E/M Labs 1-14
Update 2023

Name ________________________________ Date ___________________________

Lab 1
Electrostatics: Charging Objects by Friction

Overview

Static electricity is the result of an imbalance of charge in materials. Since all materials are made up of atoms, it is important to understand how the positive and negative charges in the atom produce this imbalance of charge in objects.

An atom encapsulates positive (protons), neutral (neutrons) and negative (electrons) charges within it. The positive and neutral charges make up the core or nucleus of the atom, while electrons carrying a negative charge surround the nucleus. A very crude model of the atom likens it to the solar system, which is described below as the Solar System Model in **Fig. 1.0.1.** A more accurate model, which we believe today, is the Electron Cloud Model, described below in **Fig. 1.0.2.**

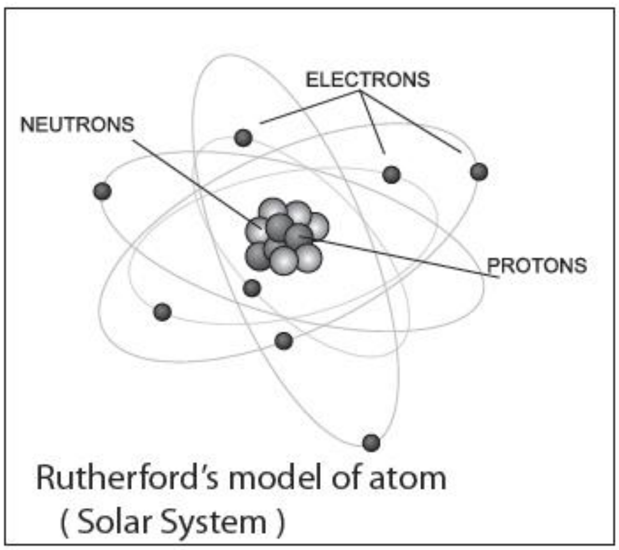

Fig. 1.0.1 Solar System Model (a.k.a Rutherford's Model of Atom) is the most common way to picture an atom. The model describes electrons orbiting around the nucleus in a fashion similar to planets orbiting the Sun. Just like planets have their orbits and are located at different distances from the Sun, the electrons have their own trajectory and distance from the nucleus. This model is still popular in teaching physics as it is easier to visualize.

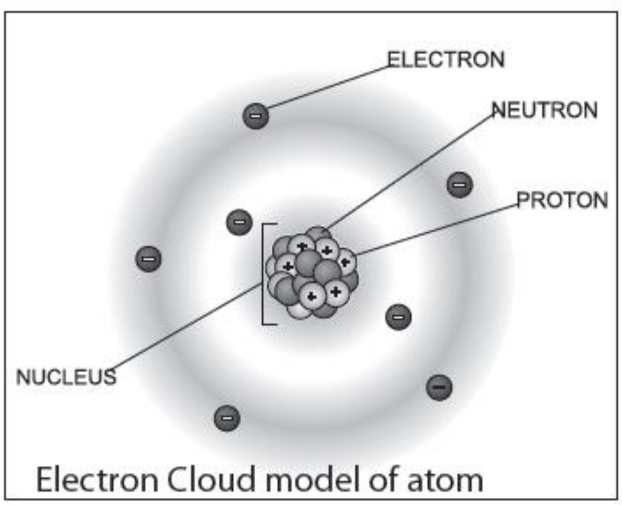

Fig. 1.0.2 The Electron Cloud Model claims that there are no orbitals. Instead, the electrons are located around the nucleus within certain boundaries or shells.
These shells are described as the most probable locations for electrons to be found. The boundaries are fuzzy and the precise locations of the electrons are unknown. This model, which is based on probability, is considered more advanced, and it is commonly used in chemistry and quantum mechanics.

Typically, the number of electrons equals the number of protons. The outer electrons are located farthest from nucleus and are held more loosely than the rest. On contact between two materials, electrons may migrate from one material to another. This migration will create an imbalance of charges. The object whose atoms lost electrons will be left with a positive charge on it and the object that received or "captured" the electrons will have a negative charge. This imbalance of charges is what creates static electricity.

Insulators and Conductors

Materials made of atoms that hold on to their electrons very tightly are called insulators. Materials made of atoms that have a weak attraction to their electrons are called conductors. If you take a segment of electric wire, you will have both types of materials in it. The silicon that wraps around the metal is an insulator, and the metal inside is a conductor. Electrons inside conductors are free to move as influenced by various forces. They either move inside the conductor itself or can migrate to another conductor.

Electrons inside insulators can only move within atoms themselves and cannot move along the insulator. They may stretch the atoms or rotate them but never leave the atoms under normal circumstances. Nevertheless, every insulator has a maximum electric field strength that it can withstand without a breakdown. At the breakdown, the electric field frees bound electrons, thus turning the insulator into a conductor. The breakdown point depends on different factors, which include humidity, temperature, thickness of the insulator, as well as the strength of the electric field.

The Triboelectric Series

Triboelectricity means electric charge generated by friction. It comes from the Greek word "tribos", which means rubbing. Historically, Benjamin Franklin named the charge on glass positive and the charge on silk negative after he rubbed them against one another. When an insulator like glass is rod rubbed against an insulator like silk, a charge transfer occurs between the two materials. Silk attracts the loose electrons from the surface of glass and becomes negatively charged. Because charge is conserved, the glass rod is left positively charged. Transfer of electrons is responsible for charging; the protons in atoms remain where they are.

Materials possess various tendencies to acquire or lose electrons; the ordering of these tendencies is referred to as the *triboelectric series*. The list below orders a number of common materials by their electrical nature. See **Fig. 1.0.3**. The tendency of a material to acquire charge determines is place in the triboelectric series. The series is also called the electronegativity scale. The chemical property of an atom to attract electrons itself is called electronegativity. The top of the list measures the ability of the material to acquire positive charge by giving up electrons while the bottom of the list is a measure of the material to acquire negative charge or electrons. The further apart in the series the two materials are, when rubbed together, the greater the charge acquired by each material. For example, when Teflon is rubbed with silk, Teflon acquires a negative charge and silk acquires a positive charge. Because they are quite far apart in the series, each acquires a large amount of charge. Another example is when glass is rubbed with silk. The glass acquires a positive charge and the silk now acquires a negative charge. Because silk and glass are close together in the series, each acquires less charge and there is less charge imbalance.

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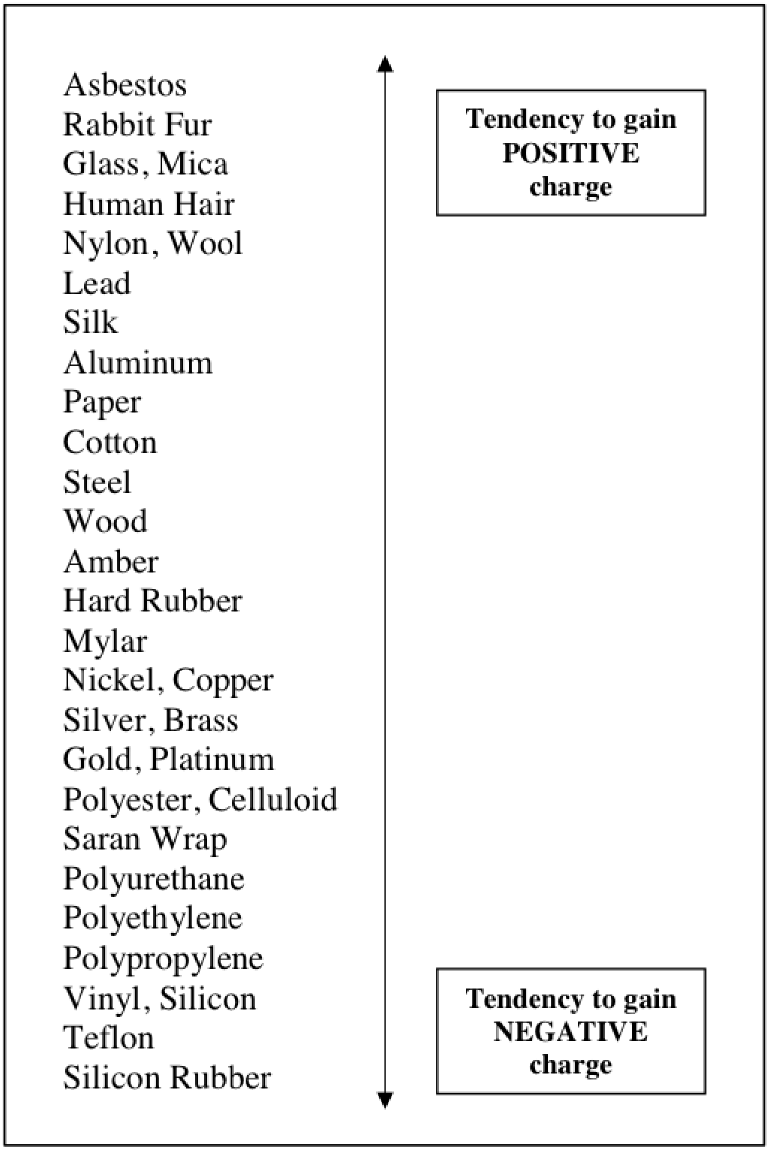

Fig. 1.0.3 The triboelectric series shows the relative tendencies of objects to gain positive or negative charges when rubbed against one another. For example, if we rub glass on silk, glass will gain positive charge and silk will gain negative charge.

Neutral and Polarized Objects

An object is said to be neutral if it contains the same number of positive and negative charges. In **Fig. 1.0.4** below the material is neutral since each atom contains the same number of positive and negative charges. The arrangement of the charge in the atom is such that the center of negative charge is on one side and the center of the positive charge is on the other. Each atom is arranged randomly so that the orientation of the charges is different throughout the material.

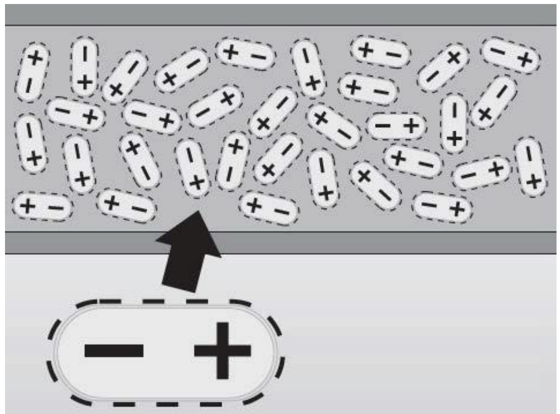

Fig. 1.0.4

A neutral object can, however, produce some of the same phenomena as a charged object as a result of a process known as polarization. We already know that opposite charges attract. If we recall that charges are somewhat free to move within an object, we should not be surprised that a positively charged object will induce a charge alignment in a neutral object so that the object's electrons are as near to the positively charged object as possible. As a result, the neutral object will appear to react to an electric force as though it were charged. See **Fig. 1.0.5**.

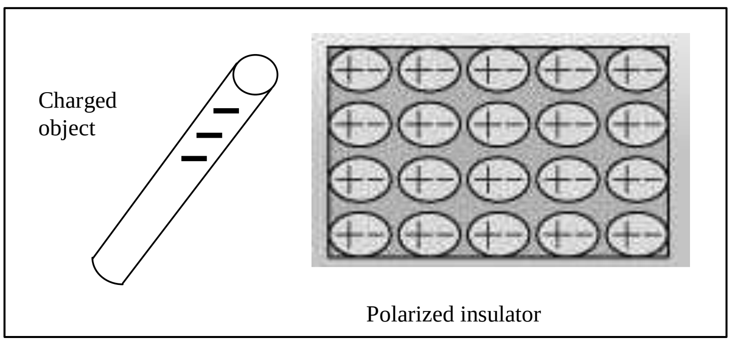

Fig. 1.0.5

The electrons and nuclei in the atoms that make up an object carry equal and opposite charges, so the whole object appears neutral. When a second, charged object comes close, it induces the electrons to align themselves slightly away from the nuclei. This process is known as polarization. For example, in **Fig. 1.0.6** below, a plastic comb (negatively charged) attracts pieces of paper (neutral) after combing through hair.

Fig. 1.0.6

Different Ways to Obtain Charge

There are primarily three different methods in how material gets charged. We call them rubbing or friction, conduction or touching, and induction. The three methods are illustrated below in **Fig. 1.0.7**. In Lab01 we will focus on charging by friction. More details on the other two methods will be given in Lab02 and Lab03.

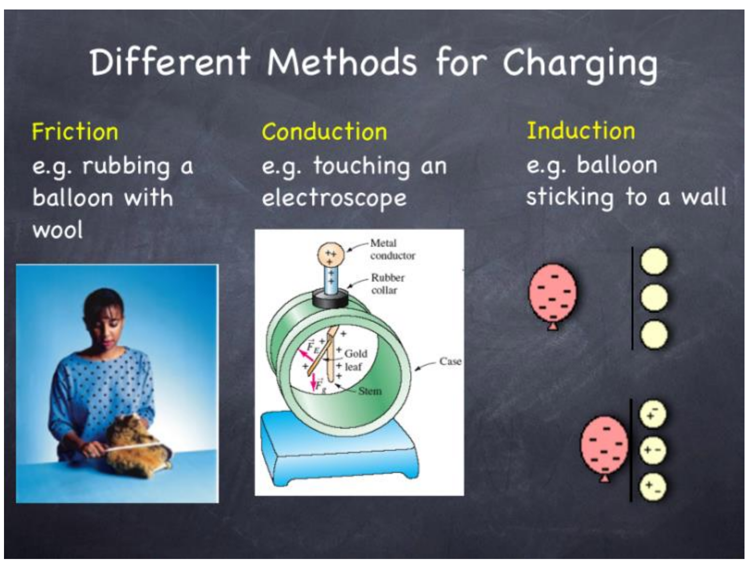

Fig. 1.0.7

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Activity 1 - 1: Charging Objects by Friction

Objective: Charge selected objects by rubbing them on silk; observe the effect of charge on small objects around it.

Materials:

- Acrylic Rod*
- Teflon Rod
- Silk
- Scrap Paper (confetti)

* We use acrylic rods instead of traditional glass rods for safety reasons. Acrylic ranks about the same as glass in the triboelectric series.

The materials except for the confetti are shown in **Fig 1.1.1.**

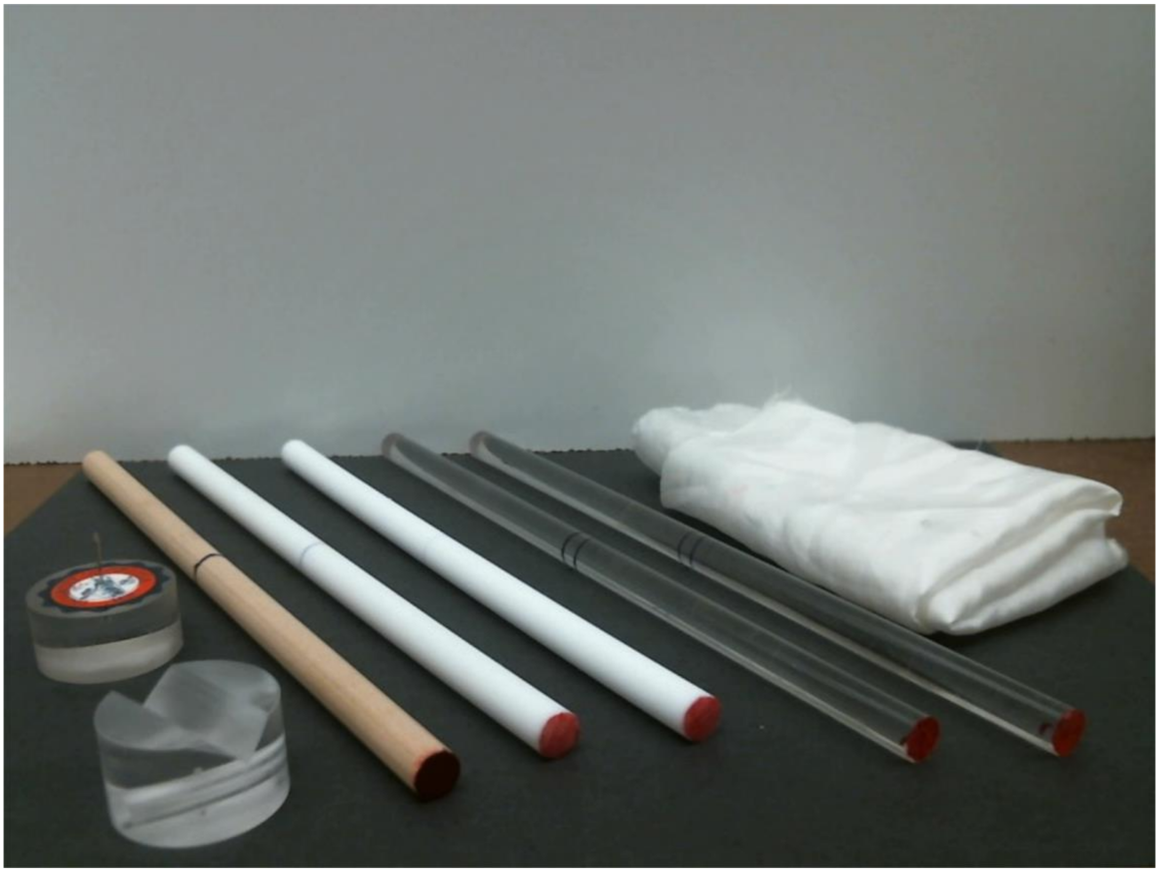

Fig. 1.1.1

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Procedure:

1. Cut a piece of dry, scrap paper into a few quarter-inch squares.

2. Neutralize the Teflon rod by sliding it slowly across your palm. Move the rod towards the paper squares. Describe the behavior of the squares. ____

3. Rub the Teflon rod with silk. Move the rod towards the paper squares. Describe the behavior of the squares. ____

4. Repeat the same process with the acrylic rod. Describe the behavior of the squares before and after the acrylic rod is charged. _____________________________

5. We have seen that paper spares are attracted to the rods when they are charged. But it is unclear why that happens. We will revisit the phenomenon in activity 3. Meanwhile, can we tell from the behavior of the paper squares alone whether the charges on the acrylic rod and the Teflon rod have the same polarity after rubbing against silk, or different? ____

6. We will examine the charges on the acrylic rod and the Teflon rod again in the next activity. What do you predict about the polarities of charges? Why? ____

Activity 1 - 2: Electrical Forces between Charged Objects

Objective: Show that charged objects could attract or repel each other, depending on the polarity of charges involved.

Materials:

- Acrylic Rod x2
- Teflon Rod x2
- Silk
- The Spinner*

* The "spinner" consists of two parts – the base and the cap. The base is a piece of acrylic with a protruding metal pin. A cork is placed over the metal pin during shipping and handling for safety reasons. Remove the cork only when the apparatus is in use. The cap is another piece of acrylic that is designed to rotate freely on the metal pin. See **Fig. 1.2.1** and **Fig. 1.2.2**.

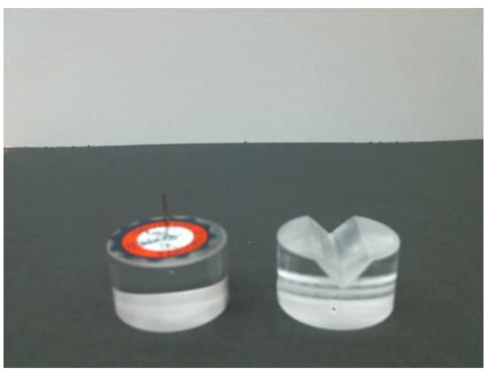

Fig. 1.2.1

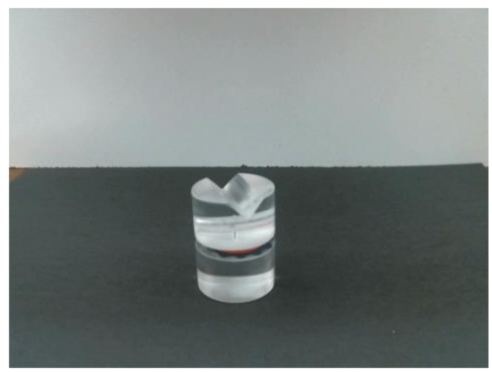

Fig 1.2.2

Procedure:

1. Charge one end of the first Teflon rod by striking it on the silk cloth and place this Teflon rod on the spinner. Now charge one end of the second Teflon rod.

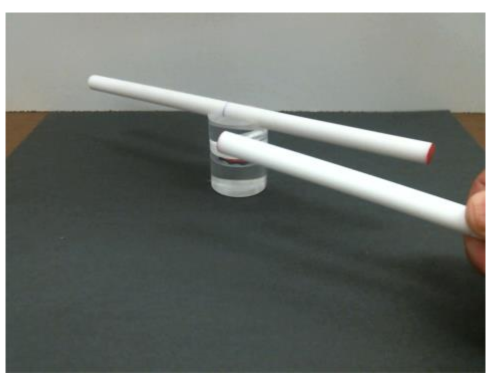

Fig1.2.3

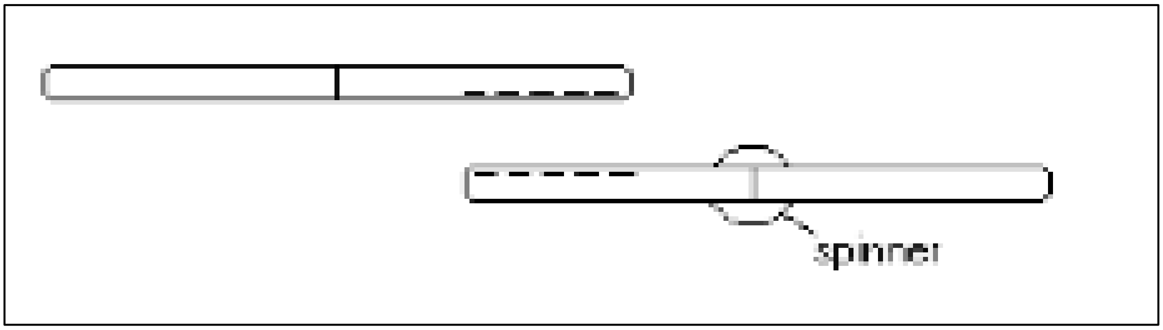

Fig. 1.2.4

2. After charging both rods, hold one Teflon rod in your hand parallel to the Teflon rod on the spinner as shown in **Fig. 1.2.3** and **Fig. 1.2.4** in order to ensure the greatest possible interaction between the two. Record the direction of the force (attract or repel) in **Table 1.2.1**.

3. Repeat the same process with two acrylic rods. Record the direction of the force in **Table 1.2.1**.

4. Repeat the same process with one acrylic rod and one Teflon rod. Record the direction of the force in **Table 1.2.1**.

Direction of Electrical Forces Between Charged Objects		
	Teflon (-)	Acrylic (+)
Teflon (-)		
Acrylic (+)		

Table 1.2.1

5. What can we generalize about the direction of the electric force between charged objects of the same kind, according to entries in the table above? If opposite charges attract, then why does positive charge stay on silk and negative charge on Teflon after we rub them against one another? ___________________________

Activity 1 - 3: Forces between a Charged Object and an Uncharged Object

Objective: Move a wooden rod on the spinner.

Materials:

- Acrylic Rod
- Teflon Rod
- Wooden Rod*
- Silk
- The Spinner

* The wooden rod likes to absorb moisture from the air and becomes slightly conductive. In addition it is not so easily charged when rubbed. Thus, it is excluded from the previous two activities.

Procedure:

1. Place the wooden rod in the slot on the spinner. Charge the Teflon rod by rubbing it on silk.

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2. Hold the Teflon rod in your hand parallel to the wooden rod on the spinner as shown in **Fig. 1.3.1** to ensure the greatest possible interaction. Record the direction of the force in **Table 1.3.1**.

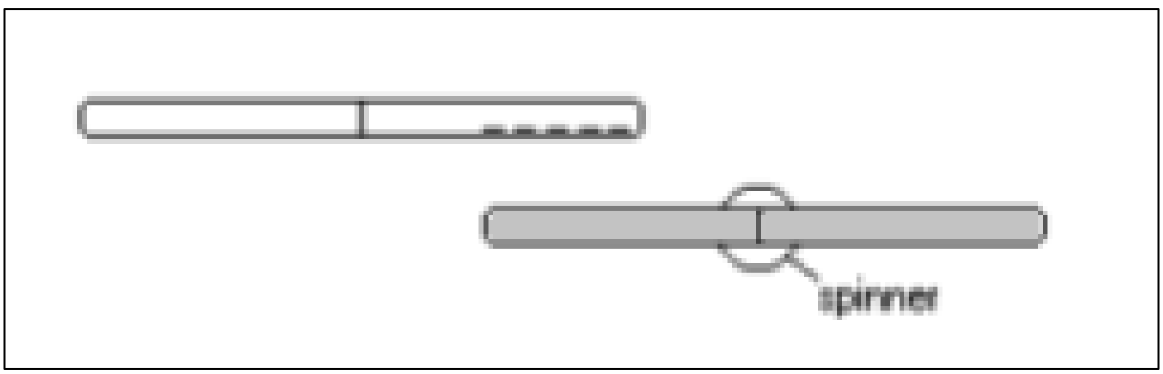

Fig. 1.3.1 A wooden rod is placed on the spinner. A Teflon rod is then charged and used to rotate the wooden rod without touching it. Note the direction of the electric force between the two.

3. Substitute the Teflon rod with the acrylic rod. Repeat the same process. Record the direction of the force in **Table 1.3.1**.

4. Recall the description about how paper squares behave near charged acrylic and Teflon rods in Activity 1. If you are not sure, redo activity 1 to double check. Fill in **Table 1.3.1**.

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Direction of Electrical Forces between a Charged Object and an Uncharged Object		
	Teflon (-)	Acrylic (+)
Wood (0)		
Paper (0)		

Table 1.3.1

5. What can we generalize about the direction of the electric force between a charged object and an uncharged object? ______________________________

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Activity 1- 4: Sneaky Static

Objective: Raise awareness of static electricity in everyday life.

Materials:

- Scotch tape
- Teflon rod
- Silk

Procedure:

1. Pull 4 segments of scotch tape of 5 cm each. Stick them on the edge of a table. As shown in **Fig. 1.4.1.** Fold back 1cm on each segment to make a handle. Label them A, B, C, and D.

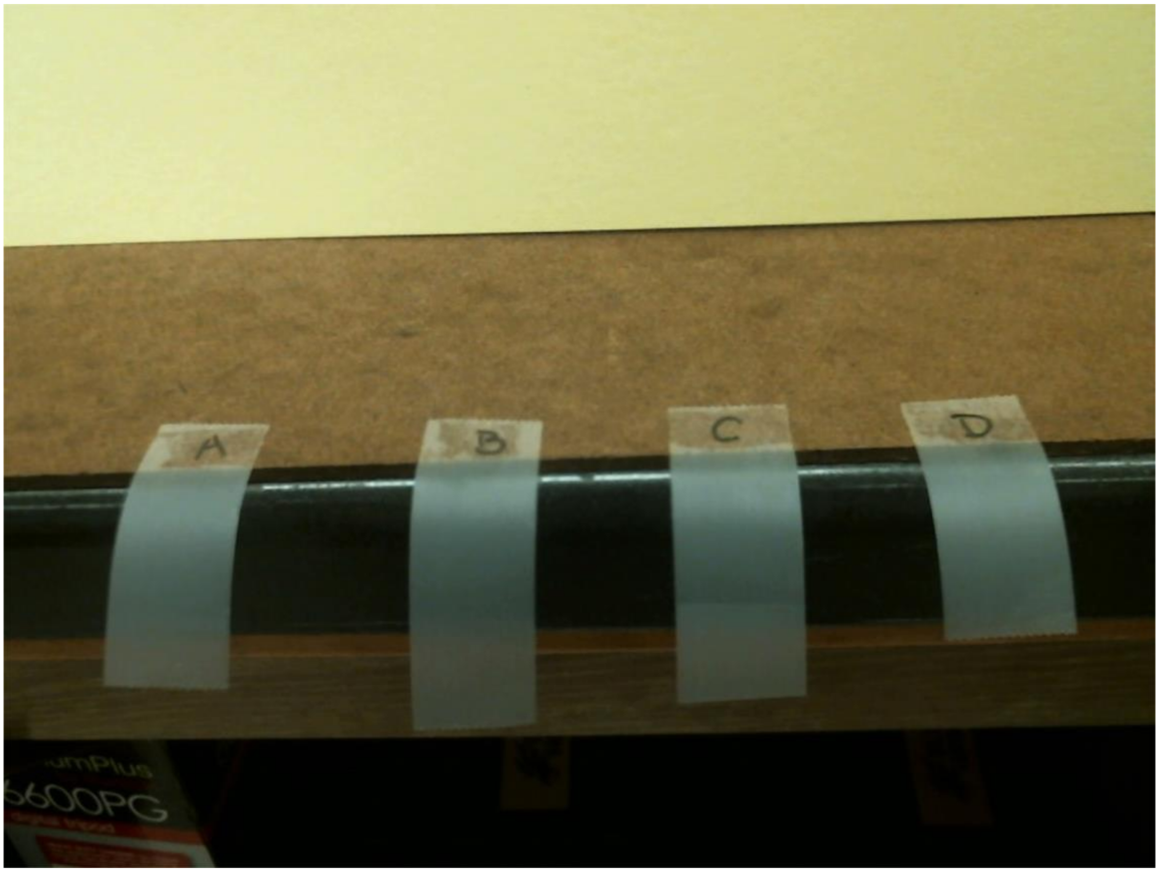

Fig. 1.4.1

2. Stick the sticky side of A against the unsticky side of B together. Then pull them apart. When you move them close to each other again, what do you observe about the force between them? ____

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3. Stick A and B on the edge of the table, using 1cm of the remaining sticky part near the handle. About 2 cm of each segment should suspend over the edge of the table and remain untouched.

