and the power output, for each of the above experiments. Tabulate the ratio as the percentage efficiency for each case in the above table. Is there a correlation between efficiency and power output?

6. Does your transformer have a rating to tell the maximum current or voltage it can handle? If so, explain the rating and give the value. Did you exceed the rating during the experiment?

7. Was there any increase in temperature of the transformer you notice, due to the experiment? Does the temperature rise seem consistent with the efficiency you found in the above question?

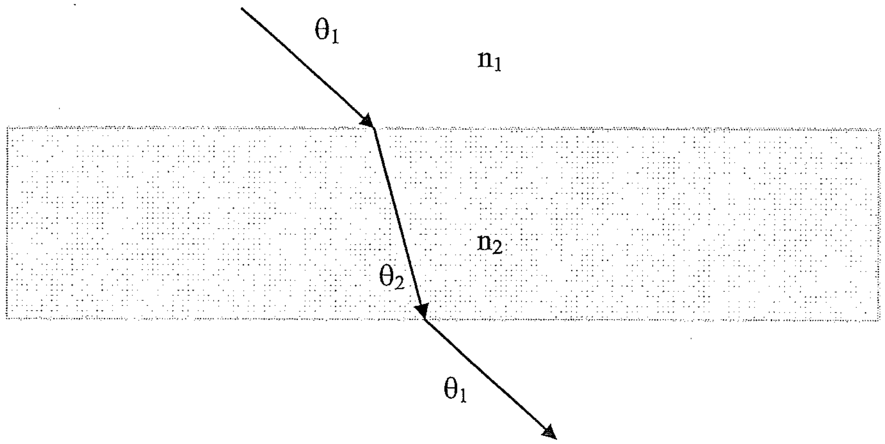
8. Look at a transformer which is not completely enclosed in a sealed case. What is the structure of the iron core and why is it built the way it is (stacked-up plates)?

Name:
Lab Partners:

Date:
Refractive Index - Acrylic

Materials: Acrylic block, 4 pins, and cardboard base, piece of paper.

Introduction – Snell's Law
When a ray penetrates a smooth surface at an angle to the normal, the ray is bent so that it bends toward the normal in the slower speed medium (slower in plastic).



The relationship between the angles is

$$n_1 * \sin\theta_1 = n_2 * \sin\theta_2$$

If the ray exits from the other side of the slower medium, the exiting ray will bend back away from the normal and be parallel to the entering ray, but displaced. This is shown in the figure. By measuring the angles entering, and going through, the slow material, it is possible to measure the index of refraction, n_2.

A. Placing the pins

Draw a straight pencil line on a diagonal on the paper. Place two pins on the line, both on one side of the acrylic block. Now place two pins on the other side of the block as follows: Line up the new pins so that they appear to be ***exactly*** in line with the first two pins, as viewed *through* the block. This will define a new line, parallel to the first, but displaced. Now trace the two edges of the block, and complete your version of the above figure by filling in the ray that crosses obliquely through the block.

B. Finding θ_1 and θ_2

Use a protractor to find measure θ_1 and θ_2. Then apply equation (1) to find n_2. This is the value of the refractive index in acrylic.

Questions:

It is certain that the light bent when going through the Acrylic block. Can you explain why it did not appear to bend when you looked through the block to see the pins all exactly lined up?

Based upon your value of n_2, predict the minimum angle at which total internal reflection occurs in acrylic.

Name:
Lab Partners:

Date:
Refractive Index - Acrylic

You can make an image of any size using a convex lens. For each of the following cases, create the image, measure sizes and distances, and confirm the lens formulas.

First you will need the focal length. One way is to take your lens outside and image the sun on a piece of paper. Have a partner measure the distance from the lens to the paper to obtain the focal length, F.
F=

This is not perfectly accurate, but it's a good value to begin with.
Use the worksheets provided to create each of the following images, and fill out the worksheet with the correct distances and sizes. You should probably measure the flame from the top of the candle to the tip of the flame; the bottom of the flame is a little to dim to image clearly, but the wax candle top should image well enough.