4. Repeat steps 2 and 3 with C and D. What do you observe about the force between them? ____

5. Now pull A and C off the table. Move them close to each other. What do you observe about the force between them? _________________________________

6. Put C back down and pick up D. Move A and D close to each other. What do you observe about the force between them? _________________________________

7. Put A back down and pick up B. Before you move B and D close to each other, what is your prediction about the force between them? What is the actual result? ____

8. Finally, charge up a Teflon rod with silk and use it to check the polarity of charge on each segment by observing whether it attracts or repels the segment. What is the polarity of charge on each segment? ________________________________

9. Static electricity can be sneaky in everyday life. List 3 household phenomena that involve static electricity. ____

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Lab 2
Electrostatics: Detection of Charge

Overview

An electroscope is an instrument that detects the presence of charge on an object, either through actual contact (conduction) or through induction. When the electroscope itself is charged, its two conductive components (which vary from electroscope to electroscope) will acquire like charge and deflect from the vertical position of gravitational equilibrium. See **Fig. 2.0.1** and **Fig. 2.0.2** for an illustration of the standard metal leaf electroscope and the UVa electroscope that we will use.

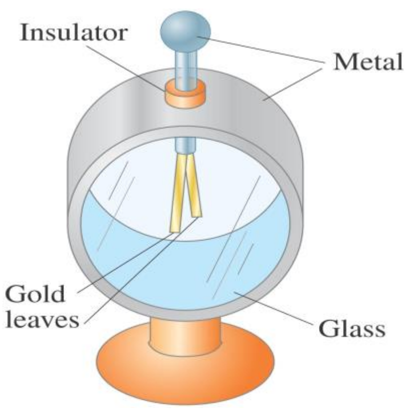

Fig. 2.0.1 Standard Electroscope

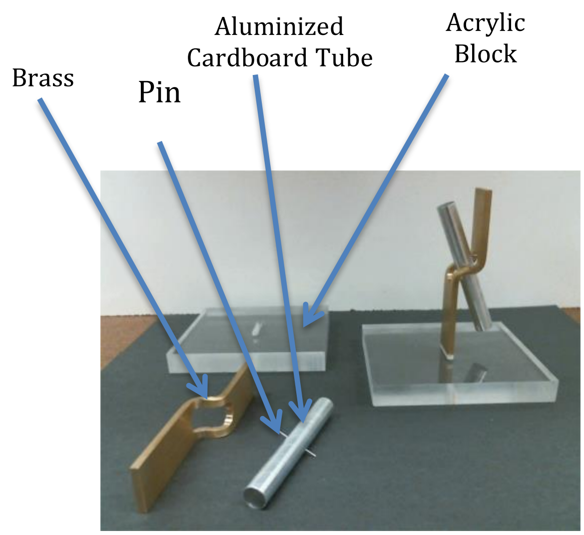

Fig. 2.0.2 UVa Electroscope

The base of the UVa electroscope in **Fig. 2.0.2** is constructed out of acrylic, an insulator, to eliminate charge leakage to the table. The electroscope is quite portable and very robust. You can also easily assemble it and move it around. Electrical charge can easily move along the tube and brass support causing a repulsive force to separate the tube and brass. The angle is a measure of how much charge is present.

The metallic looking conducting tube is aluminized Mylar which is conductive on the inside and non-conductive on the outside. The important thing about the tube is that it is conducting. A metal conducting or steel pin is inserted through the tube 2 mm from the midpoint of the tube seen in **Fig. 2.0.3** and glued with conducting glue so that the inside of the tub is electrically connected to the brass support through the conducting glue and pin. The tube is now suspended by the pin which is resting on the flat groove in the curved piece of conducting brass metal. The longer end as measured from the center of mass is pointing down so that the slightly more mass below the center allows the tube to be vertical when no charge is present. The brass, pin, and tube are all excellent

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conductors so that electrical charge, namely electrons, can move freely from the brass structure to the tube and cause a deflection of the tube due to repulsive forces between the charges in the tube and like charges in the brass support plate.

If a charged object is brought into contact and/or rubbed on the upper lip of the support structure, charge will distribute across the brass and the tube, causing the tube to deflect from the brass structure. Sometimes the tube will deflect even when you do not touch it due to the presence of a strong electric field. We will explore more on this later.

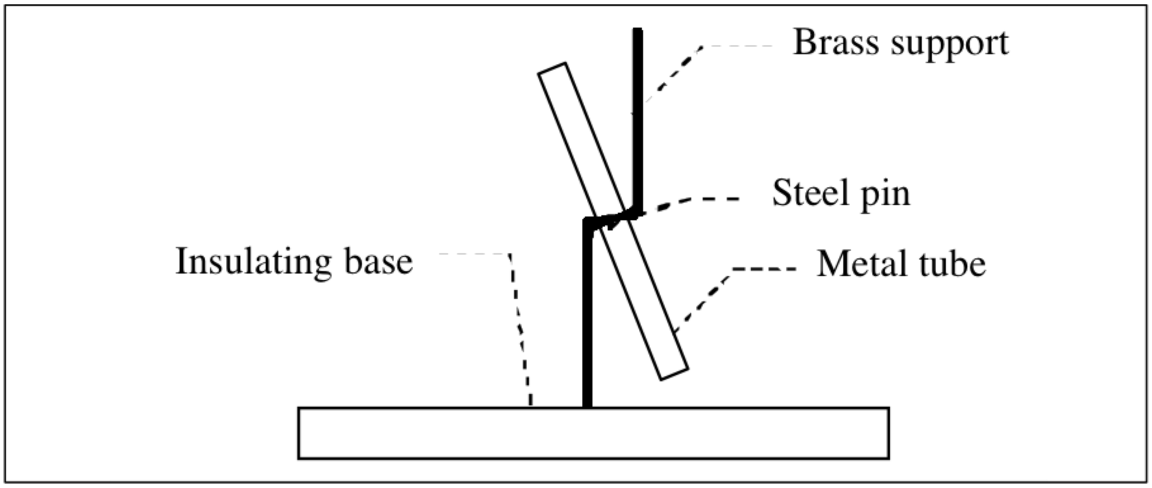

Fig. 2.0.3 The UVa Electroscope consists of an insulating base and a metal tube that can rotate around a steel pin on a brass support.

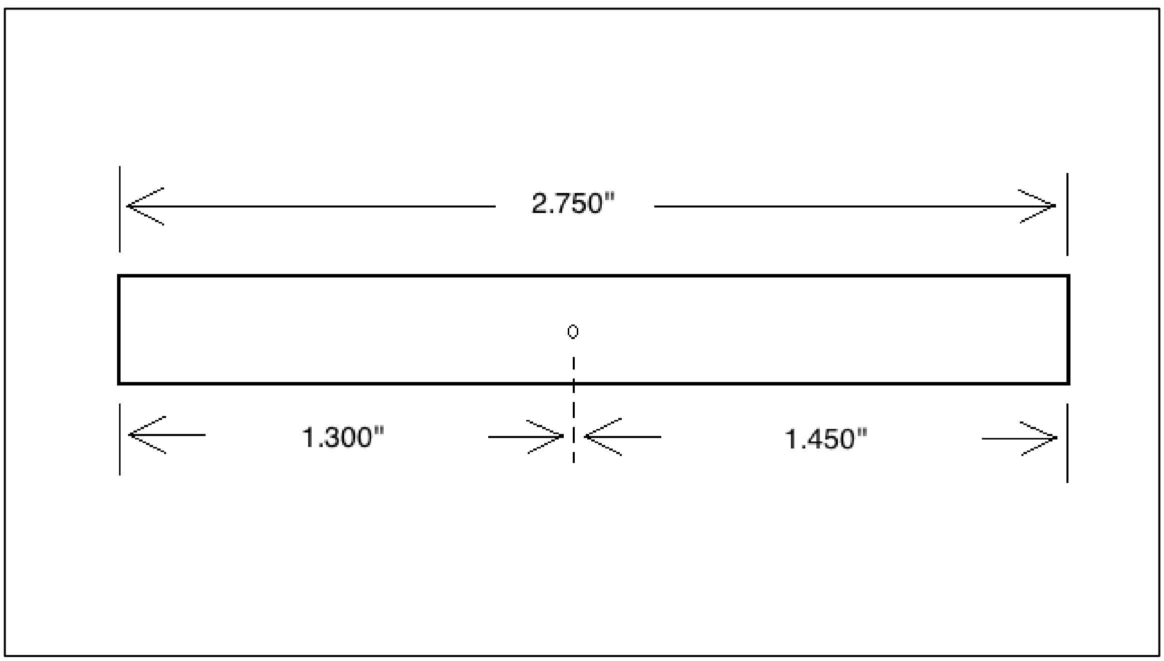

Fig 2.0.4 The hole on the tube is 0.075 inch (about 2mm) off center so that the weight of the tube will pull it upright when there is no charge on the electroscope.

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Activity 2 - 1: Using the UVa electroscope to detect the presence of charge

Objective: Use the electroscope to detect the presence of charge.

Materials:

- Electroscope
- Acrylic Rod
- Teflon Rod
- Silk

Procedure:

1. Assemble the electroscope according to **Fig. 2.0.2** and **Fig. 2.0.3**. Set the tube in the neutral position by touching the top of the brass support with your finger. Your finger is a conductor and therefore will drain any electric charge on the electroscope so it becomes neutral after you touch it.

2. Rub the Teflon rod on silk. Then slide the rod on the top of the brass support. See **Fig. 2.1.1**. You may repeat the process several times to accumulate more charge. Describe how the angle of the tube changes as you add charge. Is there a maximum angle? Why? ____

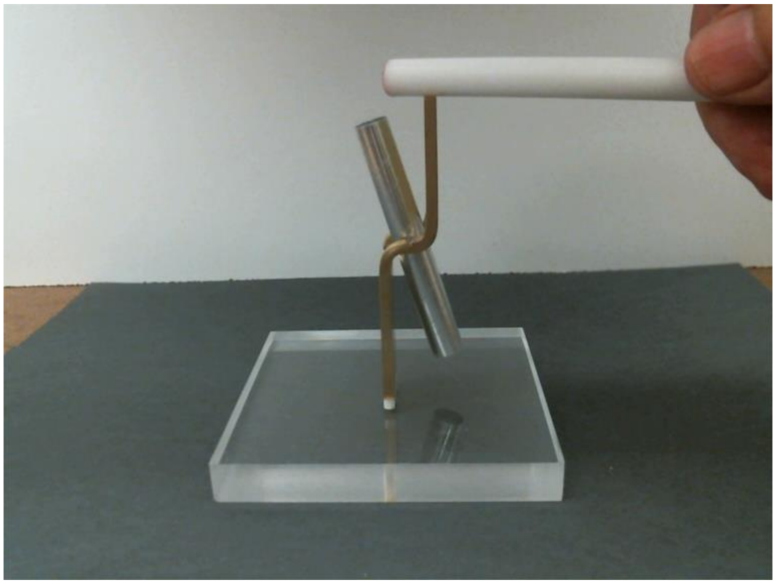

Fig. 2.1.1

3. Touch the top of the brass support with your finger to make it become neutral. Now the rub the acrylic rod with silk and repeat step 2. You may have to repeat the process a few times for the effect to be evident. Now what is the polarity of

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the charge on the electroscope and how is it the same or different than in step 2? ____

4. When the polarity of the charge on the electroscope was negative what real particle was being transferred to or from the electroscope? When the polarity of the charge on the electroscope is positive what real particle was being transferred to or from the electroscope?

5. Touch the upper lip of the brass support to make it neutral. Then using the Teflon rod, charge up the electroscope until the tube goes out as far as it can. Substitute the Teflon rod with the acrylic rod. Rub the acrylic rod on silk. Then slowly slide the rod on the upper lip of the brass support while watching the movement of the tube very closely. Describe the behavior of the tube as more charge gets rubbed off the acrylic tube. What is the polarity of the initial charge on the electroscope? What about the charge added to the electroscope? How does that explain the behavior of the tube? ____

6. What happens when an equal amount of positive charge meets an equal amount of negative charge? ____

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Activity 2- 2: Conductor or Insulator?

Introduction:

The main difference between a conductor and an insulator is that a conductor allows charge to move through it while an insulator doesn't. While the atoms in an object are stationary, the electrons can sometimes escape the grasp of the atomic nuclei and drift through the material. A material whose electrons can easily move through is said to conduct electricity. Conversely, a material whose atomic nuclei are strongly attached to all the electrons is an insulator since they are not allowed to move.

Objective: Determine whether an object is a conductor or insulator.

Materials:

- Teflon Rod
- Silk
- Electroscope
- 100% Metal Object such as Knife, Fork, or Spoon (from home)
- 100% Plastic Object such as a Plastic Knife, Fork, or Spoon (from home)
- Wooden Rod
- Acrylic Rod

Procedure:

1. Rub Teflon rod on silk. Use the rod to charge up the electroscope until a large angle appears. Now touch the top lip of the electroscope with your finger. As shown in **Fig. 2.2.1.** Describe the behavior of the tube and whether or not your finger is a conductor or insulator. ___________________________________

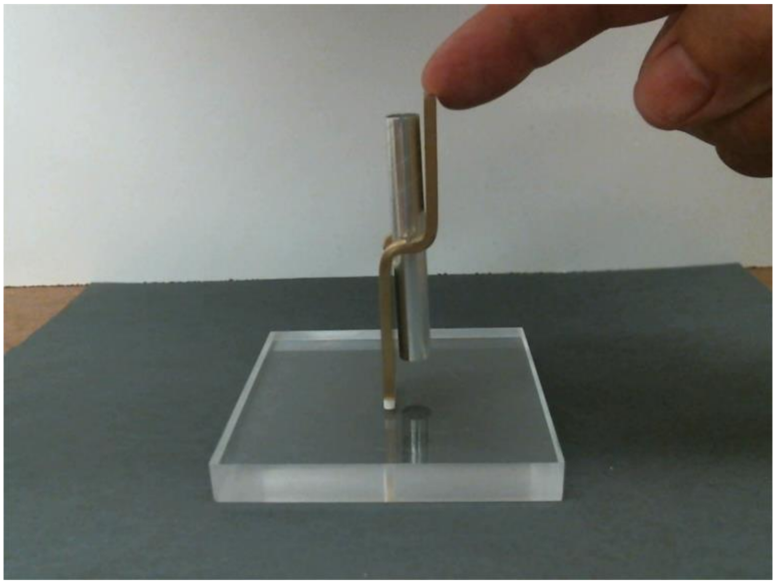

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Fig. 2.2.1

2. Charge up the electroscope again using the Teflon rod. Hold one end of the wooden rod in your hand. Touch the top lip of the electroscope with the other end of the wooden rod, as shown in **Fig. 2.2.2**. Describe the behavior of the tube and whether or not the wood is a conductor or insulator. ____

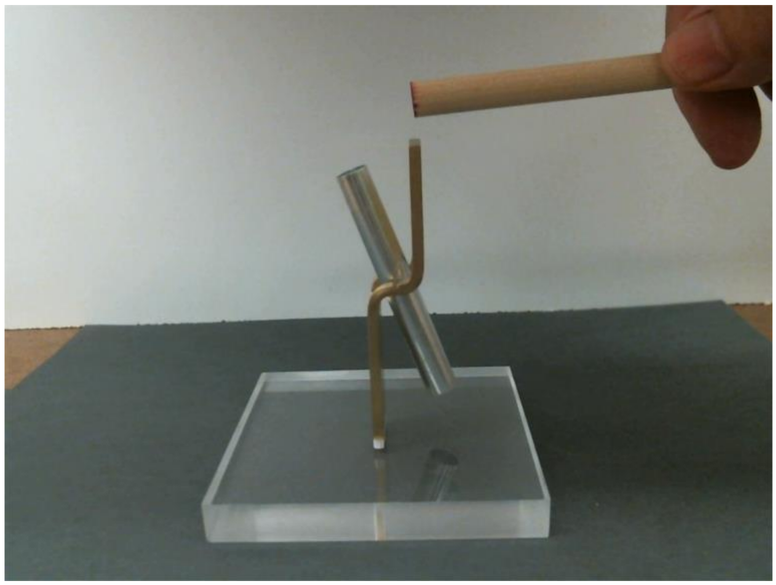

Fig. 2.2.2

3. Substitute the acrylic rod for the wooden rod. . Do not forget to neutralize the acrylic rod. Repeat step 2. Describe the behavior of the tube. ____

4. Substitute a Teflon rod for the acrylic rod. Charge the electroscope up with the Teflon rod. Now neutralize the Teflon rod thoroughly by rubbing your finger up and down it. Then repeat step 2. Describe the behavior of the tube. ____

5. Substitute a metal object for the Teflon rod. Repeat steps 1 and 2. Describe the behavior of the tube. ____

6. Now try your plastic object. Repeat step 2. Describe the behavior of the tube. ____

7. How do you decide whether a material is a conductor or insulator based on the behavior of the tube in the experiments above? State your line of reasoning. ____

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8. Fill in **Table 2.2.1** with your conclusions.

Material	**Conductor/Insulator?**
Your Finger	
Wood	
Acrylic	
Teflon	
Metal object	
Plastic object	

Table 2.2.1

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Activity 2 – 3: Movement of Charges in a Conductor

Introduction:

We already know that the fundamental characteristic of a conductor is that charges can move freely through it. If a charged object is placed close to a conductor, it will affect the spatial distribution of the charges in the conductor by attracting opposite charge while pushing similar charge away. See **Fig. 2.3.1**, **Fig. 2.3.2**, and **Fig. 2.3.3**.

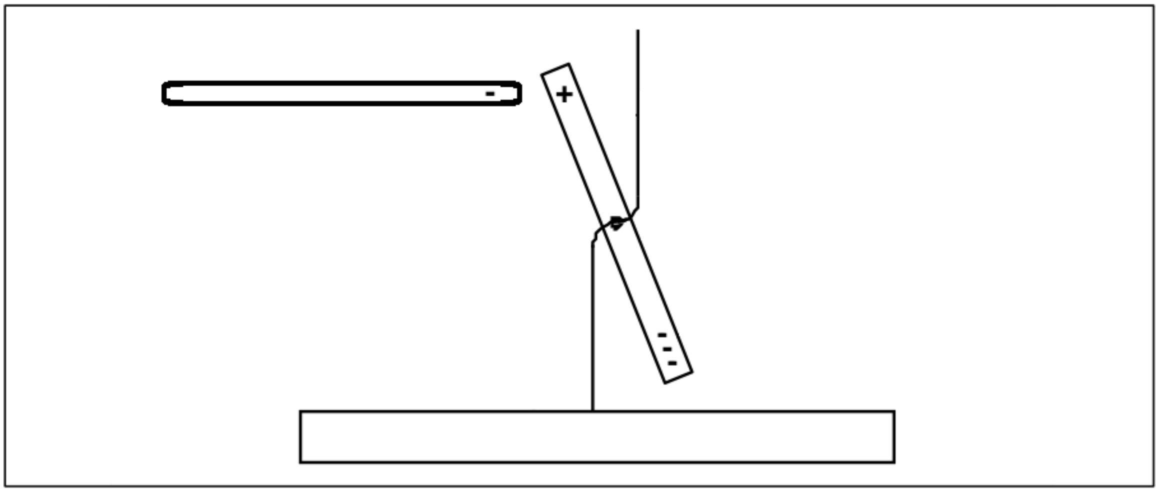

Fig. 2.3.1

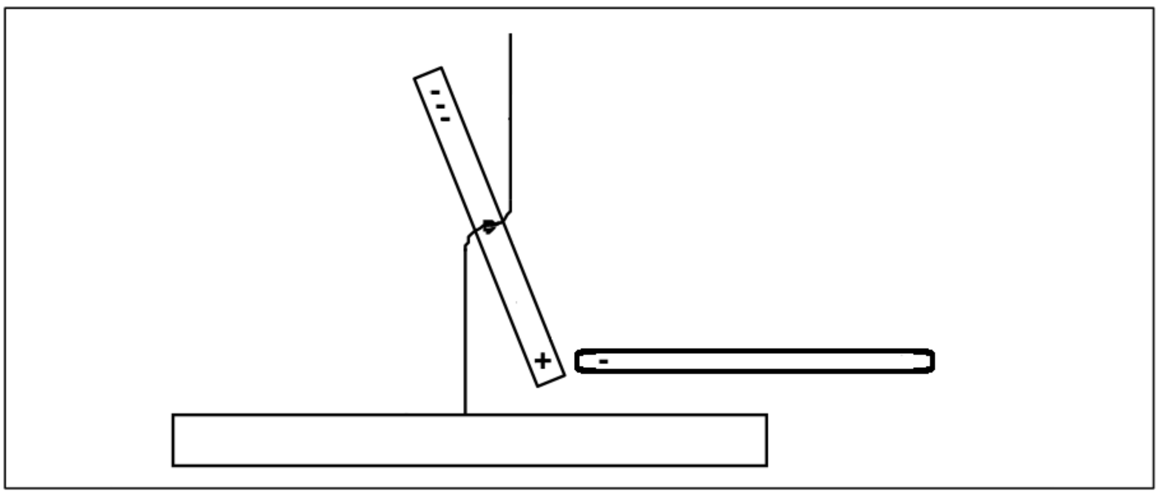

Fig. 2.3.2

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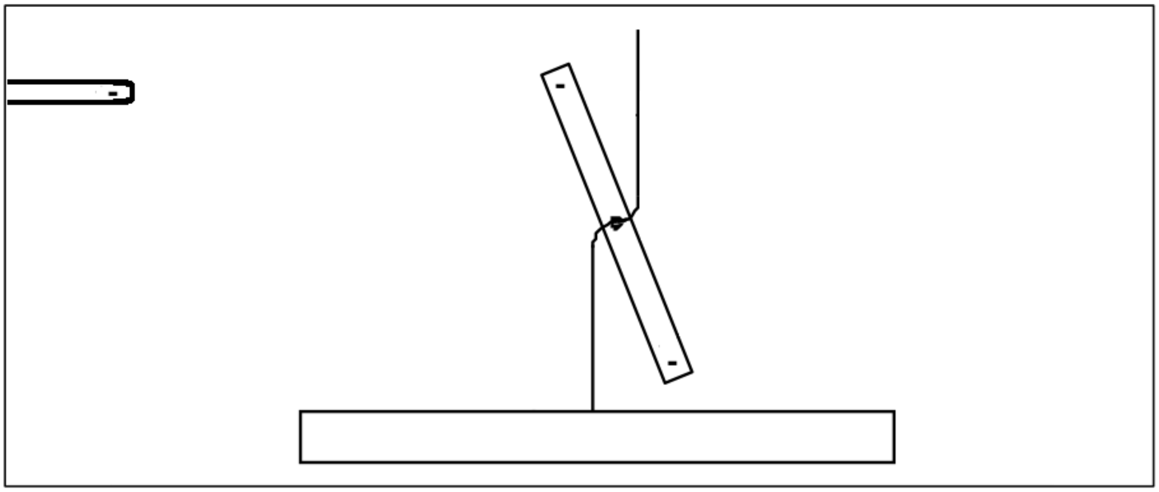

Fig. 2.3.3

Objective: Show that the spatial distribution of charges in a conductor can change easily.

Materials:

- Electroscope
- Teflon Rod
- Silk

Procedure:

1. Rub Teflon rod on silk. Rub Teflon rod across the lip of the electroscope to charge it up.

2. Rub Teflon rod on silk again. Starting from 10 cm away, slowly move the Teflon rod close to the top of the tube. Describe the behavior of the tube in the entire process. ____

3. Pull the rod away. Then slowly move the Teflon rod close to the bottom of the tube, also starting from 10 cm away. Describe the behavior of the tube in the entire process. ____

4. How can the tube be repelled and then attracted, while having the same amount of net charge on it? Explain the paradox by drawing reference to movement of charges in a conductor. ____

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Lab 3
Charging by Induction

Overview

An object can become charged through contact with another charged object. This is a phenomenon known as *charging by conduction*. When objects are charged without coming into contact with a charge source, the process is known as *charging by induction*. This process primarily works with conductors. One method of charging involves moving a charged object to the vicinity of two uncharged conductors in contact with each other. See **Fig. 3.0.1**, **Fig. 3.0.2**, **Fig. 3.0.3**, **and Fig. 3.0.4**.

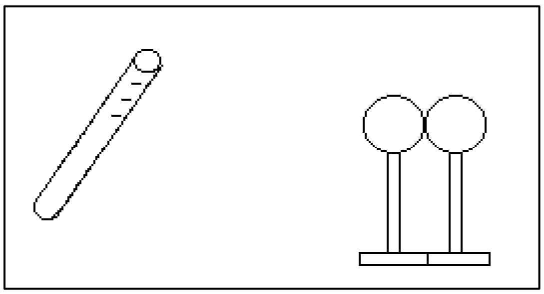

Fig. 3.0.1 Negative charge accumulates on a plastic rod after it is rubbed against some fur. Far away from the rod, two metal spheres in contact with each other are placed on insulating stands. They are electrically neutral in the beginning.

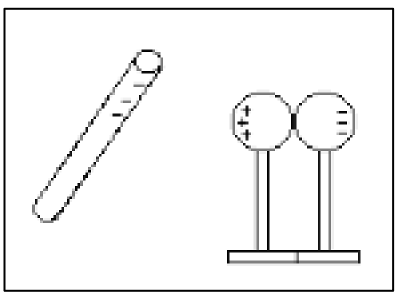

Figure 3.0.2 The negatively charged plastic rod is brought close to the metal spheres. Positive charge moves to the sphere closer to the rod and negative charge moves to the sphere farther from the rod. The two spheres as a whole remain electrically neutral, because they are insulated from the surroundings.

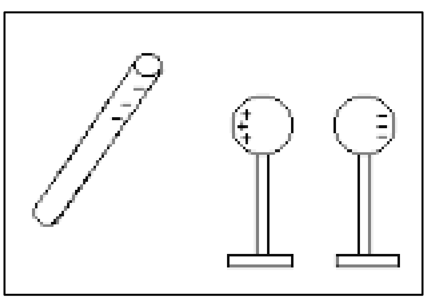

Figure 3.0.3 The metal spheres are then separated. Each sphere retains its excess charge. The energy required to charge up the spheres comes from the work done (assuming no friction) when slowly pulling the spheres away from each other.

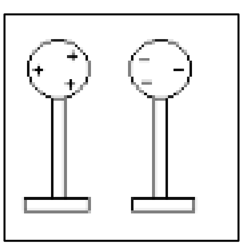

Figure 3.0.4 The negatively charged plastic rod is now removed, leaving the metal spheres individually charged. They carry equal and opposite amount of electric charge because the two spheres as a whole have to remain electrically neutral.

Name ________________________________ Date ___________________________

Activity 3 – 1: Charging the Electroscope by Induction

Objective: Charge the electroscope by induction.

Materials:

- Teflon Rod
- Silk
- Electroscope

Procedure:

1. Rub the Teflon rod on silk. Hold the Teflon rod in your right hand.

2. Move the Teflon rod horizontally towards the lower part of the brass support. The tube will start to deflect. Be very careful not to let the tube deflect more than 45 degrees.

3. When the Teflon rod is about 5 mm away from the brass support, stop the horizontal movement. Move the Teflon rod upward. The tube will deflect more and more until the middle portion of the tube comes into contact with the Teflon rod. Stop when contact is made.

4. Pull out the Teflon rod from under the tube. Pull along the length of the rod so that it slides out smoothly without touching the brass support.

5. With the rod removed, the tube will oscillate back and forth around its new equilibrium position. Wait for it to settle down. Estimate the angle of tube deflection. What does it say about the amount of charge on the tube? How does that relate to the coating on the tube? __________________________________

6. Neutralize the electroscope and the Teflon rod by rubbing them with your hand.

7. Repeat steps 1-3. Then touch the top lip of the brass support with your finger while maintaining contact between the rod and the tube. See **Fig. 3.1.1**. Then take your finger off the brass support.

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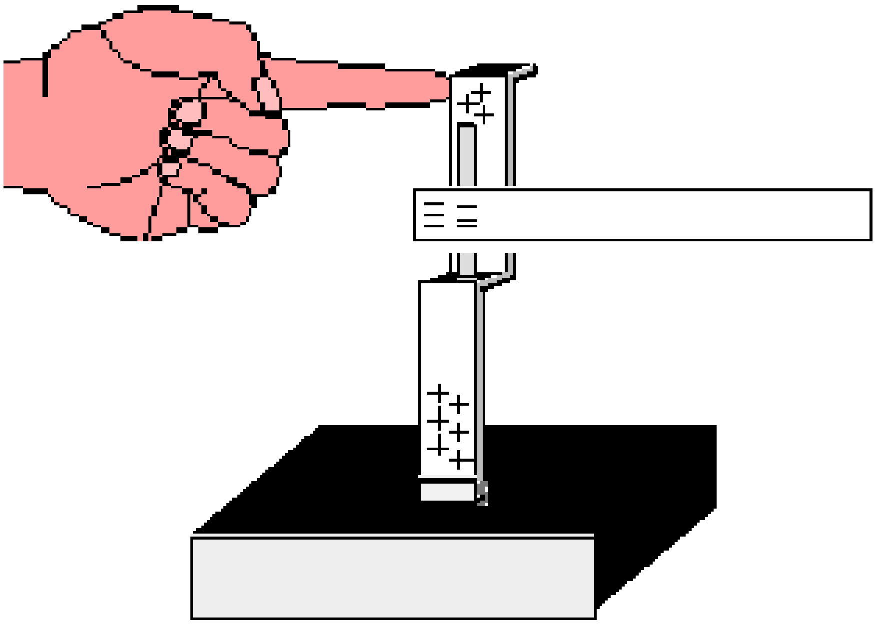


Fig. 3.1.1

8. Pull out the Teflon rod from under the tube. Pull along the length of the rod so that it slides out smoothly without touching the brass support.

9. Wait for the tube to settle down in its new equilibrium position. Estimate the angle of tube deflection. What does it say about the amount of charge on the tube? ____

10. The procedure above describes 2 experiments – the first one is a control experiment to contrast the effect made by touching the scope with finger. Draw a 3x2 (3 rows x 2 columns) table in the space below. In the first column, list the key difference in the procedure. In the second column, list the key difference in the results. Remember to label the columns in the top row.