Use the attached worksheets to record data on image size, etc. Create each of the following configurations, record data, and complete the worksheets for each of the following:

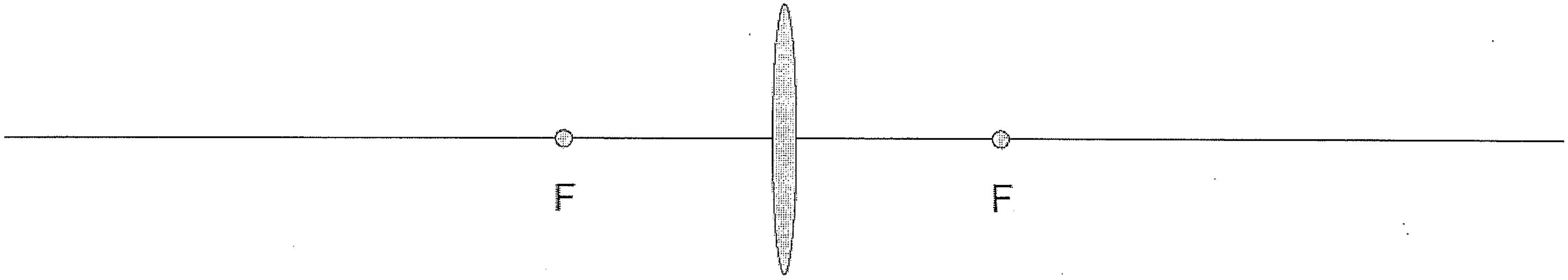
1. Arrange candle and image so that image size ~ source size.
2. Arrange candle and image so that Image size >> Source size
3. Arrange candle and image so that Image size << Source size

4. There is a simple trick to go from 2) above to 3) above. What is it?

5. If the source size is the same as the image size, there is a special relationship between S, I, and F. What is it?

Convex Lens Imaging Worksheet

1. Draw the Source candle and its Image, using ray tracing:



2. Write down the following data you <u>measure</u>:

F = ____________

S = ____________

I = ____________

Size_S = __________

Size_I = __________

3. Based on the values of S and F, what do you predict for image distance? Use

$1/I_{pred} = 1/F - 1/S$

I_{pred} =

Does I_{pred} agree with your measurement of I?

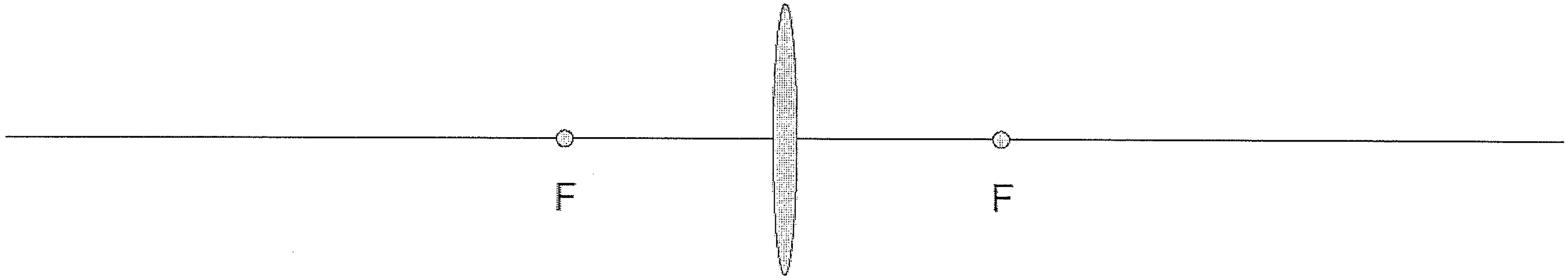
4. Based on source size, source distance, and image distance what do you predict for image size? Use

$\text{Size}_{I\ pred} = \text{Size}_S * I / S =$

Does $\text{Size}_{I\ pred}$ agree with your measurement of Size_I?