11. Previously, your finger was used to neutralize the electroscope. It seems counterintuitive that the electroscope doesn't get neutralized in experiment 2. Explain the paradox – how does charge get onto the tube when you touch the brass support? What is the polarity of the charge on the tube? ____

Name ________________________________ Date ___________________________

Activity 3 - 2: Bending a Stream of Water by Induction

Objective: Observe how a water stream behaves near a charged object.

Material:

- Teflon Rod
- Silk
- Soda Bottle (optional, from home)
- Tack Pin (optional, from home)
- Coffee Mug x2 (optional, from home)
- Water faucet and sink (soda bottle, pin, and mug are not needed if you have access to a water faucet and a sink in the classroom.)

Procedure:

1. If you have a water faucet and a sink available, you can skip steps 2-5 and 8.

2. Use the tack pin to drill a hole 0.5mm in diameter on the side of the soda bottle. The hole has to be lower than ¼ of the height of the bottle.

3. Go to a kitchen or bathroom in your building. Plug the hole with your finger and fill the soda bottle with water up to 3/4 of its height. Release your finger to test whether the hole is big enough for water to come out as a stream. If the hole is too small, use the tack pin to widen it.

4. Put the lid back on. Flip the bottle upside down so that water doesn't come out through the hole. Go back to the classroom with the bottle.

5. Put the bottle on the edge of a table. Flip the bottle right side up. Remove the lid and water will start streaming out of the hole. Set the first coffee mug on the floor to receive the stream.

6. Neutralize the Teflon rod by rubbing it across your hand. Approach the stream with the rod. Describe the behavior of the stream. ________________________

7. Rub Teflon rod on silk. Approach the stream with the rod from different directions. Describe the behavior of the stream. __________________________

8. Set the second coffee mug next to the first one. Use the charged rod to bend the stream of water into the second mug.

Name ________________________________ Date ___________________________

9. The procedure above describes 2 experiments – the first one is a control experiment and the second one is to see whether the stream can be bent. Enter your results in **Table 3.2.1**.

Charge on Teflon Rod	Effect on the stream of water

Table 3.2.1

10. Why does the water stream bend when the charged Teflon rod is nearby? How does it relate to the fact that water is a conductor? Describe the picture of how water gets charged by induction. Focus on the movement of charge along the stream of water. ____

11. If you could make a stream of ethanol or gasoline, would the charged rod bend the stream? ____

Name ________________________________ Date ___________________________

Activity 3 – 3: The Firefly

Introduction:

The firefly consists of an old discarded plastic film canister that is partially transparent. You place a Christmas tree light bulb on the inside with one end connected to aluminum foil connected and glued across the top of it. On the bottom you have the same thing. See **Fig. 3.3.1** for details. The firefly in the class kit comes preassembled.

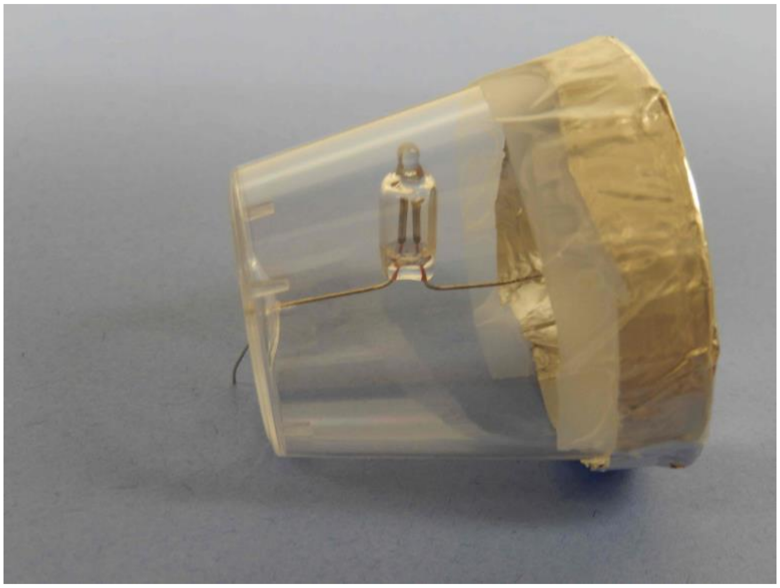


Fig. 3.3.1

Objective: Observe the transformation of electric energy into another form of energy.

Materials:

- The Firefly
- Handheld VDG
- Large Pie Tin (from home)

Procedure:

1. Dim the lights in the room.

2. Charge up the Teflon rod by rubbing it on silk. Then hold the Firefly capsule by grabbing the bottom. Maintain contact with the tin foil on the bottom with your hand.

3. Rub the charged Teflon rod on the top foil of the firefly. What do you see in the firefly capsule when the discharge occurs? _____________________________

4. Where does the energy in the light come from? Who did the work? ____

Name ________________________________ Date ___________________________

Activity 3 - 4: Electrophorus

Introduction:

An electrophorus is a device that can generate static electricity repeatedly by induction. The device consists of a charged dielectric plate, and a metal plate with an insulator handle. The metal plate can be charged as often as desired without draining the charge on the dielectric plate. See **Fig. 3.4.1 (a) – (d).**

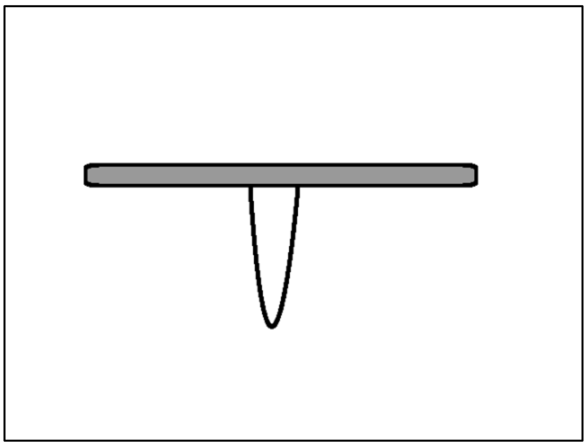


Fig. 3.4.1 (a) The metal plate is neutral in the beginning. It has an insulator handle.

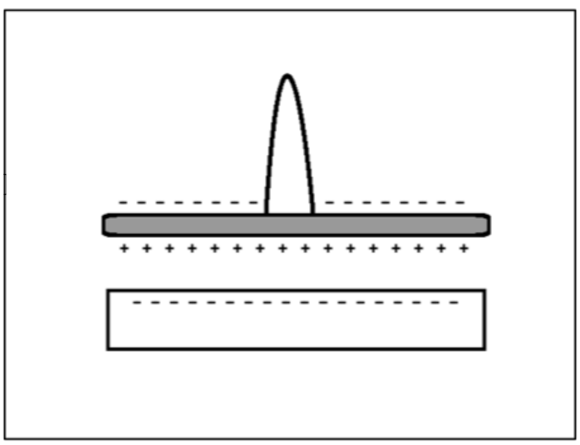


Fig. 3.4.1 (b) An acrylic insulating plate is charged. Then the metal plate is suspended above the dielectric plate. Negative charge moves to the bottom surface. Positive charge moves to the top surface.

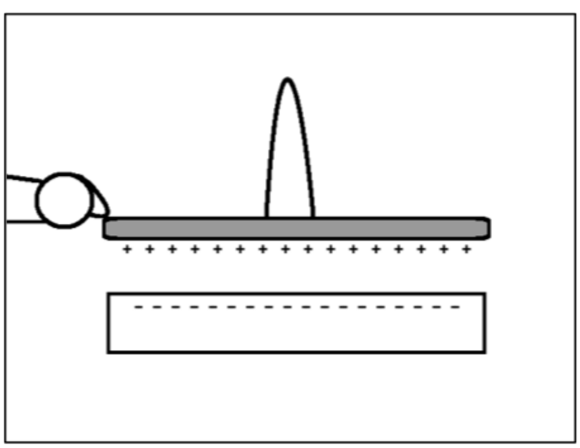


Fig. 3.4.1 (c) The top surface is touched for a brief moment. Positive charge escapes through the hand.

Name ________________________________ Date ___________________________

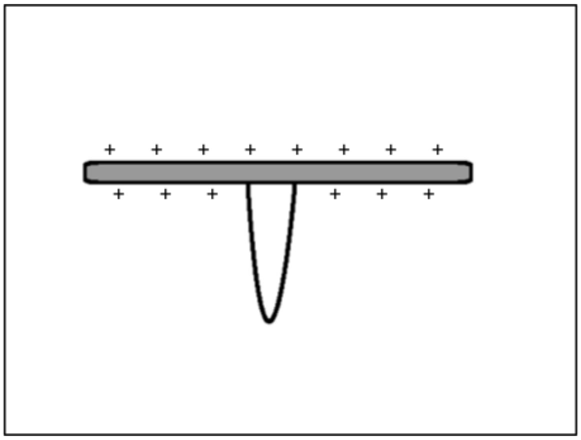


Fig. 3.4.1 (d) The metal plate is now negatively charged. It can be moved away from the acrylic plate without losing its charge.

Objective: Build and test a homemade electrophorus.

Materials:

- Class Kit plastic Box
- Silk
- Electroscope
- Letter-size Paper (from home)
- Large Pie Tin (from home)
- Styrofoam Cup (from home
- Scotch Tape (from home)

Procedure:

1. Tape the Styrofoam cup to the inside bottom of the pie tin. The tape should be strong enough to hold the weight of the pie tin when you use the cup as a handle to pick up the pie tin as shown in **Fig. 3.4.2**.

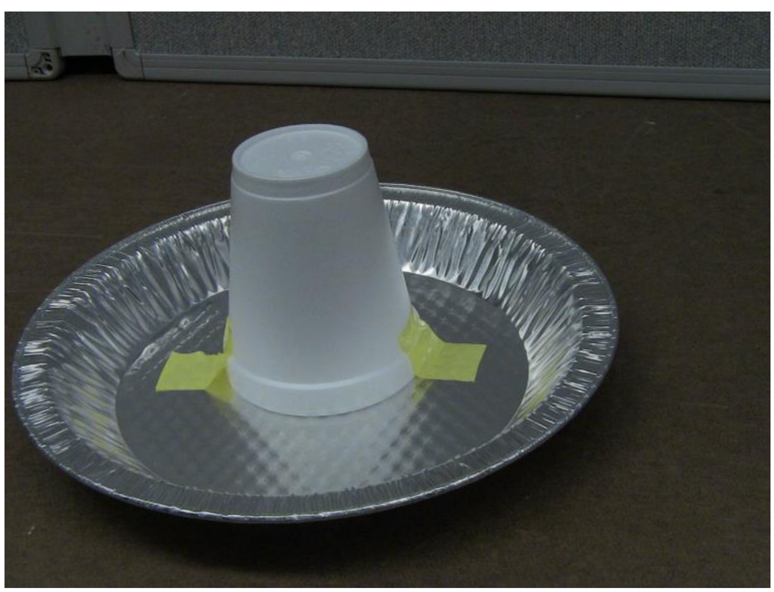


Fig. 3.4.2

Name ________________________________ Date ___________________________

2. Cut out a round shape from paper about the same size as the pie tin bottom. Tape it to the outside bottom of the pie tin in **Fig. 3.4.3.** The paper acts as an insulator and will prevent charge from flowing on to the bottom of the plate.

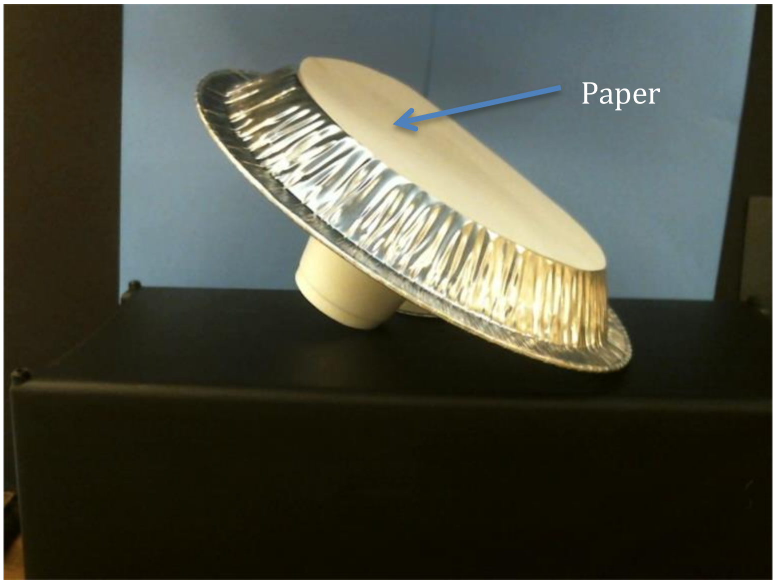


Fig. 3.4.3

3. Flip the E&M kit box upside-down. Rub silk against the plastic box. The flat surface of the box will become negatively charged. See **Fig.3.4.4**.

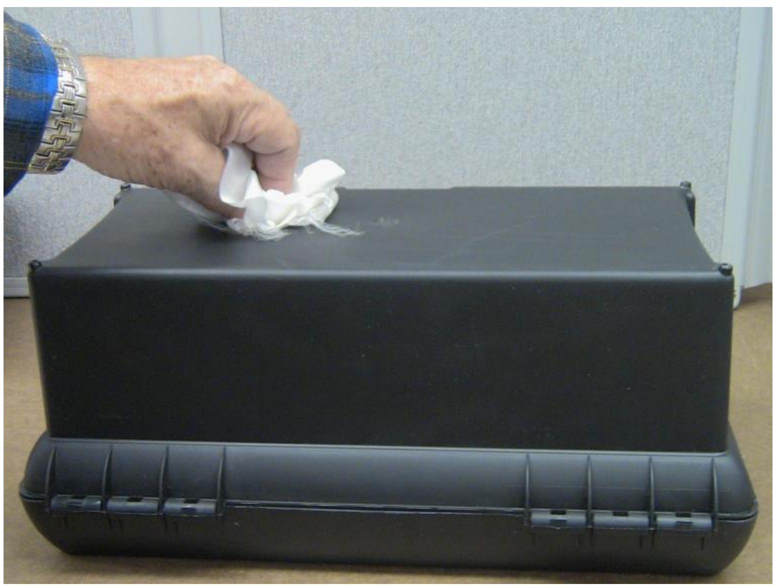


Fig. 3.4.4

4. Set the pie tin on the charged surface of the box using the Styrofoam cup as a handle. Do not touch the tin plate. Then pick it back up using your left hand and touch the rim of the plate again with your right hand finger. Instead of your finger you may use the firefly to see if a discharge occurs. If it does, the firefly will light up. See **Fig.**

Name ________________________________ Date ___________________________

3.4.5. Is there a discharge from the plate? Record your observations here. If there is a discharge, is the charge positive or negative that leaves the plate? What type of charge stays on the plate? ____

Fig. 3.4.5

5. Set the pie tin on the charged surface again using the cup as a handle. This time, touch the rim of the plate while it's sitting on the charged surface. **See Fig. 3.4.6**. What happens to the negative charge on the plate when you touch it with your finger? Does it remain on the plate or does it flow through your finger? ____

Fig. 3.4.6

Name ________________________________ Date ___________________________

6. Now pick up the pie tin with the handle using your left hand and touch the rim of the plate again with your right hand finger. Instead of your finger you may use the firefly to see if a discharge occurs. If it does, the firefly will light up. See **Fig. 3.4.7** and **Fig. 3.4.8**. Is there a discharge from the plate? Record your observations here. If there is a discharge, what type of charge leaves the plate? What type of charge stays on the plate? ____


Fig. 3.4.7

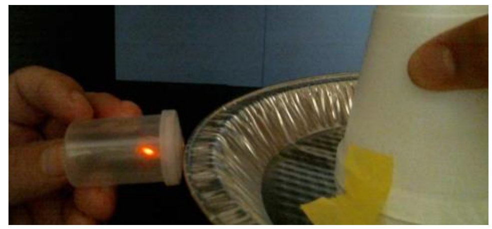


Fig. 3.4.8

7. Repeat steps 5 and 6. Does the charge on the box become exhausted? Why or why not? ____

8. Each time a discharge happens, electric energy is dissipated as light and sound. It seems paradoxical that we can create discharge events perpetually using this method. Does it violate the conservation of energy? Where does the electric energy come from? ____

Name ___________________________________ Date ______________________________

Lab 04
Van de Graaff Generator

Overview

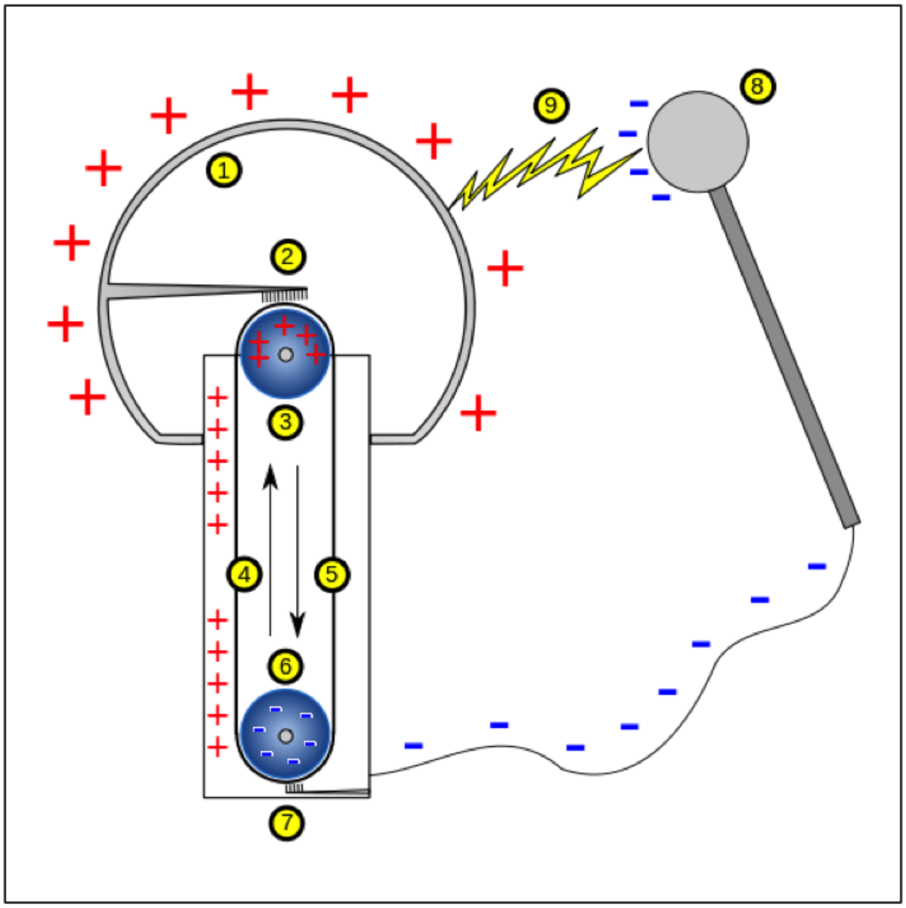


Fig. 1 A traditional Van de Graaff Generator

1) Metal dome
2 & 7) Metal brush
3) Metal roller
4 & 5) Rubber belt
6) Teflon roller
8) Metal sphere
9) Spark from electric discharge

Name ___________________________________ Date ______________________________

The Van de Graaff generator is a machine invented in 1929 by American physicist Robert J. Van de Graaff to generate static electric charge. A traditional VDG includes a motor-driven conveyer belt made of rubber going around a Teflon roller at the bottom and a metal roller at the top. See **Fig. 1**. According to the triboelectric series, rubber loses some of its electrons to Teflon when they come into contact. As the belt revolves, positive charge accumulates on the metal roller and negative charge accumulates on the Teflon roller. When there's so much charge on the roller that the insulation of air breaks down, charge on the roller can leap onto the metal brush nearby. The sharp tips on the metal brush facilitate the leap. The metal dome and the metal sphere act as reservoirs of electric charges. They allow for charges to build up. There is often hundreds of thousands of volts between them. Discharge between the dome and the sphere creates a long and bright spark that can be seen and heard. Our handheld VDG has a small reservoir, which is the front tube made of cardboard. It carries a safe amount of charge to be used in the classroom. **Fig. 2** is a picture of the handheld VDG.

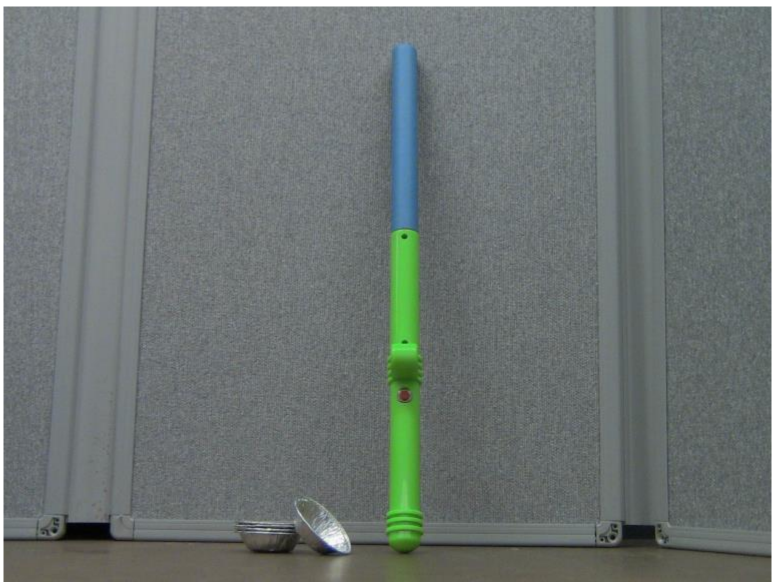


Fig. 2

Look at the inner workings of your handheld VDG. See **Fig. 3**. There are two Teflon rollers – one on the bottom and one on the top. A rubber belt runs over the rollers. See **Fig. 4**. Electrical charges are separated at the point where the rubber belt and the bottom Teflon roller separate. The top roller is made of Teflon instead of metal, presumably to reduce cost. It does not participate in charge generation. As we learned from the triboelectric series, the Teflon roller at the bottom holds on to the electrons from the belt and becomes negatively charged, while the belt becomes positively charged. **See Fig. 5**.

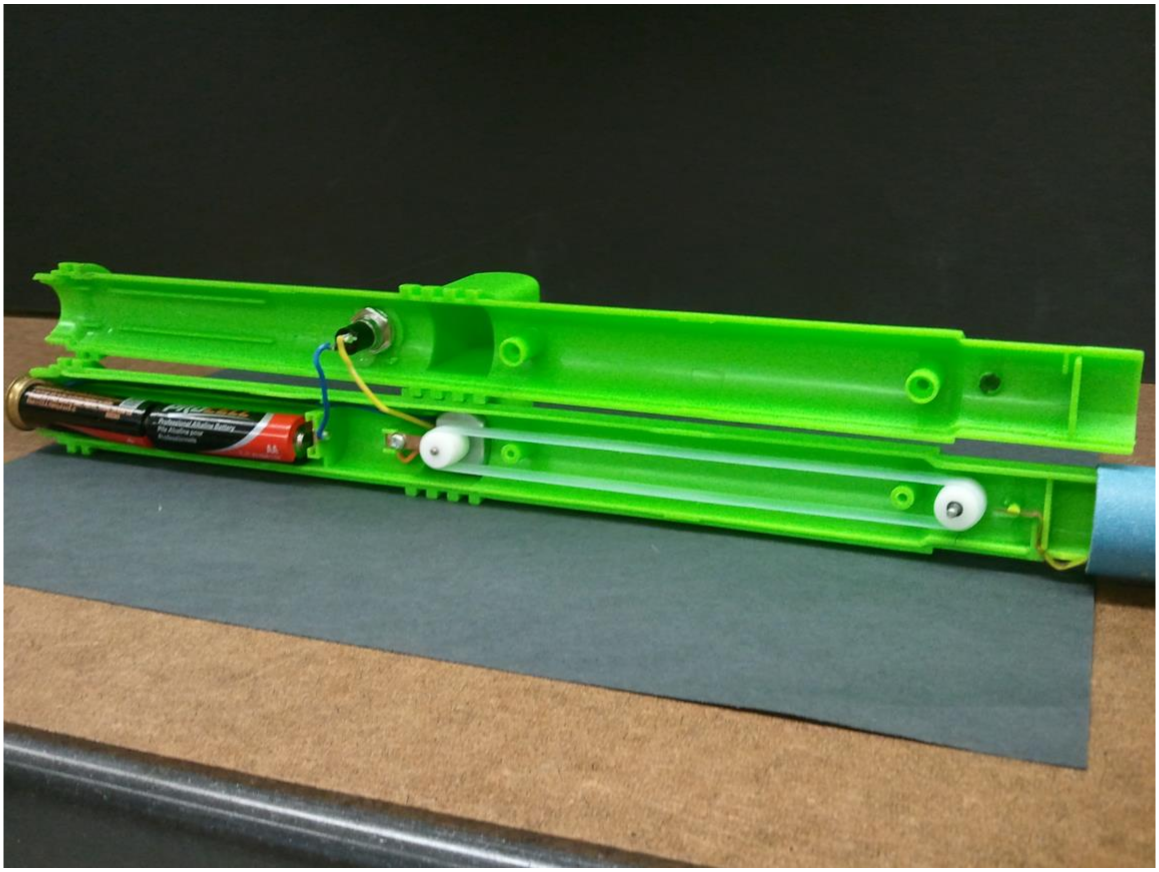


Fig. 3

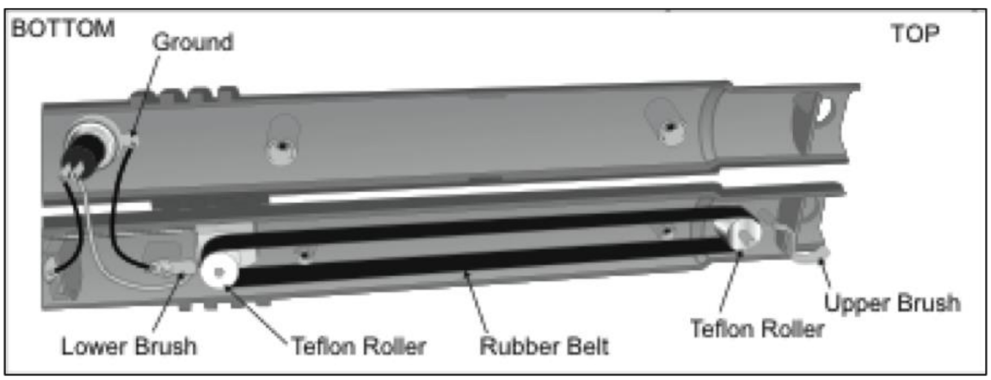


Fig. 4

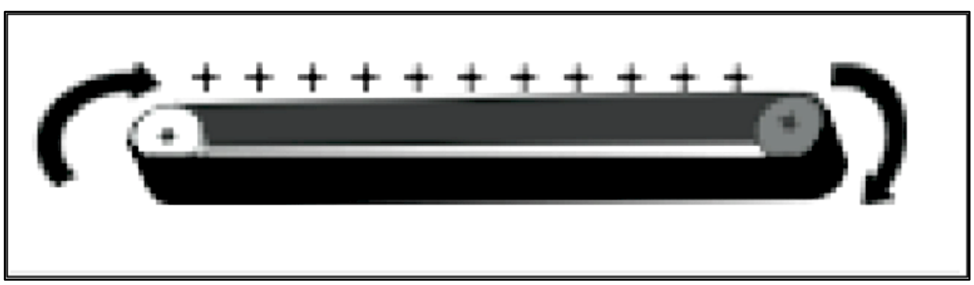


Fig. 5

There are two copper brushes, one on top and one on the bottom. They come as close as possible to contact with the belt, but never touch the belt directly. **See Fig. 6**.

Fig. 6

The bottom brush collects the negative charge and is wired to the motor casing, which is then wired to the button you push. So all the negative charge goes into your body. The top brush collects the positive charge and passes that to the cardboard tube.

The cardboard tube is in direct contact with the upper brush. It serves as a reservoir for positive charge and is analogous to the spherical metal dome on the traditional Van de Graaff generator.

A frequently repaired part on the handheld VDG is the top brush. Since the tip close to the rubber belt is constantly exposed to electric discharge, it will become oxidized over time and no longer conduct electricity. **If your handheld VDG stops producing charge, it is likely due to oxidation of the brush. You can take off the top brush and sand its tip to restore its conductivity.** (Bonus question: the bottom brush is usually immune from oxidation; can you guess the reason?)

Name ________________________________ Date ____________________________

Activity 1: Polarity of Charge of the Van de Graaff Generator

Objective: Determine whether positive or negative charge is generated by the handheld VDG.

Materials:
- VDG
- The Spinner
- Teflon Rod
- Acrylic Rod
- Silk

Procedure:
1. Set up the spinner as in Lab 1. Charge up the acrylic rod by rubbing it on silk. Place the acrylic rod on the spinner so that the center of mass falls close to the pivot. See **Fig. 1**. What is the polarity of charge on the acrylic rod? ________________________________

Fig. 1

2. Press the button on the handheld VDG to start the charge generation process. Move it towards the acrylic rod from the side. What is the reaction of the acrylic rod? ________________________________
3. Repeat steps 1 and 2 using the acrylic rod instead of the Teflon rod. What is the polarity of charge on the Teflon rod and what is its reaction to the handheld VDG? ________________________________
4. What can you tell about the polarity of charge on the handheld VDG? ________________________________

Name ______________________________ Date _________________________

Activity 2: Flying Saucer

Objective: Observe the strength of static electricity compared to gravity.

Materials:

- Handheld VDG
- Small Pie Tins x 5 (from home)

Procedure:

1. Get 5 small pie tins that are used to make mini tarts. Hold the handheld VDG pointing straight up. Stack the pie tins upside-down on the tip of the handheld VDG. Pin tins are shown in **Fig. 2** on the bottom left side next to the handheld VDG.

2. Press the button on the handheld VDG to start the charge generation process. Describe the reaction of the pie tins. _________________________________

3. What causes the pie tins to fly off as in **Fig. 2**? Describe the role of static electricity in the takeoff process. ________________________________

Fig. 2

Name ________________________________ Date ___________________________

Activity 3: Electric Levitation

Objective: Levitate thin conductive strips by means of electric repulsion.

Materials:

- Thin conductive strips
- Handheld VDG

Procedure:

1. Unfold the band-shaped conductive strip and hold it in one hand. Use the handheld VDG to generate charge. Release the strip and touch it with the handheld VDG. **Fig. 3** is an illustration of a successfully charged strip. What shape does the strip turn into? What does this have to do with static electricity? ____

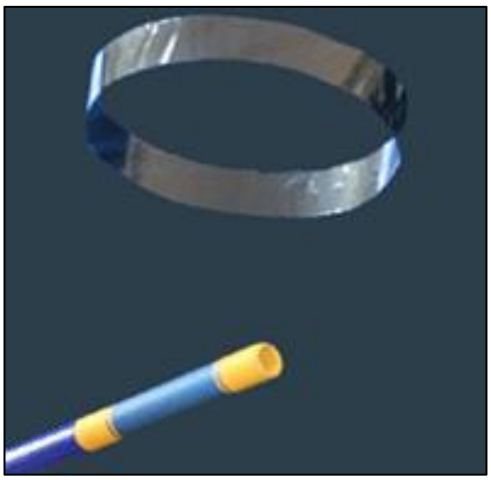


Fig. 3

2. Keep the handheld VDG underneath the strip to levitate the strip. Some people might claim the handheld VDG produces a shield against gravity. Is that true? What keeps the strip from falling to the ground? _________________________

3. Reach your palm towards the strip but don't get too close. How does the strip respond to your "beckoning hand"? Why? ______________________________

4. Now touch the strip with your hand. What shape does the strip turn into? Why? ____

5. Now use the handheld VDG to charge up another strip and practice your levitation skill!

Name ______________________________________ Date ________________________________

Activity 4: Faraday Cage

Introduction:

A metal wire mesh screen that is connected to ground can be used to prevent an electric field from permeating through the space behind it, much similar to an object making a shadow under the sun. If the screen surrounds some space entirely, then anything inside feels no electric field from the outside, even if the screen is not grounded any more. The Faraday Cage consists of such a screen that closes upon itself to provide shielding from any electric field outside the cage. The most common example of a Faraday Cage is the elevator. Cell phone signal is blocked inside the elevator unless a relay antenna is installed. Your car could be a Faraday cage if it weren't for the windows.

Objective: Demonstrate the shielding effect of a wire mesh screen.

Materials:

- Handheld Van de Graaff
- Wire Mesh Screen
- Electroscope

Procedure:

1. Neutralize the electroscope by touching the brass support with your finger. The tube should be at a negligible angle against the brass support.

2. Turn on the handheld VDG and move its front end to about 10 cm away from the electroscope. Use the handheld VDG to attract the electroscope tube.
   See **Fig. 4**. How does the tube behave? ___________________________________

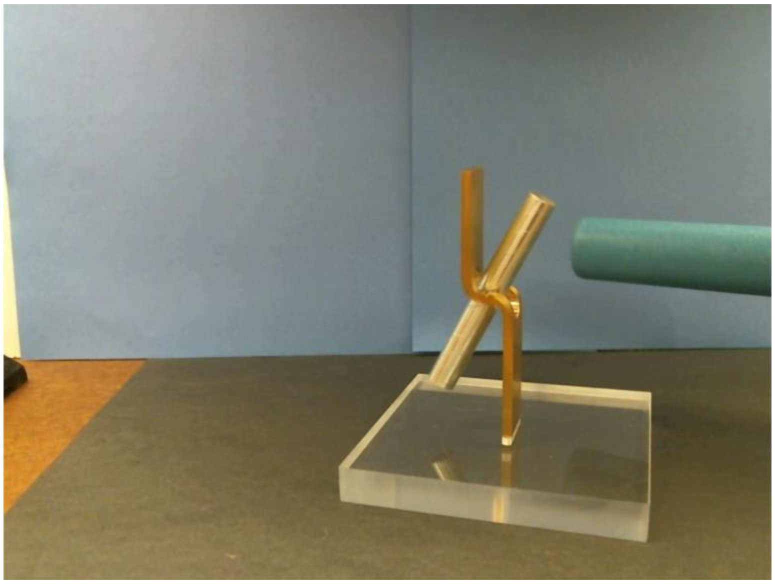


Fig. 4

Name ______________________________ Date __________________________

3. Turn off the handheld VDG and neutralize the electroscope again. Now, hold up the wire mesh screen about 5 cm in front of the electroscope. Make sure your fingers are in contact with the metal part of the screen. Then repeat step 2. See **Fig. 4**. How does the tube behave this time? What makes the difference and why? (Hint: recall the activities on "charge by induction") ____

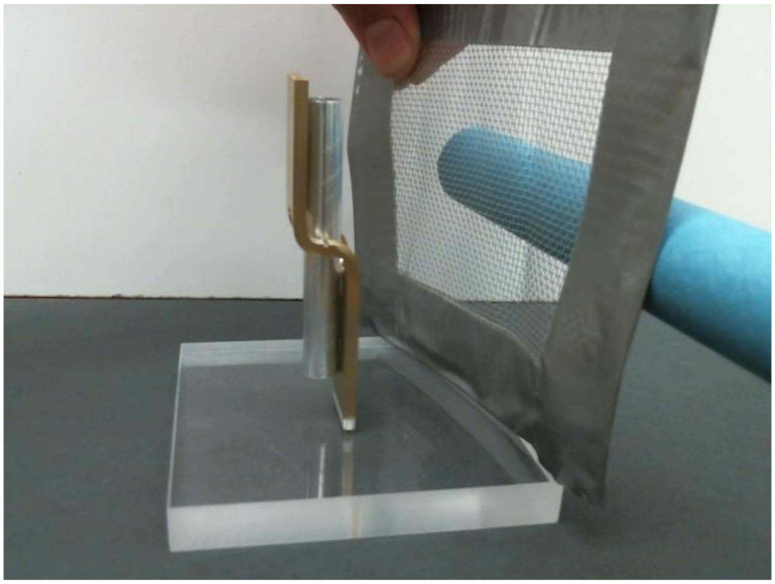


Fig. 4.4.2

4. If the mesh screen were made out of insulating material, would it still act as a Faraday cage? ____

Name ________________________________ Date ____________________________

Lab 5
Coulomb’s Inverse Square Law

Overview

The electrostatic force between two arbitrary charges Q_1 and Q_2 separated by a distance r follows an squared law given by

$$F = k\frac{Q_1 Q_2}{r^2}$$

Most notably, the magnitude of the force is proportional to the inverse square of the distance between charges. It is also proportional to the product of the two charges times the constant k, which is given by k = 8.99 x 10^9 N*m^2/C^2. Each charge has units of Coulomb C and r is in meters m. This is known as Coulomb’s Law. Note that the electrostatic force is a vector and is directed along a line joining the centers of the two charges. See **Fig. 5.0.1**.

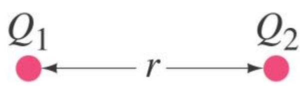


Fig. 5.0.1

French scientist Charles Augustin de Coulomb first published the formula in 1785. Coulomb‘s Law is analogous to the Newton’s universal gravitational law, which states that the gravitational force between two point masses is directly proportional to the product of their masses and inversely proportional to the square of their separation distance. For more details, see your textbook and the power point slides. The following experiments are going to put Coulomb’s Law to the test.

Name ________________________________ Date ____________________________

Activity 5 – 1: Measurement of Charge on Two Suspended Pith Balls

Introduction:

Pith is a tissue from a plant that is very lightweight. A pith ball is simply pith made into a sphere and painted to make the surface conducting. **Fig. 5.1.1** shows two uncharged round aluminized pith balls. They are suspended like a pendulum using non-conducting silk thread and attached to a wooden stick poked into a piece of Styrofoam for support. A protractor is also held in place by the wooden stick so that the angle of the hanging pith ball can be determined. If two equally charged pith balls are suspended as shown in **Fig. 5.1.2** below, it is possible to determine the approximate charge on the pith balls from simple measurements of angle between the two pith balls at equilibrium.

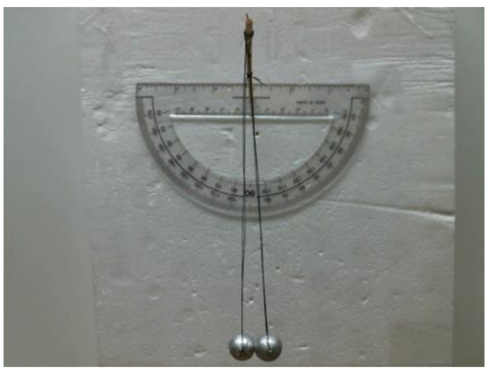


Fig. 5.1.1

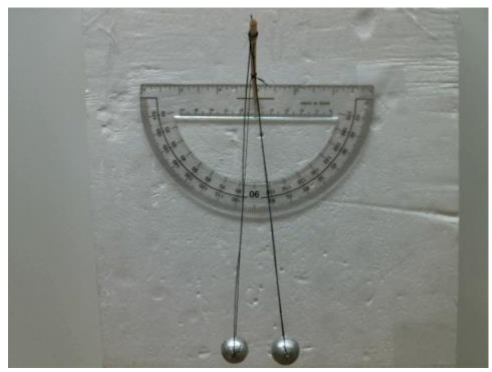
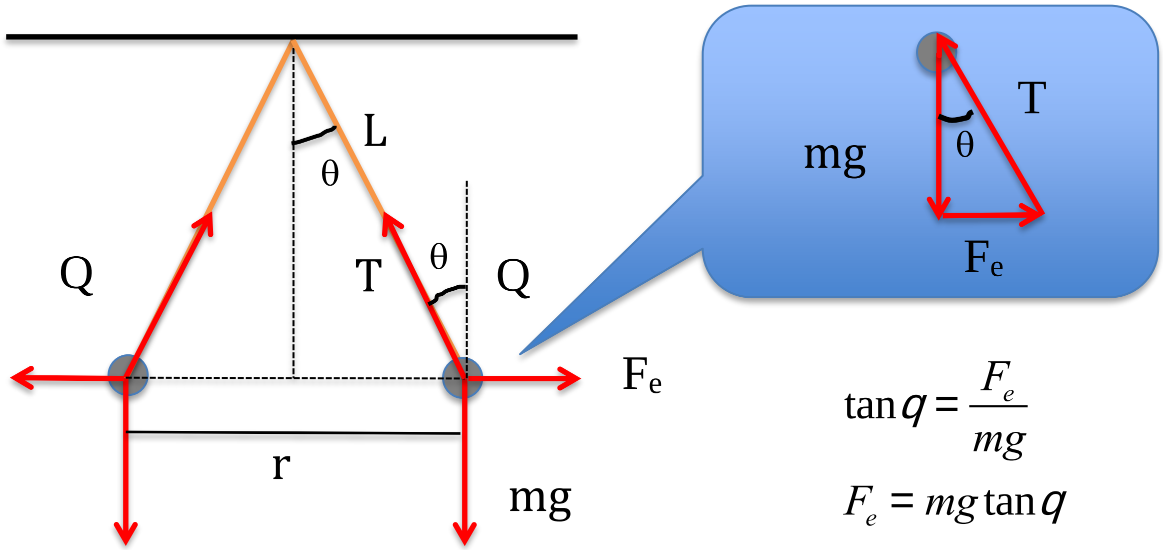


Fig. 5.1.2

At equilibrium, the repulsive force between the identical charges Q on the two silver pith balls will push the balls sideways and the force due to gravity will pull them down. So the pith balls will move out to the side and up, since they are fixed by the strings. This motion will create tension in the string such that the tension T in the string is the vector sum of the horizontal electric force F_e and the vertical gravitational force mg. See **Fig. 5.1.3**. The forces are in red.

Name ________________________________ Date ____________________________



$$\tan q = \frac{F_e}{mg}$$

$$F_e = mg \tan q$$

Fig. 5.1.13

By weighing the pith balls to get the mass and measuring the angle we can determine the force F_e. We assume $Q_1 = Q_2$ because the pith balls are the same size and shape. Then the charge Q on each pith ball is given by

$$F_e = k\frac{Q^2}{r^2}$$

Solving for the charge Q, we get

$$Q = \sqrt{\frac{r^2 F_c}{k}}$$

where k is the electrical constant $8.99 \times 10^9 \ Nm^2/C^2$, and r = 2* L * sin(θ).

Objective: To determine the amount of charge on the suspended pith balls.

Materials:

- Threaded pith ball x2
- Thin Wooden Rod / Coffee Stirrer
- Protractor
- Handheld VDG
- Blank Letter-size Paper (from home

Procedure:

1. Measure the weight of the pith balls together and take the average. Neglect the weight of the thread. What is the average mass of the pith ball? _____________

2. The pith balls in the class kit should come preinstalled on a coffee stirrer. If not, attach one end of the thread near one end of the wooden rod. Attach the other end of the thread near the other end of the wooden rod. Then pull the pith ball to the middle of the thread so that it hangs under the middle of the wooden rod, and the thread forms a "v" shape. See **Fig. 5.1.4**.

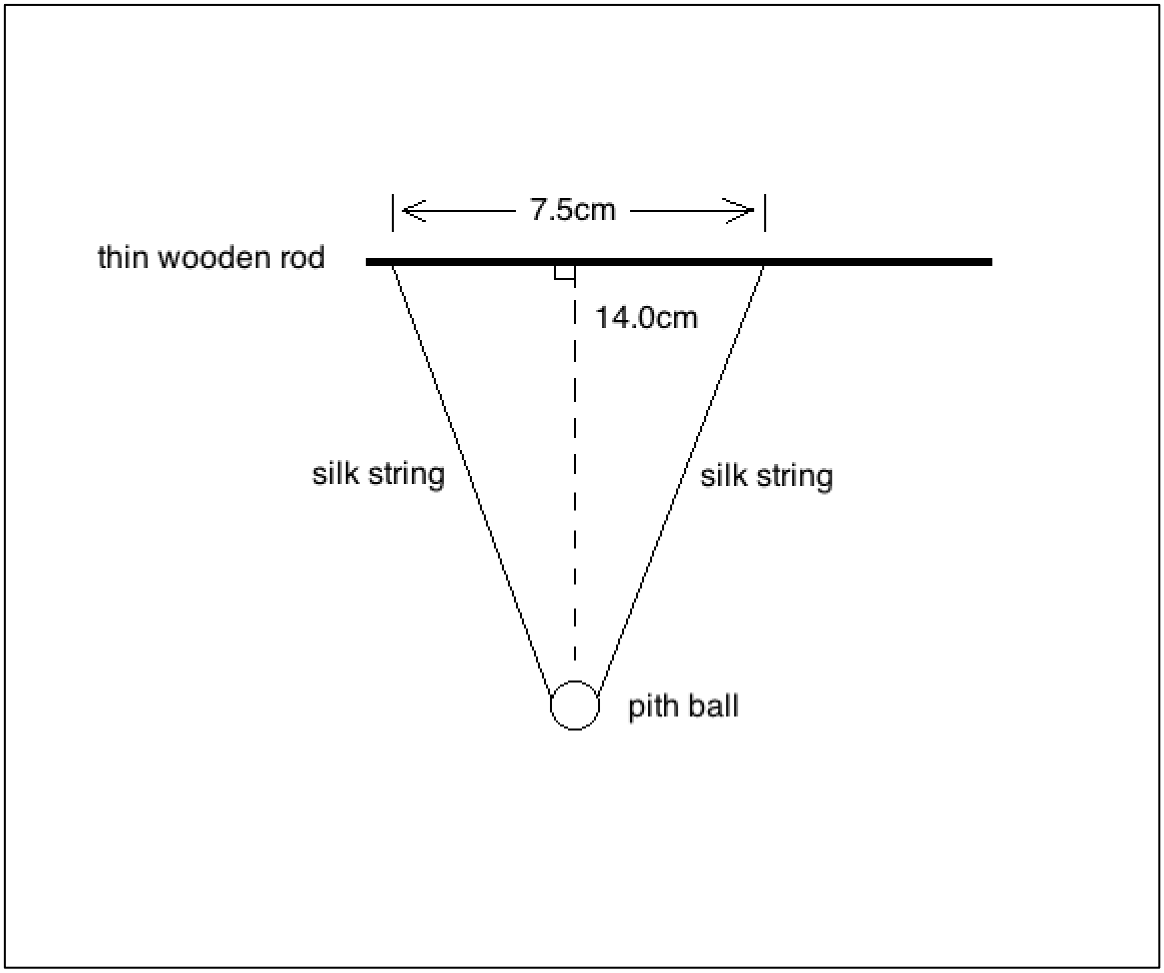


Fig. 5.1.4

3. Hang the other pith ball from the coffee stirrer in the same way. Adjust the length of the thread on the second pith ball so that the pith balls hang at the same level right next to each other, while the threads are tied onto the same spot on either end of the wooden rod. Measure the vertical distance L from the pith ball to the coffee stirrer. What is the distance? ______________________________

Name ________________________________ Date ____________________________

4. Poke the wooden rod through the hole on the protractor and stick it in a large piece of Styrofoam to support it. See **Fig 5.1.4** below. Another choice is to place the wooden rod in a gap on the class kit box, as is shown in **Fig. 5.1.5.** Push the protractor against the side of the box to leave room for the pith balls to swing.

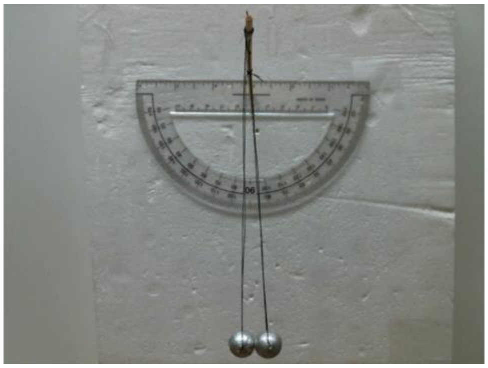


Fig. 5.1.4


Fig. 5.1.5

5. With the two pith balls hanging right next to each other, place the handheld VDG in between and touch each pith ball at the same time and press the button to start the VDG to charge each pith ball equally simultaneously. Make sure after you remove the VDG that the two pith balls touch each other again so that they obtain the same charge.

6. After you remove the VDG and release the pith balls, how do the pith balls behave? ____

7. Look straight at the protractor and shift your line of sight until the two strings on the first pith ball overlap. Record the angle you read on the protractor. Then using the same method, measure the angle of the second pith ball. Take their absolute difference as the angle θ between the pith balls. What is your measurement of θ? Enter the value in **Table 5.1.1**.

8. Calculate tan(θ). According to the force diagram above, $F_e = mg * \tan(\theta)$. Use m from step 1 and $g = 9.81\ m/s^2$ as the gravitational acceleration constant. What is the magnitude of F_e in SI units? Enter the value in **Table 5.1.1**.

9. Use L from step 3 and $r = 2 * L * \sin(\theta)$ to calculate r. Then plug in k, F_e, and r into the equation:

$$Q = \sqrt{\frac{F_e r^2}{k}}$$

Calculate the charge on the pith ball and enter the number in **Table 5.1.1**. Since charge comes in units of electron charge, calculate how many excess or missing electrons there are on the pith ball, and also enter the number in **Table 5.1.1**. Pay attention to the units.

Name ________________________________ Date ____________________________

10. Repeat steps 5 – 9 for 2 more trials where each trial has a different angle θ. Tabulate all your measurements of θ tan(θ), F_e, r, and Q in **Table 5.1.1**. Pay attention to the units.

Trial	**θ** □□□□□	**tan θ**	**F_e (N)**	**r (m)**	**Q (nC=10-9 C)**	**Number of Electrons**
1						
2						
3						

Table 5.1.1

Name ________________________________ Date ____________________________

Activity 5 – 2: Verifying Coulomb's Inverse Square Law

Introduction:

Below are two conducting balls. One is suspended from a non-conducting silk thread and one is fixed to a horizontal insulating acrylic rod. The conducting balls are uncharged in the left figure and charged in the right figure. In the right figure one ball is brought closer to the suspended ball and the suspended ball is pushed up like a swinging pendulum. See **Fig. 5.2.1 (a) – (c).**

Fig. 5.2.1 (a) Uncharged Conducting Balls

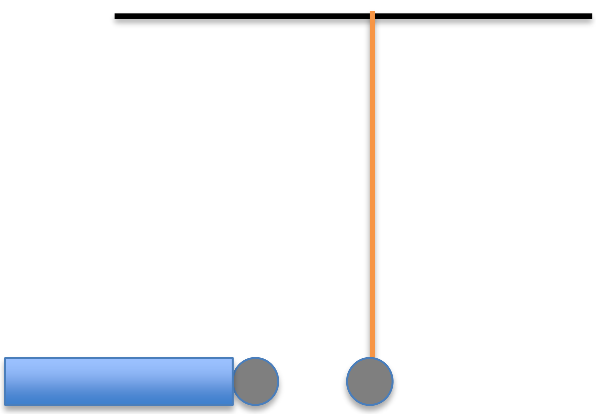
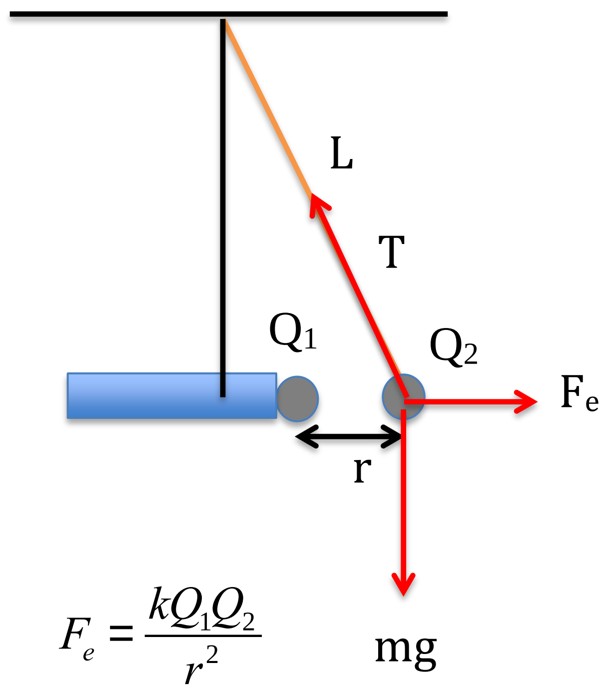


Fig. 5.2.1 (b) Charged Conducting Balls



$$F_e = \frac{kQ_1Q_2}{r^2}$$

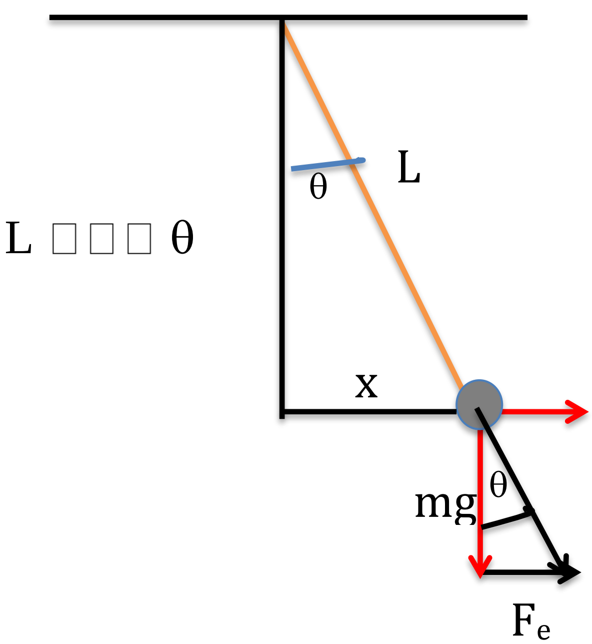


Fig 5.2.1 (c) Similar Triangles

Name ________________________________ Date ____________________________

In **Fig. 5.1.1 (b)**, r is the distance between the center of the suspended ball and center of the fixed ball. In **Fig. 5.1.1 (c)**, the angle θ of the suspended ball is the same angle between mg and tension T in the string due to similar triangles. Therefore:

$$\tan q = \frac{F_e}{mg}$$

$$\tan q = \frac{kQ_1Q_2 / r^2}{mg}$$

$$\tan q = (\frac{kQ_1Q_2}{mg})\frac{1}{r^2}$$

Our objective is to verify Coulomb’s Inverse Square Law. By moving the fixed ball closer and closer to the suspended ball, we can vary r and measure the angle in each case. According to Coulomb’s Law, if we plot the tangent of the pith ball angle θ versus $1/r^2$, we shall get a straight line.

Objective: Verification of Coulomb’s Inverse Square Law between two charges.

Materials

- Handheld Van de Graaff Generator
- Pith ball on a string
- Skinny Wooden Rod/Coffee Stirrer
- Wooden Block with Short Acrylic Rod and 0.75” Metal Ball
- Smaller Wooden Block with a Groove on One Side
- Plastic Ruler
- Protractor
- Class Kit Box
- Scotch Tape or Clear Tape (from home)
- Letter-size Paper (from home)
- Thick books (from home)

Procedure

1. In our setup, the distance r is the distance between the centers of the balls. It is the sum of the radii of the balls, plus the apparent distance d, measured between the tip of one ball and the tip of the other:
   $$r = R_1 + R_2 + d$$
   Before anything is set up, measure the diameter of the pith ball and the diameter of the metal ball. What are their diameters? What is the sum of their radii?
   ____

2. The pith balls in the class kit should come preinstalled on a coffee stirrer. Carefully remove one pith ball and its string from the coffee stirrer. If you are starting from scratch, refer to activity 1 step 2.

Name ________________________________ Date ____________________________

3. Put the class kit box on the table. Poke the sharp end of the coffee stirrer through the center hole on the protractor and stick it in a piece of Styrofoam, as shown in **Fig 5.2.2**. Alternatively, you can use the one of the hatches on the box to secure the coffee stirrer, as prescribed in activity 1. The pith ball should hang freely from the coffee stirrer about 5cm above the table. If there isn't enough clearance for the pith ball, use a thick book to prop up the box.

Fig. 5.2.2

4. Make sure the protractor stays perpendicular to the coffee stirrer, with the blank paper in the background to increase contrast. This is critical for the accuracy of angle measurement. Look at the two strings that hang the pith ball. Shift your line of sight until they overlap. Then look at the protractor. This is the standard method for angle measurement. What is the reading of the strings on the protractor when the pith ball hangs freely? ______________________________

5. Tape the smaller wooden block to the side of the big wooden block that is close to and runs parallel to the acrylic rod. Put their flat sides together and face the groove outward. Then tape the plastic ruler against the groove on the smaller wooden block. The marks on the ruler should be facing the metal ball. The ruler should run parallel to the acrylic rod when viewed from above. And the tip of the metal ball should be at least 10cm away from the tip of the ruler. See **Fig. 5.2.3**.

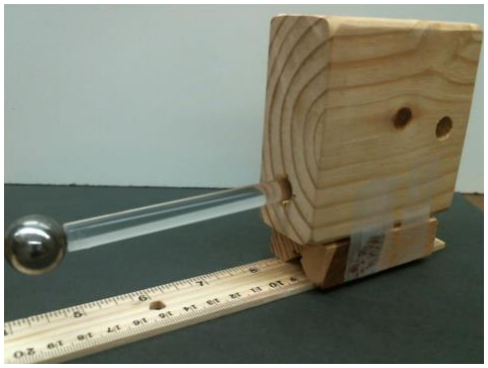


Fig. 5.2.3

Name ______________________________ Date ___________________________

6. Charge up the pith ball by rubbing it against the handheld VDG. Charge up the metal ball in a similar way. Then turn off the handheld VDG and put it way to prevent it from affecting the setup.

7. Approach the pith ball with the metal ball. Two different positions are shown below in **Fig. 5.2.4 (a)** and **Fig. 5.2.4 (b)**. Describe the movement of the pith ball. ____

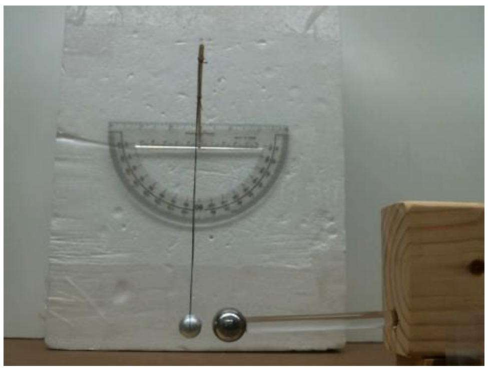


Fig. 5.2.4 (a)

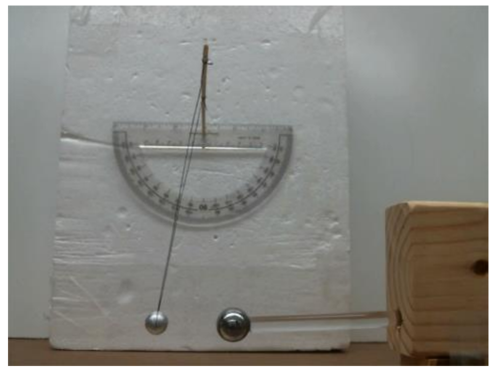


Fig. 5.2.4 (b)

8. Hold the metal ball level with the pith ball. Also make sure that the metal ball and the pith ball forms a straight line that goes perpendicular to the coffee stirrer and parallel to the ruler. Use the marks on the ruler to set the distance d to 6cm between the tip of the pith ball and the tip of the metal ball. Then obtain a reading on the protractor. (Hint: it helps to set the wooden block on a half-opened book of the right height so that it's easier to focus on angle measurement.) Enter your distance reading and protractor reading in the first two columns in **Table 5.2.1**.