Convex Lens Imaging Worksheet

1. Draw the Source candle and its Image, using ray tracing:



2. Write down the following data you <u>measure</u>:

F = ____________

S = ____________ Size$_S$ = ____________

I = ____________ Size$_I$ = ____________

3. Based on the values of S and F, what do you predict for image distance? Use

$1/I_{pred} = 1/F - 1/S$ I_{pred} =

Does I_{pred} agree with your measurement of I?

4. Based on source size, source distance, and image distance what do you predict for image size? Use

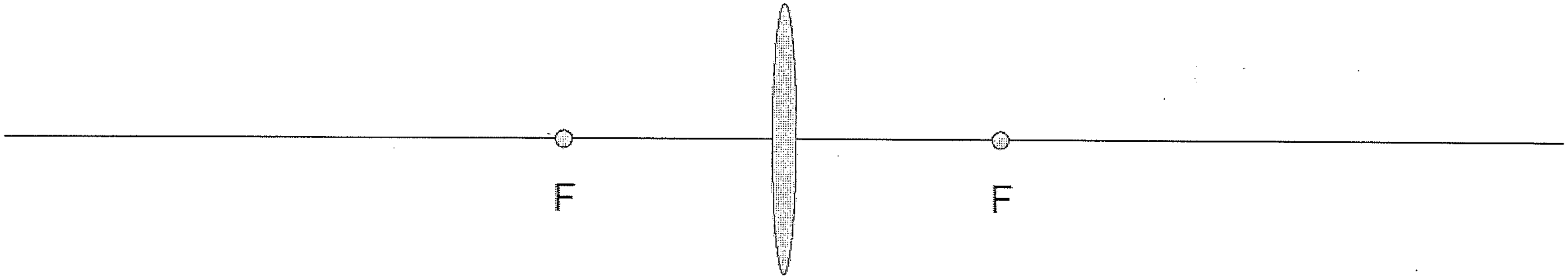
Size$_{I\ pred}$ = Size$_S$ *I / S =

Does Size$_{I\ pred}$ agree with your measurement of Size$_I$?

L44

Convex Lens Imaging Worksheet

1. Draw the Source candle and its Image, using ray tracing:



2. Write down the following data you <u>measure</u>:

F = ________________
S = ________________
I = ________________

$Size_S$ = ____________
$Size_I$ = ____________

3. Based on the values of S and F, what do you predict for image distance? Use

$1/I_{pred} = 1/F - 1/S$

I_{pred} =

Does I_{pred} agree with your measurement of I?

4. Based on source size, source distance, and image distance what do you predict for image size? Use

$Size_{I\ pred} = Size_S * I / S$ =

Does $Size_{I\ pred}$ agree with your measurement of $Size_I$?

L 45

Convex Lens Observations

Materials: various convex lenses

Sit facing your partner.

1. Determine what's the focal length of the lens by imaging a bright, distant object on a piece of wax paper.

   Focal length =

2. Slide the wax paper partly out of the way and observe the image partly on the wax paper and partly floating in space in front of the lens.

3. Hold up lens toward partner, and observe an **upside-down** image.
   a. Identify location of the image. The best way to do this is to focus on your partner's image through the lens with one eye. Then hold up a pencil near the image. Move the pencil between the lens and your eye until the pencil is in focus, to your eye, at the same time the image of your partner is in focus. Is your partner's image behind or in front of the lens?
   b. By adjusting the distance from the lens to your partner (the object), adjust his(her) image to be larger, the same size, or smaller than the actual object.

4. Move the same lens toward your partner until you can observe an **upright image.**
   a. Is this image larger than the actual object?
   b. Observe that this image is behind the lens and behind your partner.

5. Try any concave lens.
   a. Observe the image is always upright, always smaller than the actual object, and always at a distance *in between* the lens and the actual object.