9. Repeat step 7 in rapid succession. Reduce the distance each time to 5 cm, 4 cm, and 3 cm respectively. Try to write down the distance beforehand and only focus on the angle measurement to save time, because charge leaks into the air if you wait too long, especially on a rainy day. Record your numbers in **Table 5.2.1**. (Hint: leave the calculation for later as it slows you down from measuring.)

d (cm)	**protractor reading (degrees)**	**r (m)**	**θ (degrees)**	**$1/r^2$ (m^{-2})**	**tan(θ)**
6					
5					
4					
3					

Table 5.2.1

10. Finally, fill in the rest of **Table 5.2.1** and use Excel to produce a scatter plot of tan(θ) vs. $1/r^2$. See Fig. 5.2.5. Pay attention to the units. What kind of correlation do you observe? ____

Name ________________________________ Date ____________________________

11. Place a copy of your scatter plot here:

12. Based on your data, how does the magnitude of the electrostatic force vary with the distance between charges? ____

Name _______________________________ Date ___________________________

Activity 5 – 3: Electroscope Calibration

Introduction.

In the earlier labs you used an electroscope to indicate the presence of electric charge. The larger the angle of the electroscope the more charge it has on it. You can use the electroscope to get a numerical value of the charge. The formula used to describe charge Q as a function of angle θ is complicated,. It is not shown here. We have used a sensitive charge meter to measure the charge as a function of angle and then we fit it with a smooth curve and determine the parameters that give the best fit. The plot of the charge (in nano-Coulombs) on the electroscope is given below in **Fig.5.3.1**. In this activity you will determine the approximate amount of charge on the electroscope by measuring the angle of tube deflection and convert it to charge using **Fig 5.3.1**.

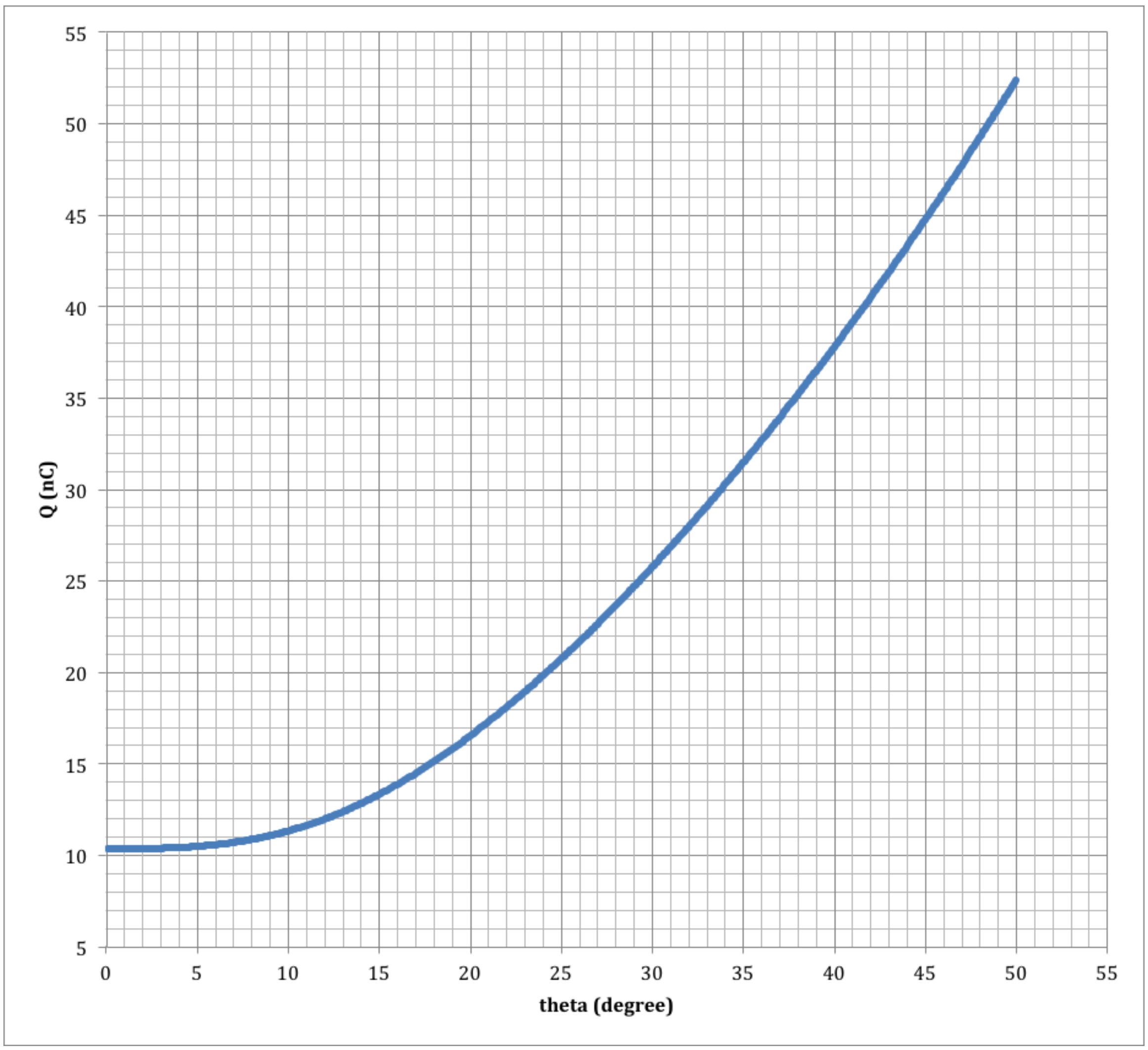


Fig 5.3.1

Name ______________________________ Date __________________________

Objective: Use angle measurement of the electroscope tube deflection to calculate the amount of charge on the electroscope

Materials

- Silk
- Teflon Rod
- Protractor
- Thin Rubber Band
- UVA Electroscope
- Scissors (from home)
- Black Marker (from home)
- Blank Letter-size Paper (from home)

Procedure

1. Cut the rubber band loop so that it becomes a single strand. Put the rubber strand through the hole at the center of the protractor. Loop it around the round edge of the protractor and tie the two ends together. You may also use the alligator clip to hold it without cutting it. You should be able to slide the rubber band along the round edge of the protractor. This will give you an easier view of the angle measurement**. See Fig. 5.3.2**

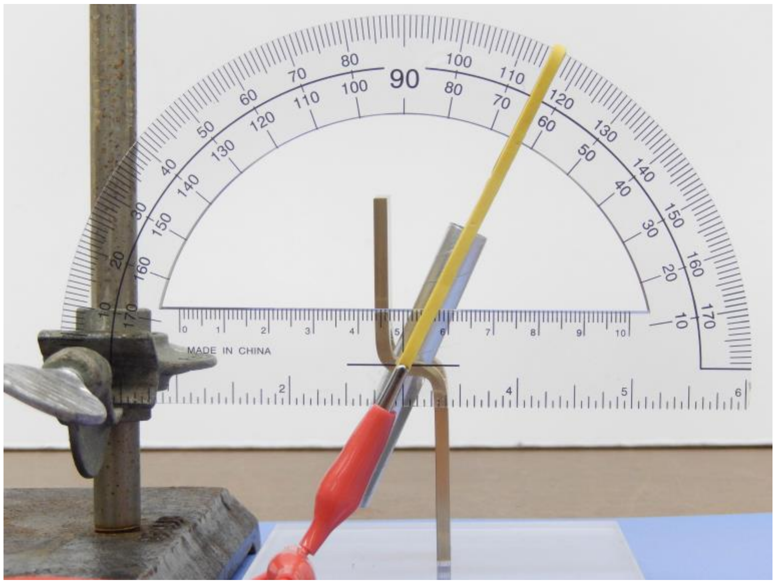


Fig. 5.3.2

2. Draw two marks near the top edge of the electroscope tube directly above the pin position. Also put the letter-size paper behind the electroscope for better contrast.

3. Use the silk and the Teflon rod to charge up the electroscope to some angle below maximum deflection. Wait for the tube to stop swinging.

Name ________________________________ Date ____________________________

4. Hold the protractor about 3cm in front of the electroscope. Check that the bottom edge of the protractor is parallel to the electroscope base. Align the hole at the center of the protractor with the pin on the electroscope tube. Maintain the same line of sight.

5. With your left hand holding the protractor steady, use your right hand to slide the rubber band along the round edge until it overlaps the mark on the electroscope tube. Be careful not to get your hand too close to the electroscope to cause a discharge.

6. Now you can bring the protractor away from the electroscope and examine the position of the rubber band to get a reading of the angle. What is the angle you read? Subtract 90 degrees to get θ, the angle of tube deflection. ____

7. Refer to the calibration formula. How much charge is on the electroscope, approximately? ____

Name ________________________________ Date ____________________________

Activity 5 – 4: Visualization of Electric Field Lines

Introduction:
Field lines are imaginary lines commonly used in physics as a convenient way to describe the spatial distribution of a force field such as the electric field. The direction of the force at a given location is represented by the direction of the field line at that location. The density of field lines at that location represents the magnitude of the force. For example, in **Fig 5.4.1** straight lines represent the uniform electric field between two parallel charged plates. The direction of each line goes from the positive plate to the negative plate.

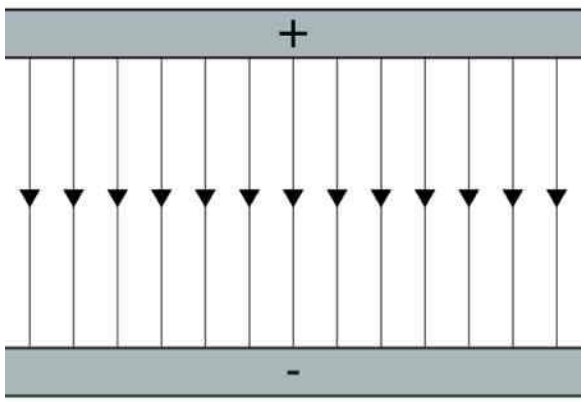


Fig 5.4.1

Objective: Examine electric field lines using pencil lead fragments as indicators.

Materials:
- Handheld Van de Graaff
- Wire Cutter
- Petri Dish or something similar
- Aluminum Foil Strip
- Penny Coin
- Scotch Tape (from home)
- Pencil Lead (from home)
- Vegetable Oil (from home)

Procedures:
1. Tape a penny onto the bottom of the petri dish at the center of the outer surface. Tape the aluminum strip along the circumference of the petri dish against the side. Be careful with the aluminum foil strip, as its edges are sharp.

2. Chop up 1 container of pencil lead with the wire cutter. Fragment size should be between 2mm and 5mm.

Name _________________________________ Date ____________________________

3. Put the pencil lead fragments into the petri dish. Pour vegetable oil over the dish until all pencil lead fragments are submerged as seen in **Fig 5.4.2**. Then put the cover on the petri dish.

Fig. 5.4.2

4. Lift the petri dish carefully. Use the Van de Graaff stick to charge up the coin taped to the bottom. How do the pencil lead fragments behave? What pattern do you observe? ____

5. Keep charging the coin. Describe the eventual pattern that forms in the petri dish. What is the shape and direction of the electric field around a charged round object? Does it agree with the inverse-squared law that we learned previously? Why or why not? ____

Name____ Date________________________

Lab 6
Simple Circuit, Breadboard, and Multimeter

Overview

Labs 1-5 have been focused on static electricity. In Lab 6 we will learn about moving electricity, i.e. electric current. We will study a simple circuit, a breadboard, and how to use a digital-Volt-Ohm-meter to make electrical measurements in a circuit.

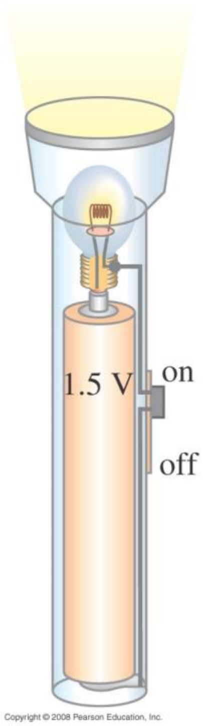


Fig. 6.0.1

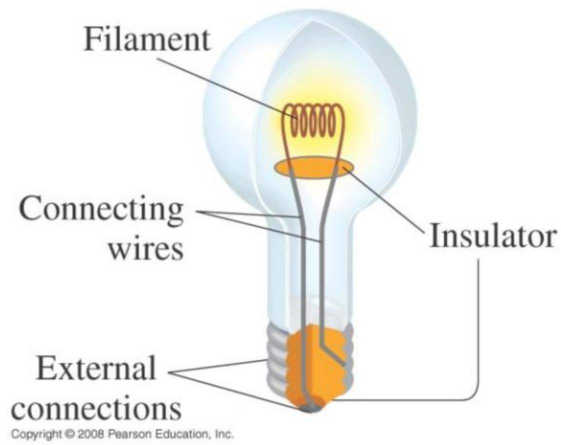


Fig. 6.0.2

Light bulbs are commonly found in flashlights. See **Fig. 6.0.1**. They serve as good indicators of current because when there is current passing through a light bulb, it lights up. The bulb lights up mainly due to the heat produced in the filament. **Fig. 6.0.2** is an illustration of the inner working of a light bulb.

The brightness of a bulb will tell us how much power the bulb consumes. Power is proportional to the current times the voltage. It is also proportional to the current squared times the resistance of the filament. In the latter part of the Lab we will use a DVOM as an indicator to accurately measure current, voltage, and resistance. We will see how the different physical quantities such as current and voltage are related to each other.

Name____ Date________________________

Activity 6 – 1: Simple Circuit

Objective: Construct a simple circuit to test continuity of the current flow.

Materials:

- Battery holder with leads
- Light bulb
- Alligator Wires
- Light bulb holder
- One D size Battery (from home)

Procedure:

1. Place the battery in the battery holder, and connect the red wire with alligator clips to the positive end of the battery and the other end of the red wire to the light bulb. Connect the black wire to the negative end of the battery and the other end of the black wire to the other side of the light bulb. See **Fig. 6.1.1** and **Fig. 6.1.2**. Describe your observations. ____

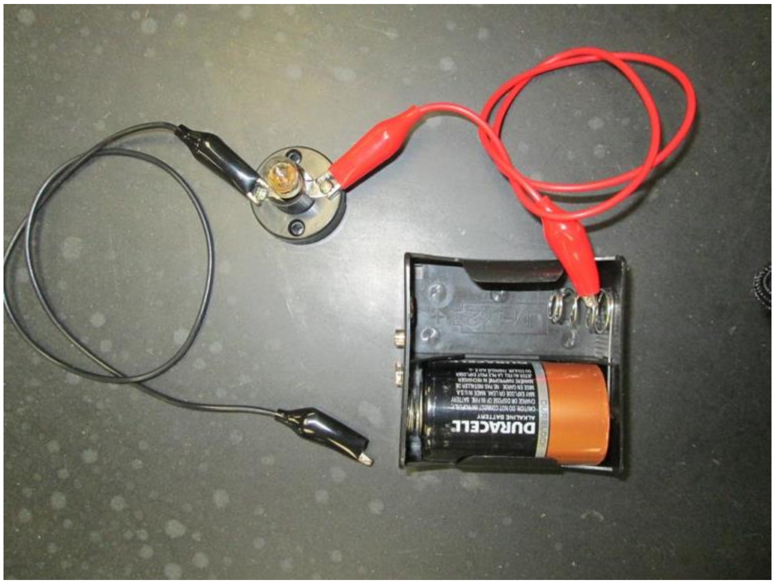


Fig. 6.1.1

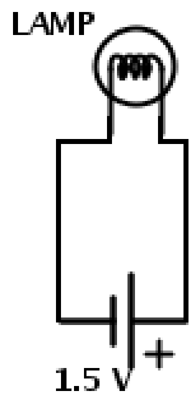


Fig. 6.1.2

2. What is moving or said to be flowing in the wires in the circuit? ____________________

3. Reverse the polarity of the wire leads by connecting the red wire to the negative end of the battery, and the black wire to the positive end of the battery. Describe your observations? ____

4. Does reversing the positive and negative terminals of the battery affect the brightness of the bulb? ____

Name_______________________________________ Date________________________

5. Based upon your observations what can you conclude about the orientation of the battery with regard to the terminals and its effect on our simple circuit? ____________________

6. Disconnect somewhere in the circuit. Does the bulb light up? ____________________

7. Now connect two batteries in series by connecting the positive terminal of one battery to the negative terminal of the second battery. See **Fig. 6.1.3**. Note the brightness of the bulb with one battery to two batteries. Brightness of the bulb is an indication of current. The brighter the bulb the more the current. Explain why the brightness of the bulbs changes as you add more batteries. ____

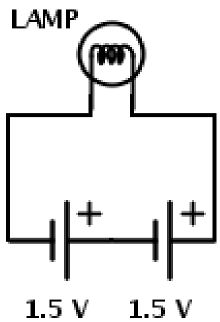


Figure 6.1.3

8. Now connect a third battery in series with the help of another battery holder. See **Fig. 6.1.4**. Note the brightness of the bulb. Explain why the brightness of the bulbs changes again as you added more batteries. ____

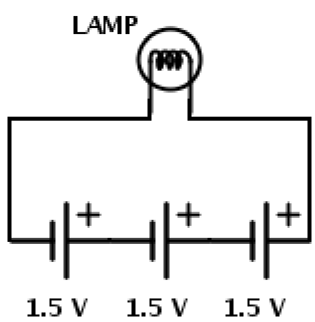


Fig 6.1.4

9. What can be inferred about the relationship between voltage and current assuming brightness as an indication of current? ____

10. Now connect three bulbs in series as shown in **Fig. 6.1.5** and **Fig. 6.1.6**. Note that the black alligator clip is not yet connected. Connect it please. Compare the brightness of each bulb with that of one bulb connected to three batteries as in step 2. Record your observations here. ____

Name____ Date________________________

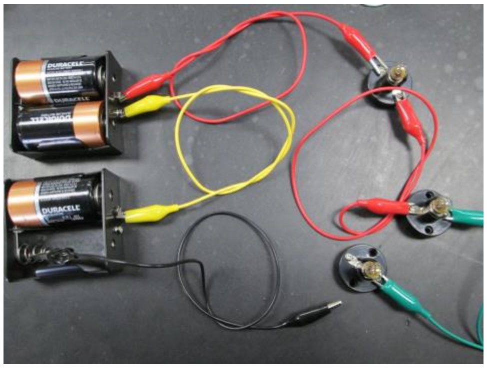


Fig. 6.1.5

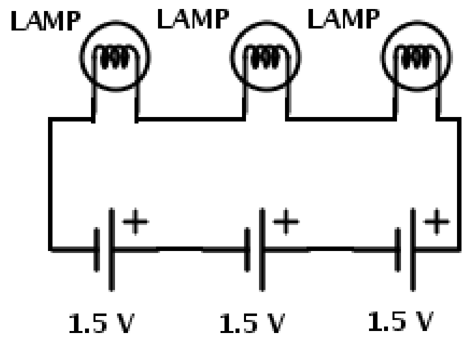


Fig. 6.1.6

11. When more bulbs are added in series, explain how the current and resistance change? ____

12. Connect three bulbs in parallel as shown in **Fig. 6.1.7** and **Fig. 6.1.8**. Note that the white alligator clip is not yet connected to the bulb in the picture.

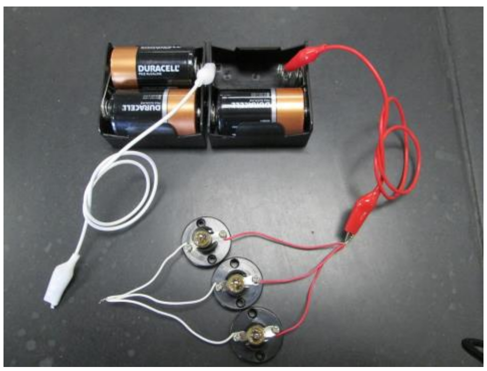


Fig. 6.1.7

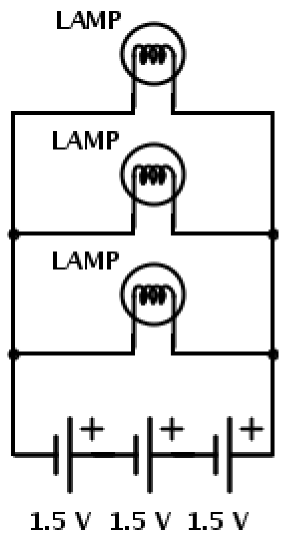


Fig. 6.1.8

13. How does the brightness of each bulb compare to the earlier case in Step 2 when one bulb was connected to three batteries? Explain. ____

14. How does the voltage across each bulb change as more bulbs are added in parallel? ____

15. As bulbs are added in parallel, does the resistance in a circuit increase or decrease compared to Step 2? Explain. ____

Name____ Date_________________________

Activity 6 – 2: Breadboard

Introduction:

In electronics, it is frequently necessary to build and to test circuits. Sometimes the circuits have components which are soldered into place. We will not be soldering components into place, but using a breadboard.

In the early days of radio, amateurs nailed bare copper wires or terminal strips to a wooden board (often literally a cutting board for bread) and soldered electronic components to them. Sometimes a paper schematic diagram was first glued to the board as a guide to placing terminals, and then components and wires were installed over their symbols on the schematic. Using thumbtacks or small nails as mounting posts was also common.

Breadboards have evolved over time, with the term now being used for all kinds of prototype electronic devices. For example, US Patent 3,145,483, filed in 1961 and granted in 1964, describes a wooden plate breadboard with mounted springs and other facilities. US Patent 3,496,419 filed in 1967 and granted in 1970, refers to a particular printed circuit board layout as a *Printed Circuit Breadboard*. Both examples refer to and describe other types of breadboards as prior art.

The breadboard most commonly used today is usually made of white plastic or neutral color plastic and is a pluggable (solderless) breadboard. Ronald J Portugal of EI Instruments Inc. designed it in 1971. [1] See **Fig. 6.2.1**

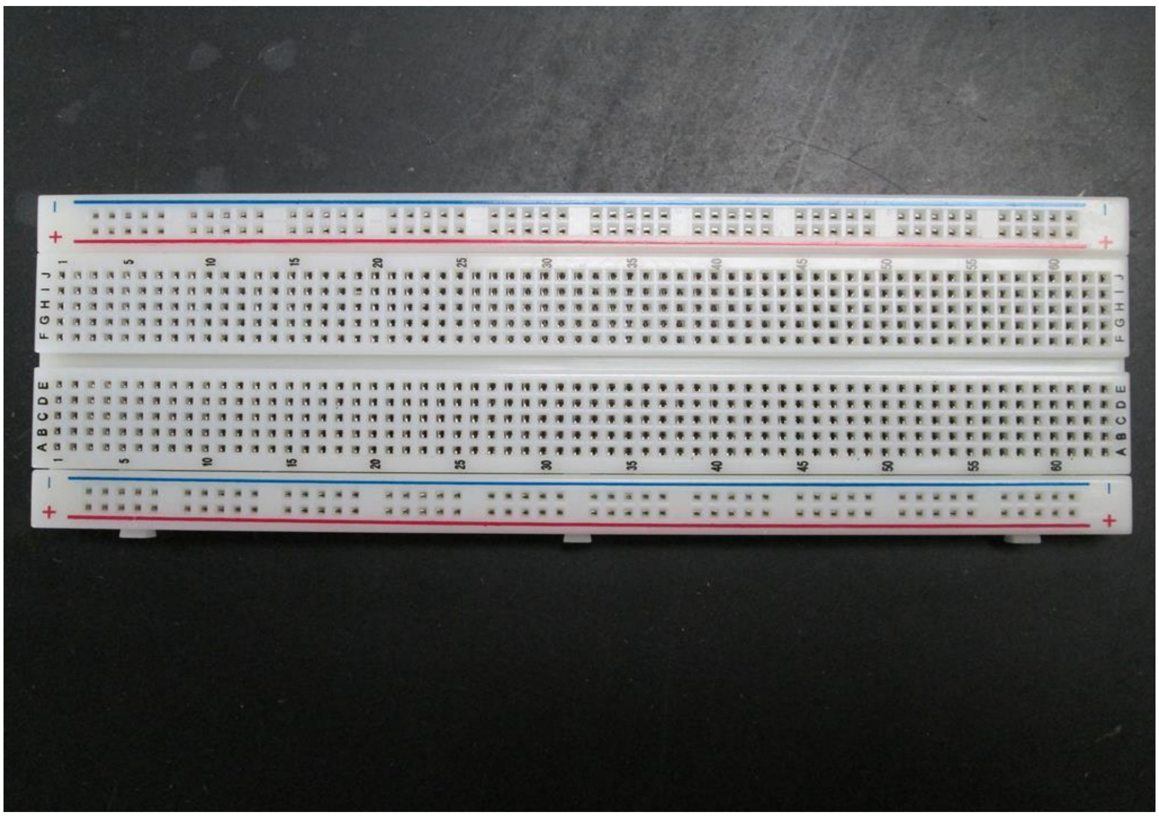


Fig. 6.2.1

The main area will be used to hold most of the electronic components. In the middle of a terminal strip of a breadboard, one typically finds a notch running in parallel to the long side. The notch is to mark the centerline of the terminal strip and provides limited airflow (cooling) to DIP ICs (Dual-inline package integrated circuits) straddling the centerline. The clips on the right and left of the notch are each connected in a radial way; typically five clips (i.e., beneath five holes) in a row on each side of the notch are electrically connected. The five clip columns on the left of the notch are often marked as A, B, C, D, and E, while the ones on the right are marked F, G, H, I and J.

The outer strips are used to provide power to the breadboard. A bus strip usually contains two columns: one for ground and one for a supply voltage. However, some breadboards only provide a single-column power distributions bus strip on each long side. Typically the column intended for a supply voltage is marked in red, while the column for ground is marked in blue or black. Some manufacturers connect all terminals in a column. Others just connect groups of, for example, 25 consecutive terminals in a column. The latter design provides a circuit designer with some more control over crosstalk (inductively coupled noise) on the power supply bus. Often the groups in a bus strip are indicated by gaps in the color marking.

Bus strips typically run down one or both sides of a terminal strip or between terminal strips. On large breadboards additional bus strips can often be found on the top and bottom of terminal strips.

Some manufacturers provide separate bus and terminal strips. Others just provide breadboard blocks which contain both in one block. Often breadboard strips or blocks of one brand can be clipped together to make a larger breadboard.

[1] http://en.wikipedia.org/wiki/Breadboard

Objective: Determine the pattern of connection among the holes on a breadboard.

Materials:

- Battery Holder
- Light bulb
- Light bulb holder
- Breadboard
- Alligator Wires
- Jumper Wires
- D size Battery (from home)
- Wire cutter (from home)

Procedure:

Differently colored wires and color-coding discipline are often adhered to for consistency. However, the number of available colors is typically far fewer than the number of signal types or paths. Typically, a red wire is connected to the positive side of a battery and a black wire to the negative side of a battery and sometimes the negative side is called “ground”. Other colors may or may not have any meaning. Some ready-to-use jump wire sets use the color to indicate the length of the wires, but these sets do not allow a meaningful color-coding schema. In the following exercises you will be using your light bulb as an indicator to determine whether you have a complete circuit or not. If the bulb lights up the circuit is complete otherwise if it does not light up, the circuit is broken or incomplete. You will use this test to determine how the holes in the breadboard are connected.

1. Look at your Breadboard. In **Fig. 6.2.2** the rows are labeled with capital letters A B C …, and the columns are labeled periodically with numbers 1 5 10 15 ….There are also + and - labels.

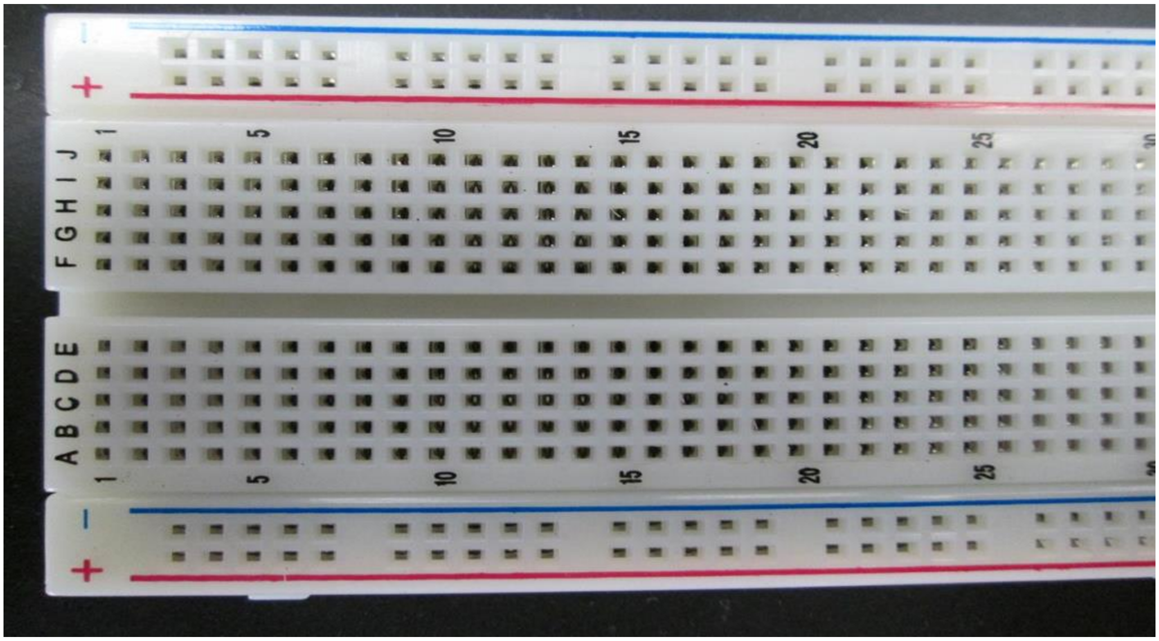


Fig. 6.2.2

2. Place the battery in the battery holder, and connect the positive terminal of the battery to the light bulb (or lamp) using wire with alligator clips. Connect the other end of the lamp to one of the connecting holes labeled + in the first grouping of 5 holes in the breadboard using jumper wire with no alligator clips. Connect the negative terminal of the battery using wire with alligator clips to a short jumper wire and connect a jumper wire to another connecting hole in the same first grouping of 5 holes as shown in **Fig. 6.2.3**. Describe your observation here. ____

Name_______________________________________ Date________________________

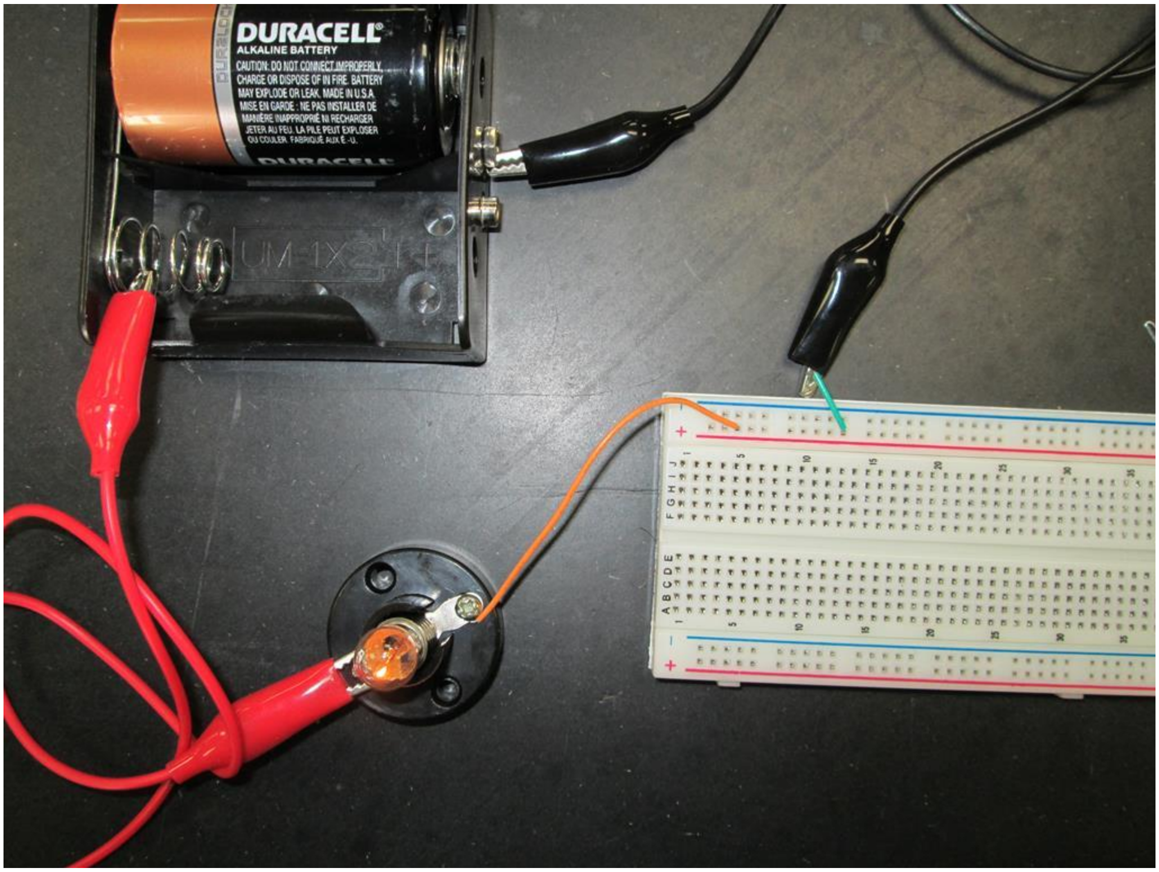


Fig. 6.2.3.

3. Move the short jumper wire to another location in row +. Look at your light bulb, and describe your observation here. ____ repeat for several more locations in row +. Record your observation here. ____

4. Look at your Breadboard. Locate the row of connections labeled -. This time connect your negative terminal of your battery to any location on Row – as in **Fig. 6.2.4**. Look at your light bulb, and describe your observations here. ______________________________________

Name______________________________________ Date________________________

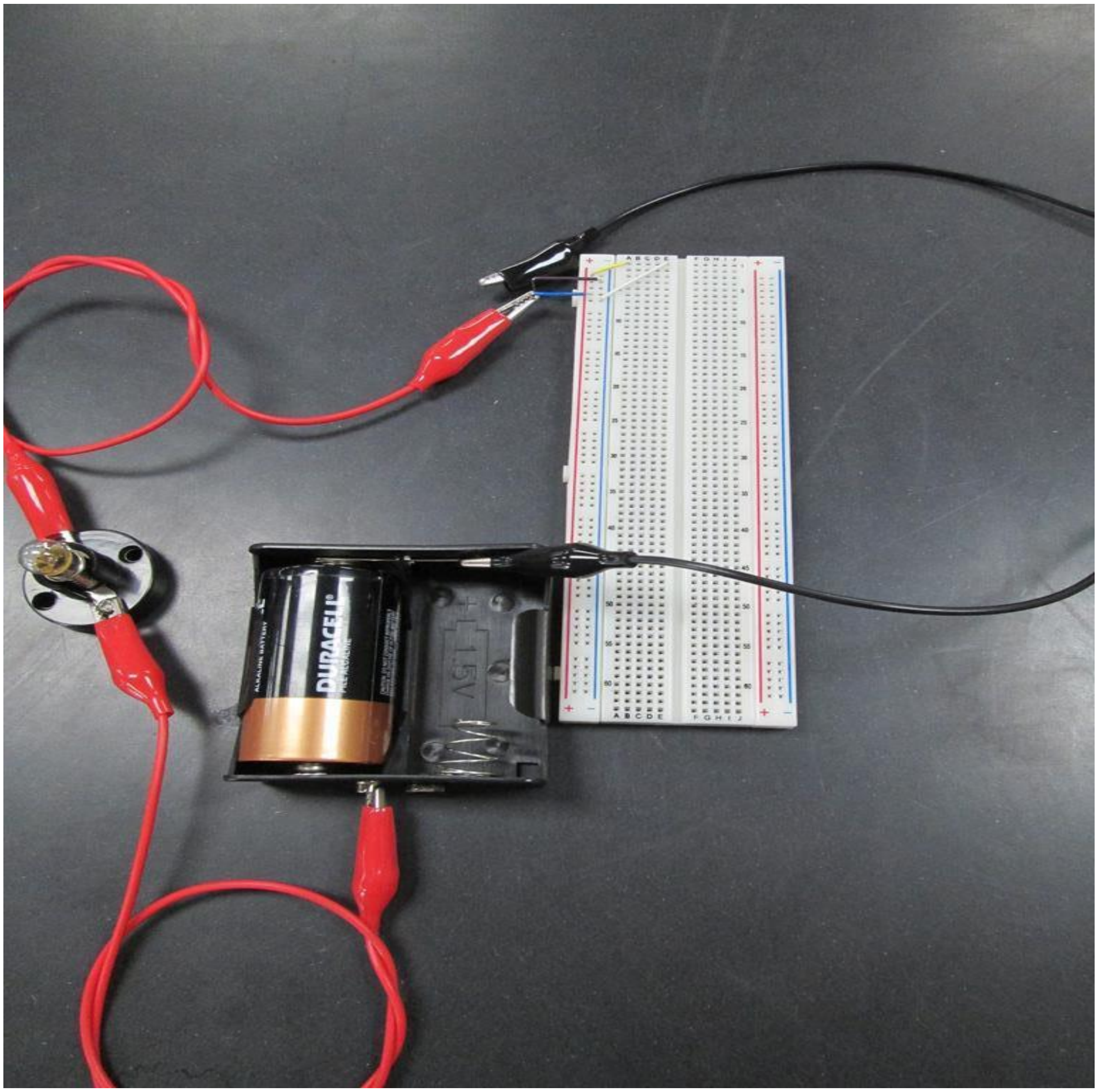


Fig. 6.2.4

5. Repeat for several more locations in row – (negative sign). Describe your observations here about the circuit light bulb. ____

6. Connect a short jumper from Row + to Row A, in Column 1. We will leave this short jumper fixed in the location. Connect your negative terminal of your battery to any location on Row -. Look at your light bulb, and determine if the circuit is completed. ____________________

7. Connect a short jumper from Row E in column 1 to any location in Row – (negative sign). See **Fig. 6.2.5.** Look at your light bulb now and determine if circuit is complete. Record your observation here. ____

Name____ Date________________________

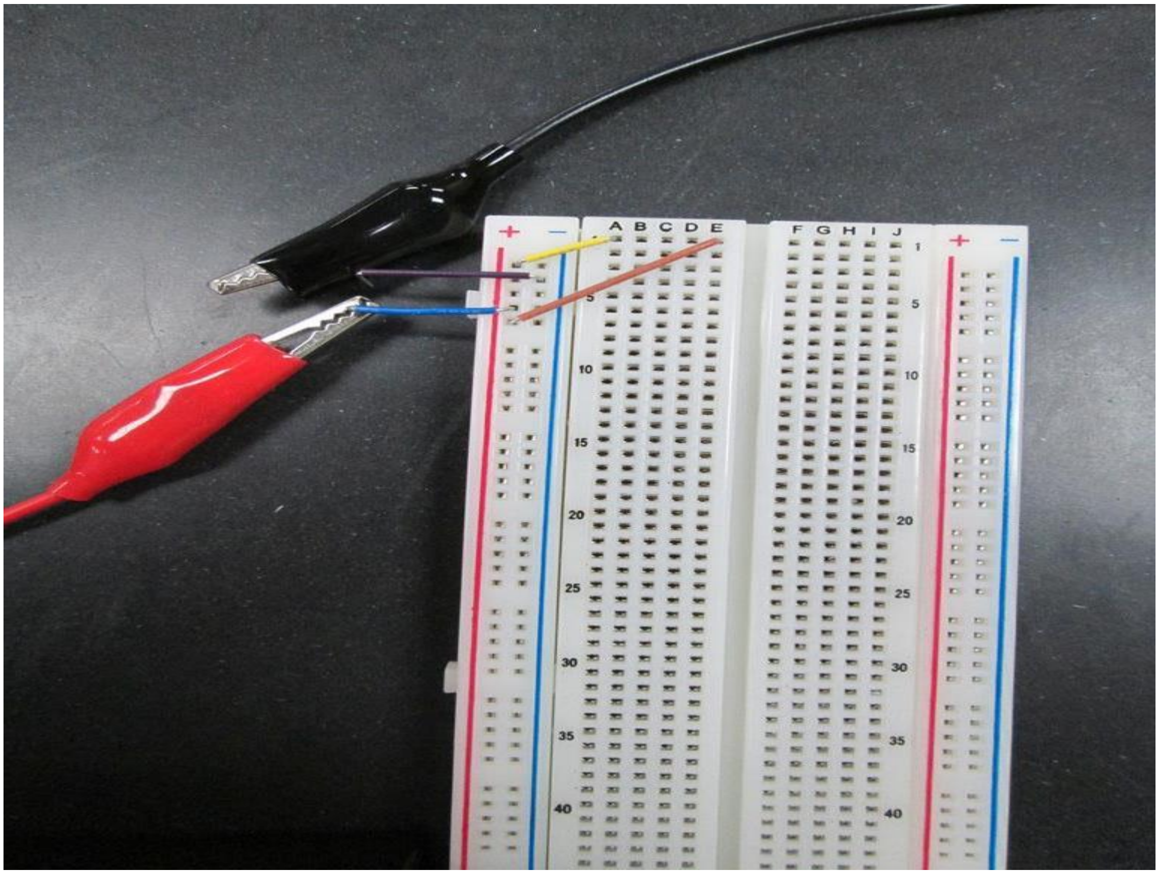


Fig. 6.2.5

8. Move your short jumper from Row E in column 1 to Row D column 1. Look at your light bulb. Repeat for Row C column 1, and Row B column 1. Record your observation here. ____

9. Now move your short jumper from to a new location in a different column then 1. Look at your light bulb, and record your observation here. ________________________________

10. Continue to move your short jumper wire around on the breadboard, until you can figure out which rows and which columns are connected so we can build a completed circuit.

11. On **Fig. 6.2.6** below, indicate which rows and columns are connected. Describe your observations in words. ____

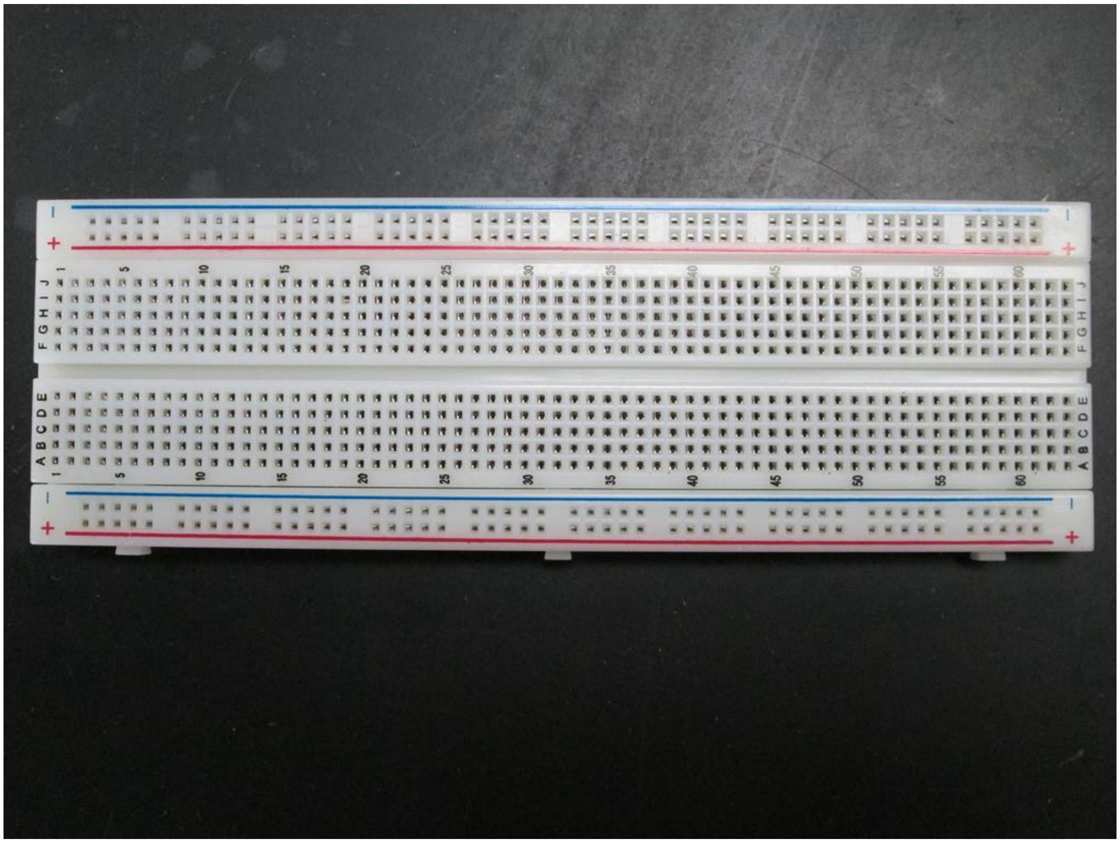


Fig. 6.2.5

Name_______________________________________ Date________________________

Activity 6 – 3: Using the Multimeter to Measure Voltage

Introduction:

The investigation of electrical effects involves the measurement of several different quantities: voltage, current, capacitance and resistance. The DT9205A Multi-meter provided in the class kit can measure all of these quantities within limits. Different quantities require that the multi-meter be hooked up differently. For example, a multi-meter used to measure voltages should have a high resistance, approximately 20 million ohms, while a multi-meter used to measure current should have a low resistance, on the order of 1 ohm or even less.

One brief warning: The multimeter will valiantly attempt to measure quantities that will blow the fuse on the meter. **Whenever the meter shows 1 with no following digits, the meter is overloaded.** See **Fig. 6.3.1.** Depending on what is being measured, this condition could damage the meter (typically by blowing the fuse). An example is shown in Fig. 1 to the right. **If this happens, please stop, disconnect the power source and check your circuit.**

The most common fix is to increase the range of what is being measured. For example, attempting to measure 3.0 V when the meter is set to 2V will result in the overload 1 showing. Simply increasing the range by turning the dial to 20V will fix this.

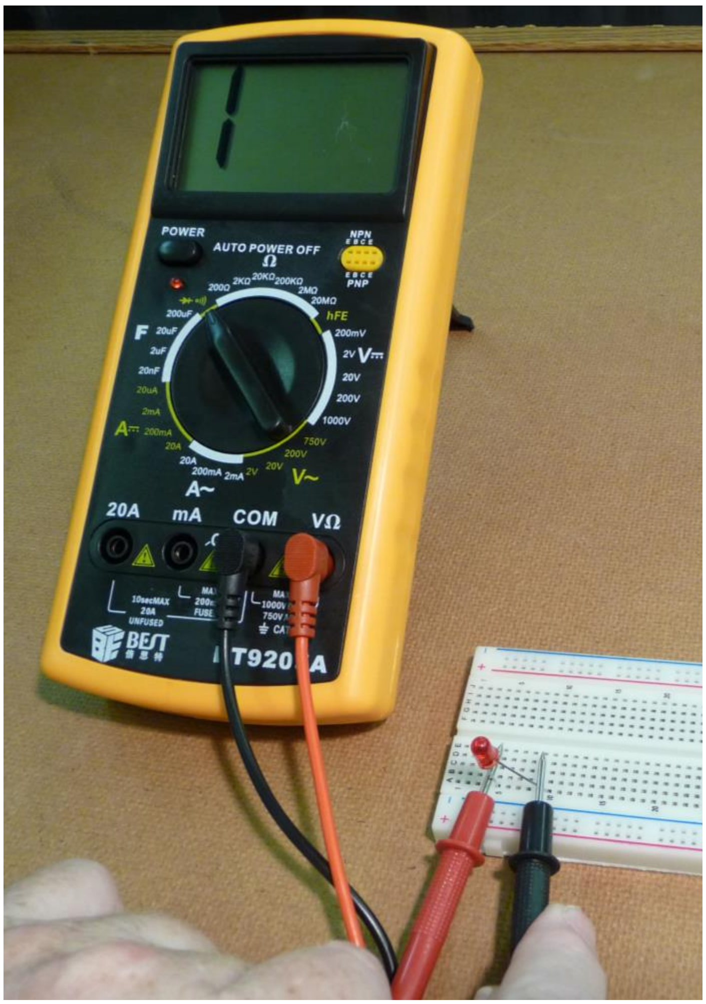


Fig. 6.3.1

Name____ Date_________________________

Objective: Measure the potential difference of a D cell.

Materials:

- DT9205A Multimeter
- Multimeter leads
- Breadboard
- 1.5 Volt D cell
- Battery holder

Procedure:

1. Place a fresh D cell in the battery holder. Turn the multimeter on by pushing the POWER button. Turn the dial so that it points to 2 V DC. The symbol for DC is a straight line over three dots while the symbol for AC is a wavy line like a Spanish tilde. The dial will be pointed to just above 3 o'clock as seen in **Fig. 6.3.2** below.

2. Insert the multi-meter leads into the two rightmost openings at the bottom of the meter. Standard practice is to put the red lead into the rightmost (VΩ) opening and the black lead into the COM opening next to VΩ, as shown in **Fig. 6.3.2.** The schematic is shown in **Fig. 6.3.3.**

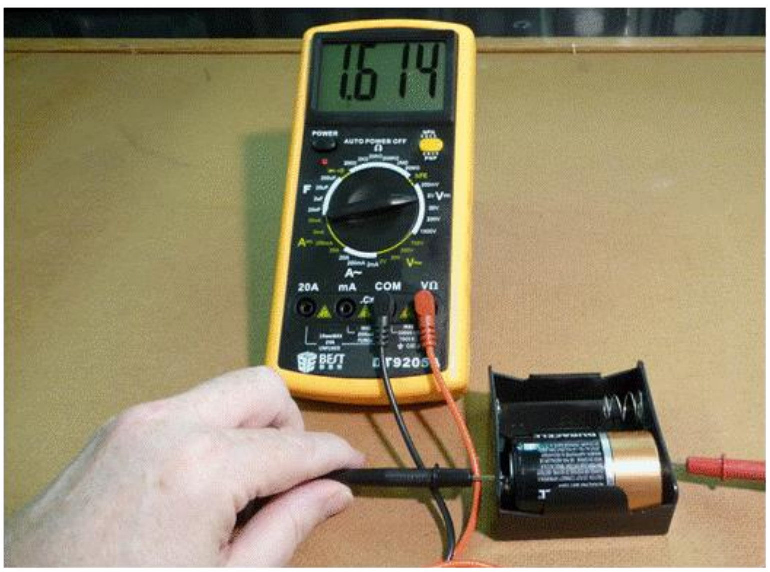


Fig. 6.3.2

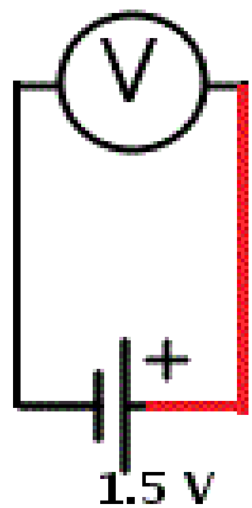


Fig. 6.3.3

3. Touch the two leads to the metal outlets of the battery holder. The red probe lead (+) should touch the metal lead of the top of the D cell. The black probe lead should touch the metal lead of the bottom of the D cell.

4. Reverse the two probes. Touch the red probe to the bottom of the D cell and the black probe to the top of the D cell. Record the potential difference (voltage) of the D cell including appropriate units. Compare the measured voltage with the nominal 1.5 V of the D cell. Does changing the probes change the sign? Does changing the probes change the magnitude of the voltage? ____

Name____ Date_________________________

Activity 6 – 4: Using the Multimeter to Measure Resistance

Objective: Measure the resistance of a resistor.

Materials:

- DT9205A Multimeter
- Multimeter leads
- Breadboard
- 100 ohm resistor

Procedure:

1. Place a 100 ohm resistor into the breadboard as shown in **Fig. 6.4.1** below

2. Turn the multimeter on by pushing the POWER button. Turn the dial so that it points to 20 Ω. The dial will point to 11 o'clock as seen in **Fig. 6.4.1** below.

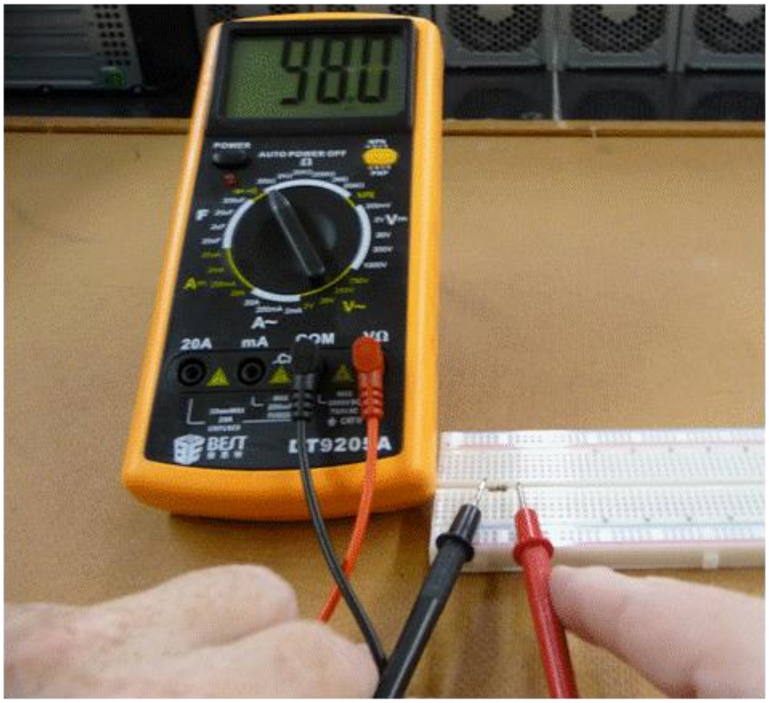


Fig. 6.4.1

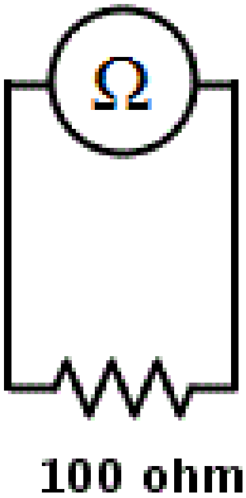


Fig. 6.4.2

3. Insert the multi-meter leads into the two rightmost openings at the bottom of the meter. Standard practice is to put the red lead into the rightmost (VΩ) opening and the black lead into the COM opening next to VΩ, as shown in **Fig. 6.4.1.** The schematic is shown in **Fig. 6.4.2.**

4. Touch the two probes to either leg of the resistor. The red probe lead (+) should touch the right lead of the resistor. The black probe lead should touch the left lead of the

resistor. **You may use your wires with alligator clips so that you do not have to hold the probe to the resistor. The wire will add negligible resistance to the probe but allow you to switch the meter scale with one hand while you do not have to hold the probe. Just clip one end of the wire to the probe and the other end to the resistor.**

5. Record the resistance of the resistor including appropriate units here and compare the recorded value to the nominal 100 Ω of the resistor. _______________________________

6. Reverse the two probes. Touch the red probe to the left leg of the resistor and the black probe to the right leg of the resistor. Record the resistance of the resistor including appropriate units. Compare the recorded value to the nominal 100 Ω of the resistor. Does changing the probes change the sign? Does changing the probes change the magnitude of the resistance?____

Name____ Date________________________

Activity 6 – 5: Using the Multimeter to Measure Current

Objective: Measure the current of a circuit.

Materials:

- DT9205A Multimeter
- Multimeter leads
- Breadboard
- 100 ohm resistor
- 1.5 Volt D cell
- Battery holder
- Electrical lead with alligator clips

Procedure:

1. Place a 100-ohm resistor into the breadboard as shown in **Fig. 6.5.1** below. The schematic is shown in **Fig. 6.5.2.**

2. Place a fresh D cell in the battery holder in the correct orientation. Turn the multi-meter on by pushing the POWER button. Turn the dial so that it points to 200 mA.

3. Insert the multi-meter leads into the two middle openings at the bottom of the meter. Standard practice is to put the red lead into the left middle (mA) opening and the black lead into the COM opening next to (mA).

4. Connect an electrical lead from the bottom of the D cell to the right leg of the resistor. Touch the two probes to the circuit as shown below in **Fig. 6.5.1.** The red probe lead (+) should touch the top of the D cell. The black probe lead should touch the left leg of the resistor.

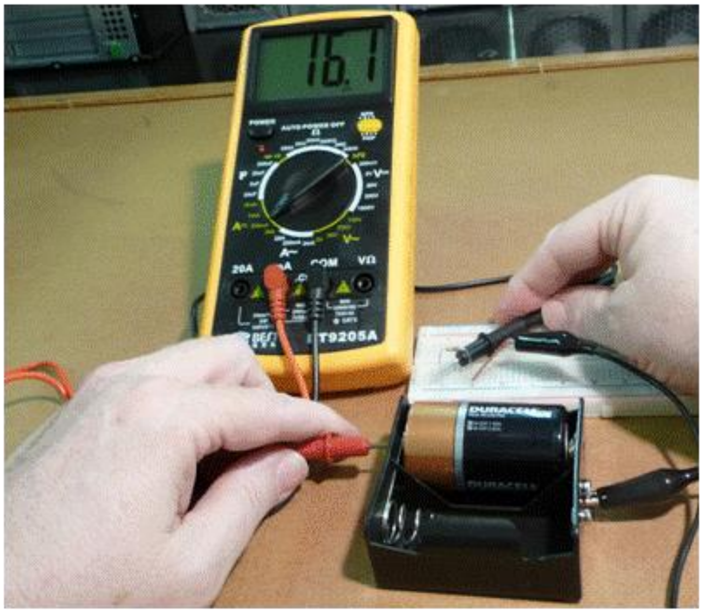


Fig. 6.5.1

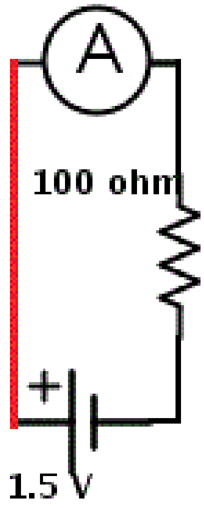


Fig. 6.5.2

Name____ Date_________________________

5. Record the current of the circuit including appropriate units. ______________________

6. Reverse the two probes. Touch the red probe to the left leg of the resistor and the black probe to the top of the D cell. Record the current of the circuit including appropriate units. Does changing the probes change the sign? Does changing the probes change the magnitude of the current?____

Name____ Date_________________________

Lab 7
Ohm's Law

Overview

In the last lab, we studied some relationships in simple electric circuits. In this lab we will explore those relationships in greater detail and explore quantitative laws that exist.

There are several important relationships in electric circuits. One is a relationship discovered in 1827 by the German physicist Georg Ohm. In this relationship, which is known as Ohm's Law, there is a relationship between voltage, current, and resistance in an electrical circuit. This relationship is expressed mathematically as:

$$V = I / R$$

where **V** is the voltage measured in volts, **I** is measured in amperes, and **R** is measured in ohms.

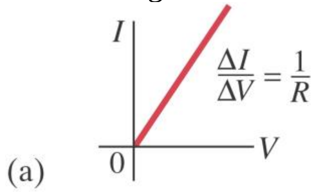


Fig. 7.0.1 (a) Ohm's law is satisfied for resistors.

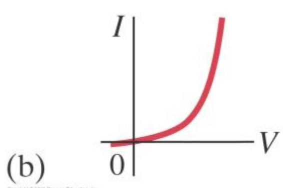


Fig. 7.0.1 (b) Ohm's law is **not** satisfied for Diodes

This is an important relationship for many electrical circuits. Resistors obey this law and are referred to as Ohmic. Not all electrical devices that have resistance follow this relationship. One example that doesn't follow this relationship are diodes. Those that do not follow this relationship are referred to as non-Ohmic.

In electrical circuits, it is frequently desirable to hook resistors up in various combinations. Those combinations are referred to as series and parallel. As resistors are hooked up in either of these combinations, the effective resistance of the circuit, $R_{T,}$ changes. One of the objectives of these activities is to explore that relationship. It is also important to know how to determine values of resistors in circuits using the standard color code. For example would you know how to determine the values of resistors seen in **Fig. 7.0.2**?

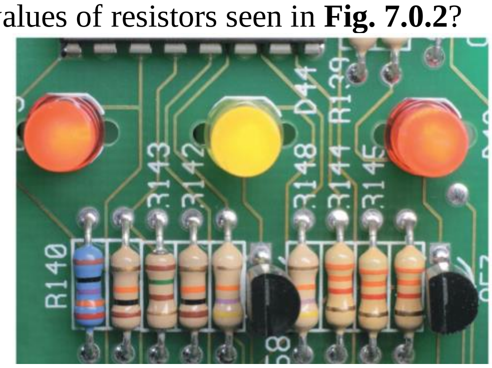


Fig. 7.0.2

Name____ Date_________________________

Activity 7 – 1: Recognition of parts and measurements of resistance.

Objective: The student will be able to recognize resistors and capacitors. The student will be able to determine the resistance of a resistor by reading a color code chart.

Materials:

- Bag of electrical components
- Multimeter (VOM) and leads

Procedure:

1. On a clean surface, open the bag of electrical components, and sort the components by their various shapes. We will be interested in separating the resistors and the capacitors in this activity. Later we will deal with the remaining components.

2. Resistors are shown in **Fig. 7.1.1** below. They will have 3-4 colored bands around them, or they may have none. If they have none, then the resistance will be printed on them. You will be determining the resistance of a resistor by reading the color bands. Capacitors are shown in **Fig. 7.1.2** and **Fig. 7.1.3**.

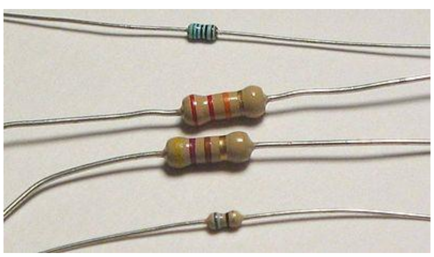


Fig. 7.1.1

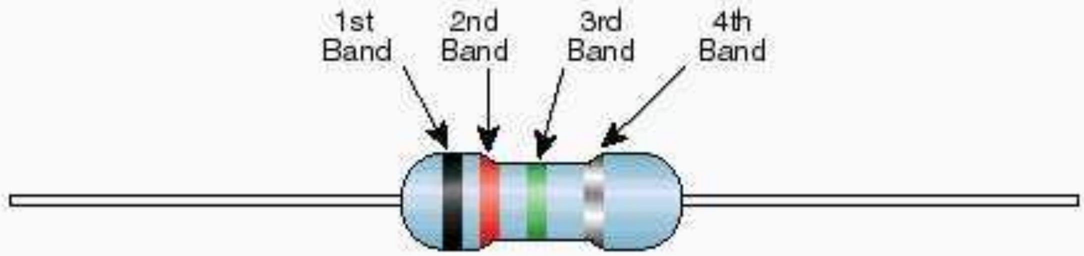
Fig. 7.1.2

Fig. 7.1.3

3. On the resistors, there are four colored bands, which are referred to as bands A, B, C, and D. There is a gap between bands C and D to help determine which way to read the bands. Band A is the first significant Fig. of the resistor. B is the second significant Fig. of the resistor, band C is the decimal multiplier, and band D is the tolerance or +/- of the resistor. The colors are associated to numbers using **Fig. 7.1.4**.

Name______________________________________ Date________________________

Standard EIA Color Code Table **4 Band:** ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Fig. 7.1.4

4. Select three of your resistors, and write down in **Table 7.1.1** the colors you see.

5. Look up the colors in **Fig. 7.1.4**. Convert the colors to the proper resistance value. Record the values in **Table 7.1.1**.

6. Use your VOM to check your value. Place the black lead in the ground plug of the VOM, and red lead in V/Ω plug. Set your VOM to the highest setting for resistance. Adjust your VOM settings, so that you can get the most number of significant digits. Record the values in **Table 7.1.1**.

7. Repeat steps 4 – 6 for your 3 resistors. Record the values in **Table 7.1.1**.

8. Calculate the percent error of the resistors. Record these values in **Table 7.1.1.**

$$Percent\ Error = \frac{|Color\ coded\ value - Measured\ Value|}{Measured\ \ Value} * 100\%$$

Name____ Date___________________________

Resistor	1st ring	2nd ring	3rd ring	4th ring	Color Coded Value with +/-	Measured Value	Percent Error
1 - color							
1 - value							
2 - color							
2 - value							
3 - color							
3 - value							

Table 7.1.1

9. Give a plausible reason why your measured value does not equal the manufacturer or color-coded values. ____

Name____ Date__________________________

Activity 7 – 2: Ohm's Law V = IR

Objective: Explore Ohm's Law

Materials:

- Breadboard
- Multimeter
- 150 Ω resistor
- 100 Ω resistors x3
- 33 Ω resistor
- Battery holder
- Alligator Wires
- Jumper wires
- D size battery (from home)

Procedure:

1. Locate the three 100 Ω resistors in the bag of electronics. Use your volt/ohm meter (VOM) to determine the exact value. Record the values of the three resistors here.

   ____

2. Use appropriate jump wires to make a simple circuit with your battery holder, one battery, and the 100Ω resistor in the breadboard. See the schematic in **Fig. 7.2.1** and the photo of the actual circuit in **Fig. 7.2.2**.

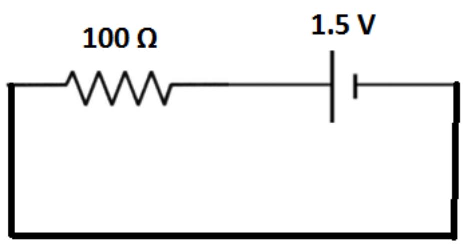


Fig. 7.2.1

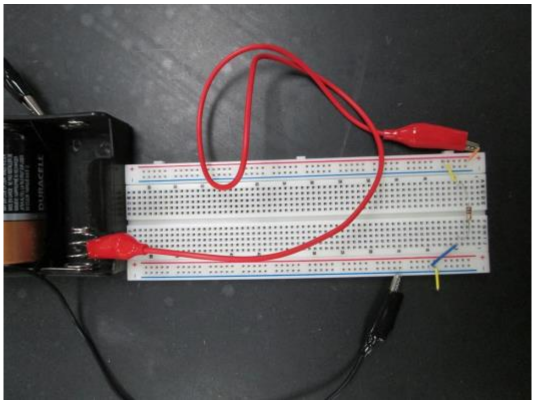


Fig. 7.2.2

3. We will now hook the volt/ohm meter (VOM) in the circuit. To measure voltage, the VOM must be hooked in parallel with the resistance. To measure current, the VOM must be hooked in series. See **Fig. 7.2.3** and **Fig. 7.2.4**.

Name______________________________________ Date________________________

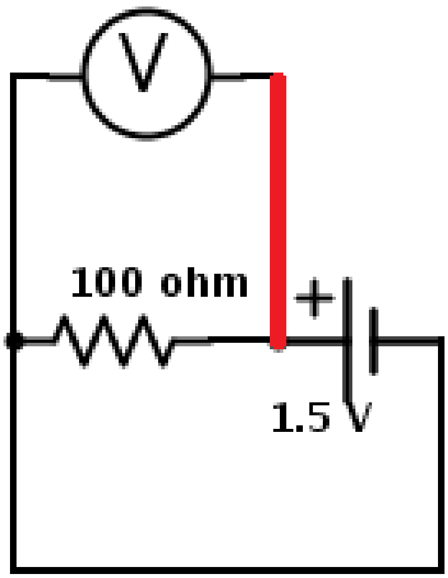


Fig. 7.2.3

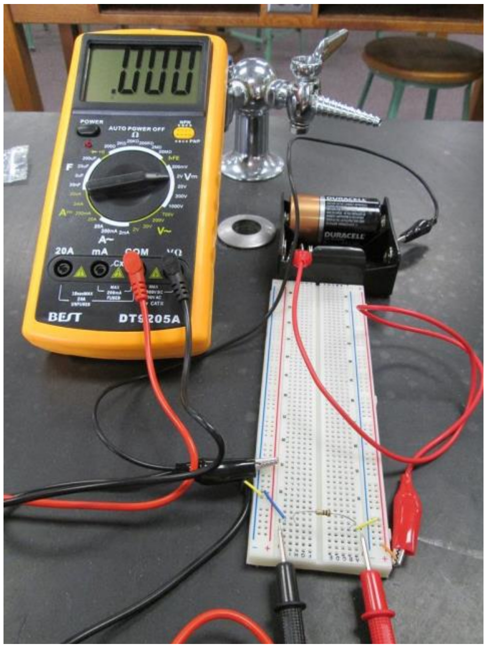


Fig. 7.2.4

4. We will now determine the voltage and the current in the circuit. Remember to start your VOM on the HIGHEST voltage/current scale when making measurements. Failure to do so may damage your VOM. Measure the voltage and the current in the circuit with the VOM. (To measure the current with the VOM see Fig. 7.3.3 as example of how to connect up VOM as ammeter (A) in series to measure current.) Record your values in volts and amps in **Table 7.2.1**. Pay attention to the units.

5. Now place two batteries in your circuit. We will hook another battery holder in series with the first battery holder. Record the voltage and the current in the circuit in Table 7.1.1. Then repeat with 3 batteries. Record the values in **Table 7.2.1**.

Number of Batteries in series	**Measured Voltage (V)**	**Measured Current (A)**	**Measured Resistance (Ω)**	**Calculated Voltage using Ohms Law V=I*R**
1				
2				
3				

Table 7.2.1

6. In the final column of Table 7.2.1, calculate the voltage by multiplying the measured Current (I) times your measured Resistance (R).

7. How does the calculated voltage from Ohms Law compare with the measured voltage?
____

Name____ Date__________________________

Activity 7 – 3: Series Combination of Resistors

Objective: The student will discover and explore Ohm's Law for series circuits.

Materials:

- Breadboard
- Multimeter
- 150 Ω resistor
- 100 Ω resistor
- 33 Ω resistor
- Battery holder
- Alligator Wires
- Jumper wires
- D size batteries x2 (from home)

Procedure:

1. Connect a 100-Ω resistor and a 150-Ω resistor in series and connect two batteries in series across the resistors as shown in see **Fig. 7.3.1**, and **Fig. 7.3.2**. (Note that the black alligator clip is not yet connected.) Measure the voltage drop across the two resistors. Record it in **Table 7.3.1**.

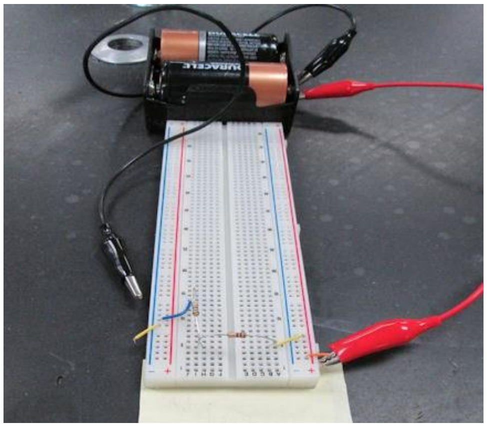


Fig. 7.3.1

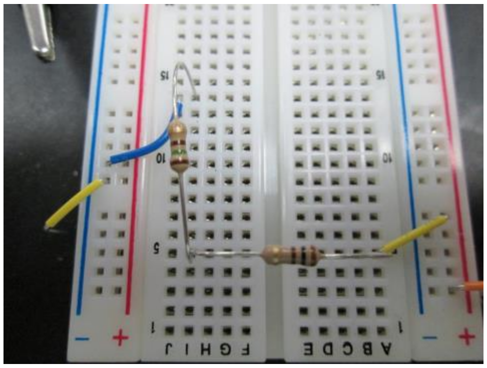


Fig.7.3.2

2. Measure the current between the battery and the 100-Ω resistor by connecting the VOM in series between the battery and the resistor. See **Fig. 7.3.3** Record your value here. ______________________________

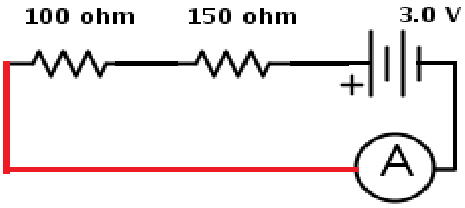


Fig. 7.3.3

Name____ Date__________________________

3. Use the VOM to measure the current between the 100Ω resistor and the 150Ω resistor. See **Fig 7.3.4**. Record your value here. ____

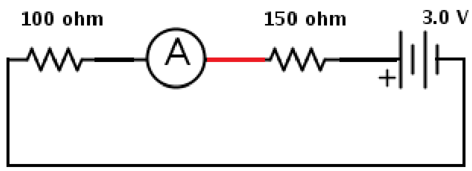


Fig. 7.3.4

4. Do the same in between the 150 Ω and the battery. See **Fig 7.3.5.** How did your current readings compare? ____

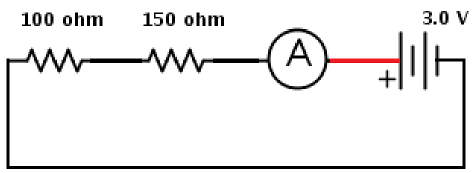


Fig. 7.3.5

5. Measure the resistance of your nominal 100 Ω and 150 Ω resistors individually. Then measure the total resistance when they are connected in in series. Record the values here.
____

6. We know $R_T = R_1 + R_2$, where R_T is the total resistance, and R_1 and R_2, are the individual resistors. Measure R_1 and R_2 with your multimeter. What is the expected R_T for the two resistors in series? ____

Number of Batteries in series	Measured Voltage (V)	Measured Current (A)	Measured Resistance (Ω)	Calculated Voltage Using Ohms Law V= I*R
2				

Table 7.3.1

7. In the final column of **Table 7.3.1**, fill in the calculated voltage. How does the calculated voltage compare to the measured Voltage? ____________________________________

8. Does the current in the circuit change or remain the same as you add more resistors in series? Explain.____

9. Does the voltage across the resistors change or remain the same as you add more resistors in series? Explain. ____

10. Calculate your percent error for the combination of resistors in series and record your values here. ____

Name____ Date_________________________

11. Comment on any differences between your values, and the theoretical values on how to combine resistors in series. ____

Name_______________________________________ Date________________________

Activity 7 – 4: Parallel Combination of Resistors

Objective: Explore Ohm's Law for resistors in parallel.

Materials:

- Breadboard
- Multimeter
- 150 Ω resistor
- 100 Ω resistor
- 33 Ω resistor
- Battery holders x2
- Alligator Wires
- Jumper Wires
- D size batteries x3 (from home)

Procedure:

1. Now make a circuit with a 100 Ω and a150 Ω resistor hooked in parallel, and one battery in your battery holder. See **Fig. 7.4.1** and **Fig. 7.4.2.** Measure the voltage across the resistors. Record the values in **Table 7.4.1**.

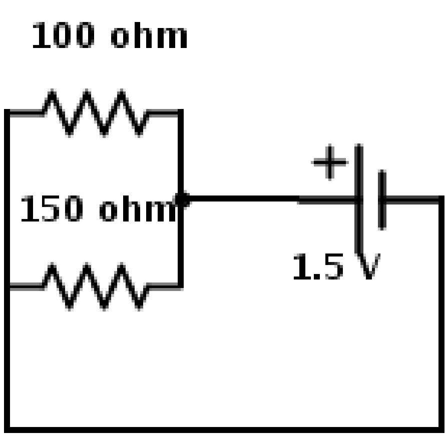


Fig. 7.4.1

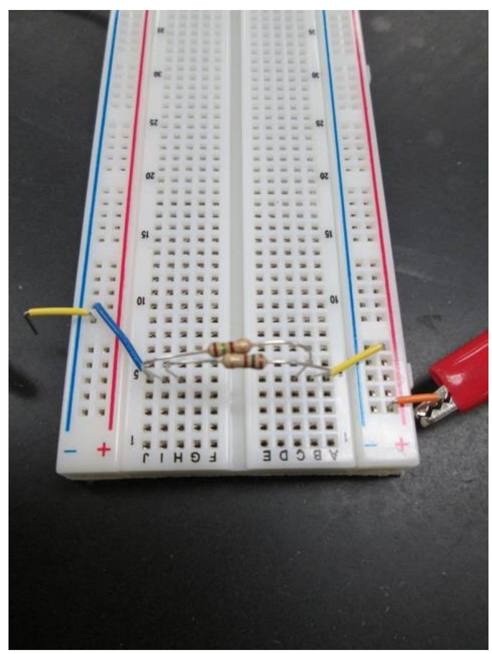


Fig. 7.4.2

1. Determine the current between the battery and your parallel combination. Record this value in **Table 7.4.1**.

2. With your VOM, determine the effective resistance of your two resistors in parallel. Record this value in **Table 7.4.1**.

Name____ Date__________________________

3. Replace the 150 Ω with the 33Ω resistor. Now you have made a circuit with the 100 Ω and the 33Ω resistors in parallel and one battery in your battery holder. Determine the voltage across the battery again. Record your values in **Table 7.4.1**.

4. Repeat steps 2-3. Record your values in **Table 7.4.1**.

Number of Batteries	**Measured Voltage (V)**	**Measured Current (A)**	**Measured Resistance (Ω)**	**Calculated Voltage Using Ohms Law I*R**
1				
1				

Table 7.4.1

5. How does the total resistance change as you added resistors in parallel? ____

6. Does the total current in the circuit change or remain the same as you add more resistors in parallel? Explain. ____

7. Does the voltage of the battery change as you add more resistors in parallel? __________

8. In the final column of **Table 7.4.1**, fill in the calculated voltage. How does the calculated voltage compare to the measured Voltage? ________________________________

9. You learned earlier, that resistors add in series. $R_T = R_1 + R_2$ Total resistance for resistors in parallel can also be determined by a mathematical formula, but it is slightly more complicated. Resistors in parallel add by the following formula $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$, where R_T is the total or effective resistance. Using the above formula, calculate R_T for the following two cases. ____

10. Calculate your percent error for each combination of resistors in parallel. Record your values below. Remember the percent error formula is: $Error = \frac{|your\ value - accepted\ value|}{accepted\ value} * 100\%$. ______________________________

11. What is the cause of the percent error in the results in step 11 and why is there a difference percentage wise? ____

Name____ Date___________________________

Lab 8
Kirchhoff's Laws

Overview:

Kirchhoff's circuit laws are two equations that are based on conservation of charge and energy in electrical circuits. Gustav Kirchhoff first described the laws in 1845. Widely used in electrical engineering, they are also called Kirchhoff's rules or simply Kirchhoff's laws.

Kirchhoff's First Law is the junction law: At a junction in an electrical circuit, the sum of currents flowing into that junction is equal to the sum of currents flowing out of that junction. For example in **Fig. 8.0.1**, $I = I_1 + I_2 + I_3$ at Junction A.

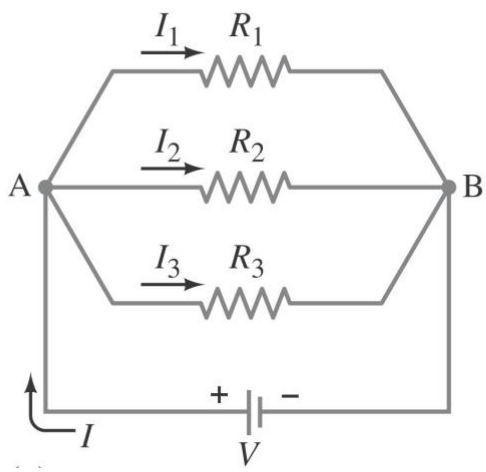


Fig. 8.0.1

Kirchhoff's Second Law is the loop law: The algebraic sum of voltage drops along any closed loop is equal to the sum of voltage supply. For example in **Fig. 8.0.2**, suppose all the voltages in the picture are positive values in loop 1, then $V_1 + V_4 + V_7 = V_B$ in loop 1; $(-V_4) + V_2 + V_5 + V_8 = 0$; etc. The straight arrows are the assumed direction of the current.

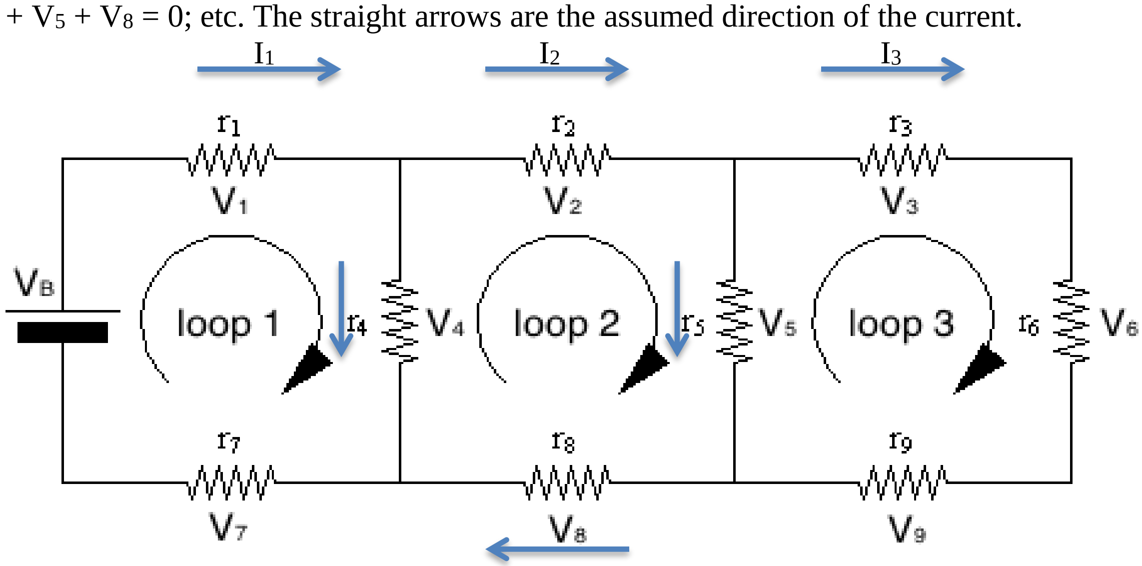


Fig. 8.0.2

Name____ Date_________________________

Note that the voltage drop across r_4 in loop 2 is opposite to that in loop 1. Generally, the voltage drop across a resistor is defined as positive if the current goes along the direction of the loop, and negative if the current goes against the direction of the loop. It becomes a voltage gain instead of a voltage drop. Of course, you are initially free to choose the loop direction and current direction anyway you like. If you end up calculating or measuring a negative current, then your assumed direction was incorrect.

Similarly, if a battery goes along the direction of the loop, as shown in **Fig. 8.0.3**, its voltage supply is defined as positive. Otherwise, its voltage supply is defined as negative, as shown in **Fig. 8.0.4**. The straight arrows below are the loop direction and not the current.

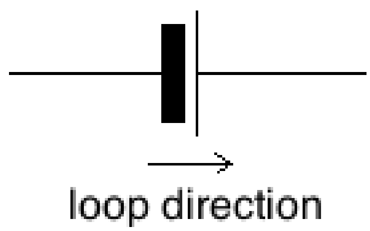


Fig. 8.0.3 Along loop direction, voltage supply >0

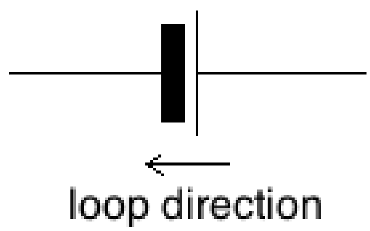


Fig. 8.0.4 Against loop direction, voltage supply < 0

Kirchhoff's laws can now be directly derived from Maxwell's equations. But Kirchhoff predated Maxwell and only had Ohm's Law to work with back in his days. Kirchhoff's laws are instrumental in the understanding of DC circuits. They generally do not apply, however, to AC circuits, which are in the regime of Maxwell's equations.

Name____ Date__________________________

Activity 8 – 1: Kirchhoff's Junction Law

Objective: Observe Kirchhoff's First Law – the sum of currents flowing into a junction is equal to the sum of currents flowing out of that junction.

Materials:

- 100 Ω resistor x2
- 33 Ω resistors x2
- Multimeter
- Breadboard
- Alligator Wires
- Jumper Wires
- Battery holder
- D size battery (from home)

Procedure:

1. Make a circuit on the breadboard according to **Fig. 8.1.1**.

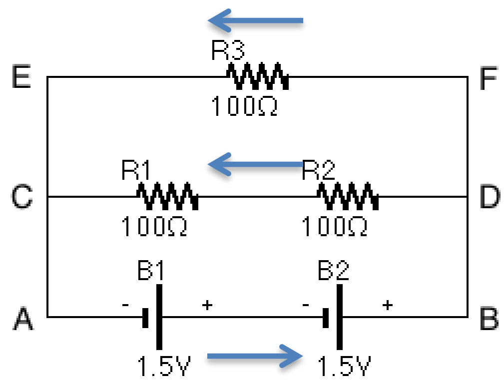


Fig. 8.1.1

2. In the above figure, for the sake of discussion, we call the current coming out of the batteries the total current. Explain where and how you hook the VOM to measure the total current.____

3. Measure the total current coming out of the batteries before it branches out into R1-R2 and R3. Record the value in **Table 8.1.1**.

4. We call the wire through R1 and R2 closer to the battery (between C and D) Branch 1, and the farther wire through R3 (between E and F) Branch 2. Measure the current in each branch. Record those values in **Table 8.1.1**. Then calculate the sum of the currents. The junction law states that at junction D the current from the batteries which is going into the junction is equal to the sum of the two currents leaving the junction.

Name_______________________________________ Date________________________

5. Make a new circuit according to **Fig. 8.1.2**. Repeat steps 3 and 4. Record the values of your measurement in **Table 8.1.1**.

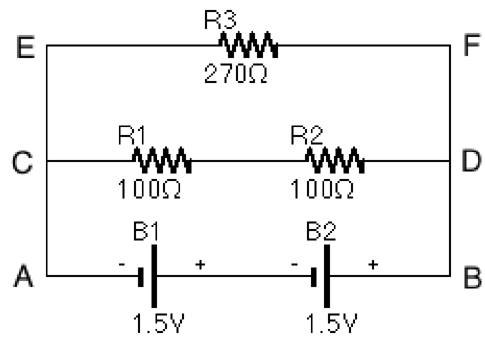


Fig. 8.1.2

6. Make a new circuit according to **Fig. 8.1.3**. Repeat steps 3 and 4. Record the values of your measurement in **Table 8.1.1**.

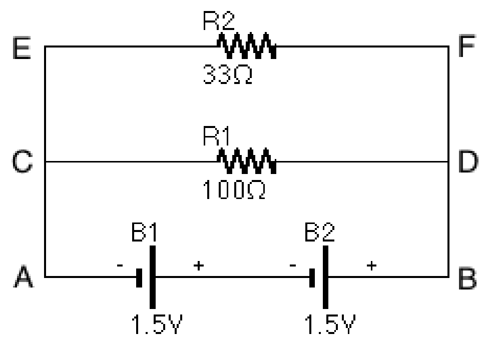


Fig. 8.1.3

Circuit Number	**Current Supplied by Battery**	**Current through Branch 1**	**Current through Branch 2**	**Sum of Measured Currents**
1				
2				
3				

Table 8.1.1

7. According to your results, how well does the junction law hold in terms of percentage error? How do you explain the discrepancy if there is any? ________________________

Name______________________________________ Date________________________

Activity 8-2 Kirchhoff's Loop Law

Objective: The student will explore Kirchhoff's Second Law – the sum of voltage supplied in a closed loop is equal to the sum of the voltage drops in that loop.

Materials:

- 100 Ω resistor x2
- 270 Ω resistor
- 33 Ω resistor
- Breadboard
- Multimeter
- Alligator Wires
- Jumper Wires
- Battery holders x2
- D size batteries x3 (from home)

Procedure:

1. Pick out three 100Ω resistors, one 150Ω resistor, and one 33Ω resistor from the bag of electronics. Use the multimeter to measure their resistances. What is the exact value of each resistor? Write them down here. _______________________________________

2. Assemble the circuit according to **Fig. 8.2.1**. The arrows are assumed direction of current flow.

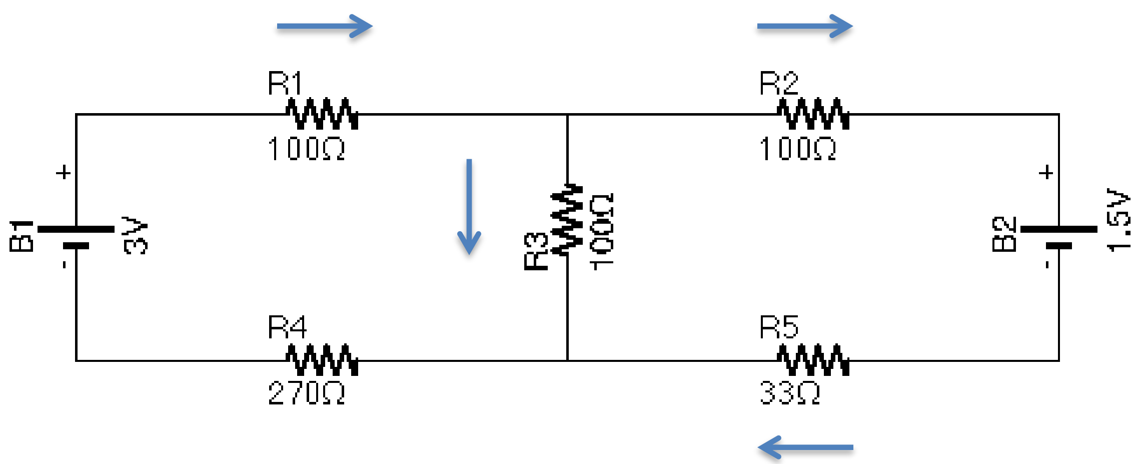


Fig. 8.2.1

3. Explain where and how you hook the VOM to measure voltage. ___________________

4. To determine the sign of the voltage drop, you will need to know the direction of current flow in each resistor. Describe how you can obtain that knowledge using the voltage scale of the multimeter so that you don't have to switch to current scale at all. ____

Name____ Date_________________________

5. Use your multimeter to measure the terminal voltages of B1 and B2. Record the values in **Table 8.2.1**.

6. Use your multimeter to measure the voltage drop (or gain) across each resistor taking note of the direction of current flow. Are the assumed direction of current flow correct? _________Explain. ____

7. Record the absolute voltages in **Table 8.2.1**.

	B1	**B2**	**R1**	**R2**	**R3**	**R4**	**R5**
Absolute Voltage (V)							

Table 8.2.1

8. Look at the loops in **Fig. 8.2.2**. Then use your data from **Table 8.2.1** to fill in **Table 8.2.2**, **Table 8.2.3**, and **Table 8.2.4**. Voltage drop is negative and voltage gain is positive.

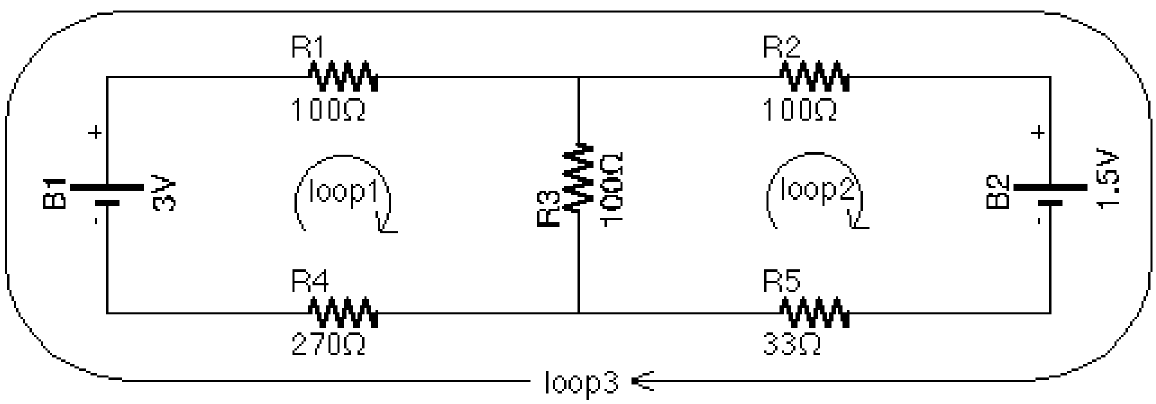


Fig. 8.2.2

Loop 1	**B1**	**R1**	**R3**	**R4**	**Sum**
Voltage Supply (V)					
Voltage Drop or Gain (V)					

Table 8.2.2

Loop 2	**B2**	**R5**	**R3**	**R2**	**Sum**
Voltage Supply (V)					
Voltage Drop or Gain(V)					

Table 8.2.3

Loop 3	**B1**	**R1**	**R2**	**B2**	**R4**	**B5**	**Sum**
Voltage Supply (V)							
Voltage Drop or Gain(V)							

Table 8.2.4

Name____ Date_________________________

8. According to your results, how well does the loop law hold in terms of percentage error? How do you explain the discrepancy if there is any? ______________________________

Name____ Date_________________________

Lab 9
Capacitors

Overview

We have been studying about electricity and various types of circuits. We have learned about resistors, and how resistors can be used in a circuit to control the flow of electricity. It is now time to begin to look at some of the other electrical components that are used in a circuit. The one that this lesson will be dealing about is capacitors.

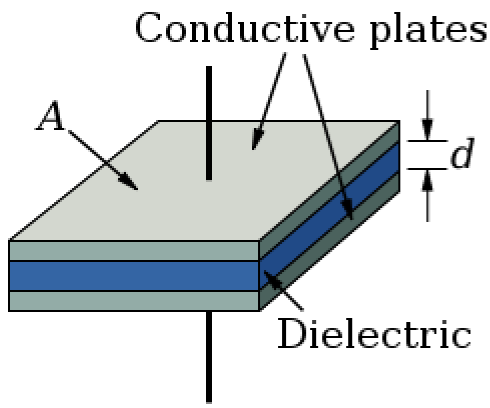


Fig. 9.0.1

A capacitor (originally known as condenser) is a passive two-terminal electrical component used to store energy in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors separated by a dielectric (insulator); for example, one common construction consists of metal foils separated by a thin layer of insulating film. Capacitors are widely used as parts of electrical circuits in many common electrical devices.

Capacitors are widely used in electronic circuits for blocking direct current while allowing alternating current to pass, in filter networks, for smoothing the output of power supplies, in the resonant circuits that tune radios to particular frequencies, in electric power transmission systems for stabilizing voltage and power flow, and for many other important purposes.

Capacitance is measured in farads, a unit named after the English scientist Michael Faraday. The capacitance of the majority of capacitors used in electrical devices is several orders of magnitude less than a farad. Typical units are microfarads (μF) and picofarads (pF).

Capacitance can be calculated if the geometry of the conductors and the dielectric properties of the insulator between the conductors are known. For example, the capacitance of a parallel-plate capacitor shown in **Fig. 9.0.1**, which consists of two parallel plates both of area A separated by a distance d is approximately, is equal to the following:

$$C = K\varepsilon_0 \frac{A}{d}$$

where

C is the capacitance;
A is the area of overlap of the two plates;
K is the dielectric constant of the material between the plates (for a vacuum, $K = 1$);
ε_0 is the permittivity of free space and has the value $\varepsilon_0 = 8.854\times10^{-12}$ F m^{-1} and
d is the separation between the plates.

Capacitance is proportional to the area of overlap and inversely proportional to the separation between conducting sheets. The closer the sheets are to each other, the greater the capacitance. The equation is a good approximation if d is small compared to the other dimensions of the plates so the field in the capacitor over most of its area is uniform, and the so-called *fringing field* around the periphery provides a small contribution.

The above equation can also be written as

$$C = \epsilon \frac{A}{d}$$

where $\varepsilon = K\varepsilon_0$ and ε is called the permittivity of the dielectric material.

The value of K of paper is affected by several different factors. Paper can be wood-based, rice-based or rag-based for example. Different inks and bleaching processes are used in its production as well as various surface finishes. Wood-based paper – presently the most common paper undergoes a drying process and chemical process with aging. Residual acids left on the surface from the manufacturing process cause the paper to yellow and become drier over time. In addition, paper is hygroscopic and the dryness of paper is very important for the value of the dielectric. For this reason, the value of the dielectric constant can vary from a value as low as 1.7 to as high as 4.0. [1]

[1] http://users.df.uba.ar/sgil/physics_paper_doc/papers_phys/e&m/dielectr_const_2k4.pdf

Name____ Date_________________________

Activity 9 – 1: How to Measure Capacitance

Objective: Measure the capacitance of a capacitor.

Materials:

- Multimeter
- Multimeter leads
- Breadboard
- 47 microfarad capacitor

Procedure:

1. Place a 47-microfarad capacitor into the breadboard as shown in **Fig. 9.1.1**.

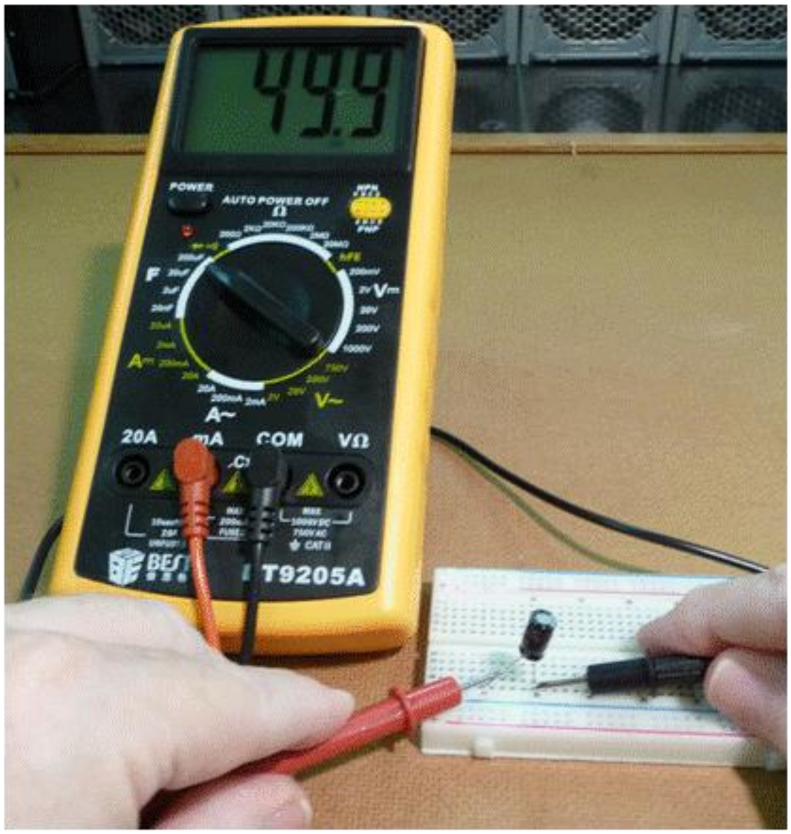


Fig. 9.1.1

2. Turn the multimeter on by pushing the POWER button. Turn the dial so that it points to 200 uF. The dial will be pointed 10 o'clock.

3. Insert the multimeter leads into the two middle openings at the bottom of the meter. Standard practice is to put the red lead into the left middle (mA) opening and the black lead into the COM opening next to (mA).

4. Touch the two probes to either leg of the capacitor. The red probe lead (+) should touch the long leg of the capacitor. The black probe lead should touch the short leg of the capacitor.

5. The schematic for this activity is shown in **Fig. 9.1.2**. Record the capacitance of the capacitor including appropriate units. Compare the measured capacitance with the nominal 47 microfarads of the capacitor. ____________________________________

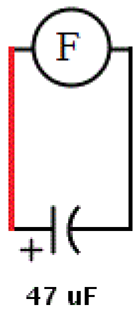


Fig. 9.1.2

6. Reverse the two probes. Touch the red probe to the short leg of the capacitor and the black probe to the long leg of the capacitor. Record the capacitance of the capacitor including appropriate units. Compare the measured capacitance with the nominal 47 microfarads of the capacitor. Does changing the probes change the magnitude of the capacitance? ____

Name______________________________________ Date________________________

Activity 9 – 2: Construction of a capacitor

Objective: We will learn how distance and area affect the ability of a capacitor to store energy.

Materials:

- VOM (digital multimeter) Meter with Capacitance Meter
- Wires to connect to VOM
- Fat textbook or thick phone book (from home)
- 2 sheets of aluminum foil (from home)
- Ruler with centimeter scale (from home)
- Graph paper or Computer Spreadsheet program (from home)
- Scissors (from home)

Procedure:

Part A

1. Cut out two sheets of 14cm x 14cm aluminum foil so that your sheets are the same size, and will just fit into your fat textbook.
2. With your ruler, measure the actual length and width of your sheets of aluminum foil. Record the values here. Then calculate the area of your sheets. ____
3. You need to determine the thickness of a sheet of paper in the book that you are using. With your ruler measure the thickness of your **all your** book pages. Do not include the thickness of the book covers. Record the thickness of the paper in the entire book, not including the covers. Then find out the number of pages there are. __________________
4. Determine the conversion factor for separation by dividing the thickness of the book in cm by the number of pages. Record the value here. ______________________________
5. Cut a small rectangular aluminum tab on each of your aluminum foil sheets. This is where you will connect a wire lead.
6. Place your aluminum foil sheets inside your fat textbook separated by 2 pages.
7. Place a heavy mass upon the top of the textbook. This will press the sheets of paper close together. This is **very important** for the success of the lab.
8. Carefully hook your VOM digital multimeter to the tabs on your aluminum foil sheets. Adjust your meter to determine the capacitance of your sheets of aluminum foil.
9. Record the # of pages in between and the capacitance in **Table 9.2.1.** ________________

Name____ Date_________________________

Separation # of pages	**Separation (cm)**	**Capacitance (F)**	**Dielectric Constant K**
2			
4			
8			
16			
32			
64			
128			

Table 9.1.1

10. Increase the distance between the aluminum foil by moving one of the sheets of aluminum foil to a later page in the book. Repeat steps 7 – 9 until you have a total of six data points.

11. Determine the **Separation (cm)**. To do this, multiply your **Separation # of pages** by your conversion factor determined in step 4.

12. Determine the values for your dielectric constant K and record them in **Table 9.2.1**. Note that you must convert cm to m in your equation to determine K.

13. Calculate the average value for your dielectric constant. Record your value here. ________

14. Compare your average dielectric constant value to the value for the dielectric constant for paper given in the **Overview**. ____

15. On your sheet of graph paper or in a spreadsheet, graph the capacitance vs. separation (cm). When you graph Capacitance vs. Separation (cm), the Capacitance is on the y-axis. Include a copy of your graph here.

16. Does your graph look like a linear relationship? Explain your answer. If so, determine the slope of the linear line and record the value here. ________________________________

Part B

17. Now we will determine if there is a relationship between area and capacitance. Separate the two 14cm x 14cm square sheets of aluminum foil by 16 sheets in the book. We will keep this separation distance constant, and vary the area of the aluminum foil sheets.

18. Place the heavy mass upon the book, and with your multimeter, measure the capacitance of the two sheets of aluminum foil. Remember that you are keeping the separation constant. Record your values in **Table 9.2.2.**

19. With your scissors, reduce the area of your aluminum sheets. Go from 14cm square to 10cm, 7cm, 5cm, 4cm, 3cm. It will work best if you reduce the area each time by cutting out a smaller rectangular region of each aluminum sheet. Measure the actual length and width of your sheets and record the values in **Table 9.2.2**.

Name____ Date_________________________

Length cm	**Width cm**	**Area cm^2**	**Capacitance (F)**	**Dielectric Constant K**

Table 9.2.2

20. Repeat steps 18 and 19 until you have a total of six data points.

21. Determine the values for your dielectric constant K and record them in **Table 9.2.2**.

22. Calculate the average value for your dielectric constant. Record your value here. ____

23. Compare your average dielectric constant value to the range of values for the dielectric constant for paper given in the Overview. ______________________________________

24. Make a graph of capacitance vs. area. Does this graph look like a linear relationship? If this graph does look like a linear relationship, use the linear fit function in Excel to, determine the slope of the graph. Record the slope here. What is the unit of the slope? ____

25. Include a copy of your graph here.

26. Summarize the relationship between capacitance, sheet separation distance, and the area of the sheets. ____

Name____ Date_________________________

Activity 9 – 3: Capacitors in parallel and series

Introduction:

Many capacitors are polarized. This means that one end of the capacitor is positive, and the other end of the capacitor is negative. Many capacitors are polarized to protect the central layer of the dielectric material that separates the plates. When a capacitor fails, it will heat up, possibly leading to a short circuit, or it may crack the case. In **Activity 1** we did not need to worry about this; now we do. One way that the manufacturers of the capacitors indicate polarity is to place a black stripe on the negative side of your capacitor. Another way to indicate the negative side of the capacitor is to make the negative lead wire shorter.

The formula for combining capacitors in parallel is $C_1 \| C_2 = C_1 + C_2$. The formula for combining capacitors in series is $C_1 \&\& C_2 = \frac{1}{C_1} + \frac{1}{C_2}$. (We use the || symbol for parallel combination, and the && symbol for series combination, following the convention in computer programming.) We will check our formula in the following experiments.

Objective: The student will explore the relationship between capacitors hooked in parallel and in series.

Materials:

- Bag of assorted electrical components
- Multimeter
- Breadboard
- Jumper Wires
- Scotch tape (from home)

Procedure:

Part A

1. From your bag of assorted electrical components, remove your capacitors. Capacitors may look like the one shown in **Fig. 9.3.1** or the one in **Fig. 9.3.2**.

Fig. 9.3.1

Fig. 9.3.2

2. Once you have sorted out your capacitors, and located the negative lead of your capacitor, hook them to your VOM with capacitance to measure the capacitance of your

capacitors. Record the values in **Table 9.3.1**. Label the capacitors with tape if needed so that you will be able to distinguish the capacitors. Label them C_1, C_2, etc. in **Table 9.3.1**. The manufacturer usually puts the value of the capacitance on the capacitor. Record the measured values and the manufacturer's values in **Table 9.3.1**.

Capacitor Label	**Capacitance (uF)**	**Manufacturer Value (uF)**

Table 9.3.1

3. Using your breadboard, select the two 47uF capacitors and hook them up in parallel. Be sure that you hook up the capacitors with the proper polarity. See **Fig. 9.3.3** for a schematic of the proper construction. Use your VOM to determine their combined capacitance. Record the value in **Table 9.3.2**.

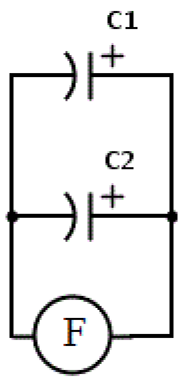


Fig. 9.3.3

Capacitor Combination (Example: 47.7 || 47.3)	**Measured Capacitance (uF)** (Example: 91.8)

Table 9.3.2

4. Repeat step 3 with i) 10uF and 10uF, ii) 47uF and 10uF, iii) a different 47uF and a different 10uF. Finally, select any three capacitors and repeat step 3. Record the combined capacitances in **Table 9.3.2**.

5. Generally, when you put capacitors in parallel, is the combined capacitance bigger or smaller than each of the original ones? Explain the reason why. (Hint: you can either do a mathematical proof, or just draw an analogy to increasing/decreasing the area of the parallel plates in a single capacitor.) ____

Name______________________________________ Date________________________

Part B

6. Now hook the two 47uF capacitors in series on your breadboard, and determine the equivalent capacitance. See **Fig. 9.3.4** for a schematic of the proper construction. Remember the to be sure the polarity of the capacitors is hooked up properly. This time that will mean that you will hook the positive of one capacitor to the negative of the other capacitor. Record your capacitor combinations and the measured capacitance in **Table 9.3.3**.

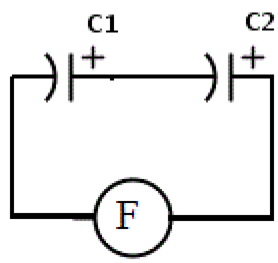


Fig. 9.3.4

Capacitor Combination (Example: 47.1 && 47.2)	**Measured Capacitance (uF)** (Example: 23.7)

Table 9.3.3

7. Repeat step 6 with i) 10uF and 10uF, ii) 47uF and 10uF, iii) a different 47uF and a different 10uF. Finally, select any three capacitors and repeat step 3. Record the combined capacitances in **Table 9.3.3**.

8. Generally, when you put capacitors in series, is the combined capacitance bigger or smaller than each of the original ones? Explain the reason why. (Hint: you can either do a mathematical proof, or just draw an analogy to increasing/decreasing the distance of separation between the parallel plates of a single capacitor.) ________________________

9. In **Table 9.3.4,** enter all the data you have gathered in this activity, and calculate percentage error for each data run. How do you account for the error?

Capacitor Combination	**Series/Parallel**	**Measured Capacitance (F)**	**Theoretical Capacitance (F)**	**Percent Error (%)**

Name____ Date___________________________

Table 9.3.4

Name____ Date_________________________

Activity 9 – 4: Analyzing an RC* Circuit

*** RC** stands for resistor-capacitor, not remote control.

Objective: To observe charging and discharging of a capacitor when you hook a resistor and capacitor in series.

Materials:

- 1 kΩ Resistor
- 100 kΩ Resistor
- Red LED
- 47µF Capacitor
- 220µF Capacitor
- Breadboard
- Wire leads
- VOM multi-meter
- 9 volt battery (from home)
- Computer Spreadsheet (from home)
- Stopwatch (from home)

Procedure:

1. On your breadboard, wire the 1kΩ resistor or larger and the 47µF capacitor in series with the LED. The LED has a positive side and a negative side. It the two legs are of different length, the longer leg is the positive side and the shorter one is the negative side. Some LED's have the legs the same length. In this case look inside the LED and you will find two triangular pieces of metal. One of these triangular pieces of metal will be smaller than the other. The smaller of the two pieces is the positive side of the LED and the larger of the two will be the negative side of the LED. You will hook the negative side of the LED to the positive side of the capacitor. See **Fig. 9.4.1**

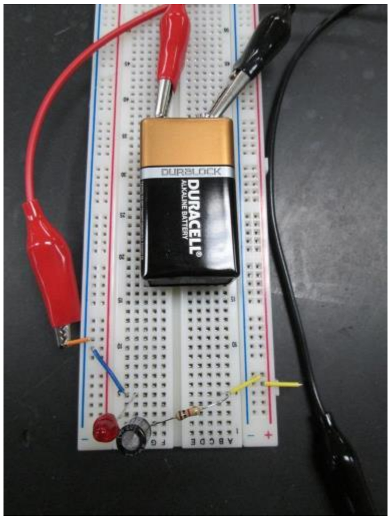


Fig. 9.4.1

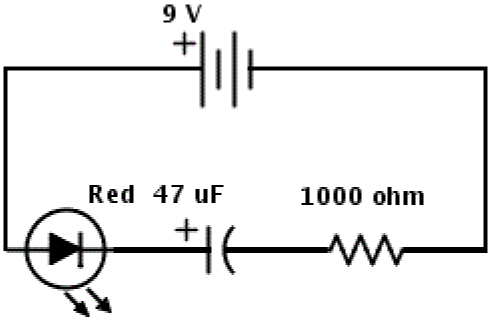


Fig. 9.4.2

2. Hook the positive side of the LED to the positive side of 9-volt battery, and the negative side of your battery to the resistor. See **Fig. 9.4.1**. Submit a photo of your circuit.

3. Describe what happens to the LED in your circuit. ______________________________

4. Remove the battery from the circuit, and insert a short jumper wire where the battery was. See **Fig. 9.4.3**.

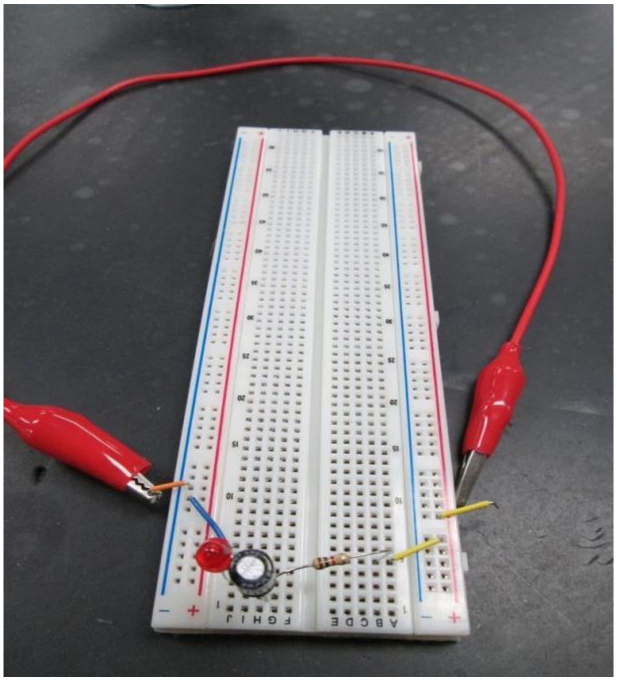


Fig. 9.4.3

5. This would normally allow the capacitor to discharge, but since the LED will only allow current to flow in one direction, this will not happen. Switch the direction of the LED. Describe what happens now. Where does the energy come from to light the LED after the battery is removed? ____

6. Based upon what we have just observed, we see that the current flow through this circuit is reduced very quickly over time. We can change this time by increasing the resistance or capacitance. Use a short piece of wire and short out any charge that remains on the capacitor before you make any new measurements. Replace the 1-kΩ resistor, with a 100-kΩ and add an ammeter in series in the circuit in between the resistor and capacitor. Use the 20-ma or 2-ma scale on the meter. Connect up the battery to the circuit and the LED as in step 1 and watch the current decrease. Disconnect the battery, reverse the LED and replace the battery with a short jumper wire and include the ammeter in the circuit. Describe the brightness of the LED. ________________________________

7. Now replace the 47 uf capacitor with the 220 uF capacitor. Remove the LED from the circuit. Connect up the 100–kΩ resistor and battery to the circuit as in step 1. Watch the current decrease as the capacitor charges up. Disconnect the battery and replace the battery with a short jumper wire. The current will slowly decrease. With your ammeter

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and a stopwatch measure the current every 2 seconds. Record the time and current values in **Table 9.4.1**.

Time (sec)	**Current (milliamps)**
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	
22	
24	
26	
28	
30	
32	
34	
36	
38	
40	
42	
44	
46	
48	
50	
52	
54	
56	
58	
60	
62	
64	
66	
68	
70	
72	
74	
76	
78	
80	

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82	
84	
86	
88	
90	

Table 9.4.1

8. From the data in the **Table 9.4.1** estimate the time it took for the current to reduce to ½ of its original value at t=0. Record the time here. Also measure the resistance R.

    ____

9. The theoretical time it takes the current to reduce to half of its original value is given by t = 0.69 x R x C, using SI units. Since the multimeter cannot measure over 200uF, we will use the manufacture's value, so C = 220uF. What is the theoretical time for your circuit? ____

10. Plot a graph of current vs. time using Excel. Include a graph here.

11. Comment on the agreement or disagreement between your value and the theoretical value. ____

Name____ Date_________________________

Lab 10
Magnetism

Overview

Young people are fascinated with magnets, largely because magnets act at a distance. You can put your hand between a magnet and a steel paper clip and move the paper clip. A neurosurgeon can guide a pellet through brain tissue to an inoperable tumor, or implant electrodes while doing little harm to brain tissue.

The term *magnetism* comes from the name Magnesia, a costal district of ancient Thessaly, Greece, where unusual stones were found by the Greeks more than 2000 years ago. These stones, called lodestones, had the property of attracting iron. The Chinese were the first to use magnets that were fashioned into compasses and use them in navigation.[1]

In the 16th century, William Gilbert, Queen Elizabeth's physician, made artificial magnets by rubbing pieces of iron against lodestone, and he suggested that a compass always points north and south because Earth has magnetic properties.

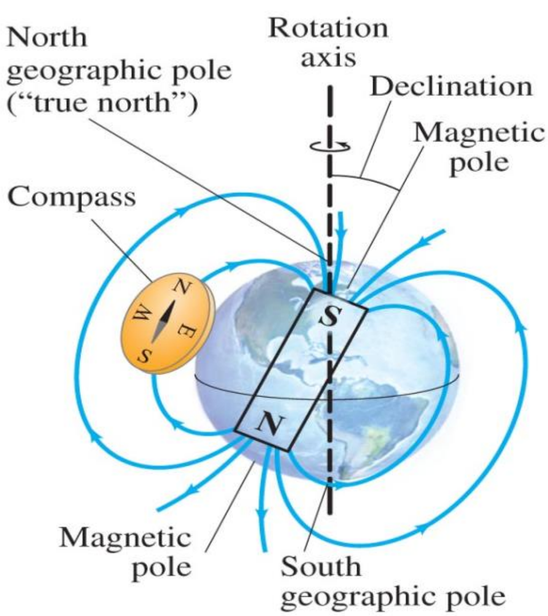

Fig.10.0.1

In Fig. **10.0.1** the magnetic field of the Earth resembles that of a bar magnet with the South magnetic pole in the Northern hemisphere and the North magnetic pole in the Southern hemisphere. A compass aligned as is shown have its North pole arrow pointing towards the South magnetic pole which is what we normally call North. You will have the opportunity in Lab to use a compass to map out the magnetic field of a bar magnet

In 1750 John Michell, an English physicist and astronomer, found that magnetic poles obey the inverse-square law, and his results were confirmed by Charles Coulomb. The subjects of magnetism and electricity developed almost independently of each other until 1820, when a Danish physicist named Hans Christian Oersted discovered, in a classroom demonstration, that an electric current affects a magnetic compass. He saw confirming evidence that magnetism was related to electricity. Shortly thereafter, the French physicist André Marie Ampere proposed that electric currents are sources of all magnetic phenomena.

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A permanent magnet is a magnet that does not lose its magnetic field. However, what makes a magnet permanent? In order to understand this we need to know how magnets work. Magnetism is an aspect of the phenomenon known as the electromagnetic force a fundamental force of the physical universe. Magnetism, like its other aspect electricity, manifests itself as a field. What makes a magnet is when certain substances and elements are induced with a strong magnetic field. In the case of permanent magnets this field remains over time without weakening.

A permanent magnet is a magnet because of the orientation of its domains. Domains are the small magnetic field inherent in the crystalline structure of ferromagnetic materials. It is believed that the magnetism comes from the spinning electrons in the atom. Since electrons are charged this corresponds to a current flowing in a wire which we know produces a magnetic field.. Ferromagnetic materials are the only substances capable of being made into magnets; they are normally iron, nickel, cobalt, or alloys that are made of rare-earth metals. A magnet is created when certain condition cause separate domains in a ferromagnetic item to be all aligned in the same direction. However the method used in most cases can make only weak magnets. The normal method is normally by either direct contact with a naturally magnetic material or by running an electric current through it. However in the case of a field produced by rubbing it against a strong magnet is too weak and will fade over time as the domains return to their original positions.

[1] http://faculty.piercecollege.edu/kocharan/classes/Fundamentals%20Physics%20-%2012/Lectures/24_Lecture_Magnetism.pdf

Name____ Date_________________________

Activity 10 – 1: Properties of Magnetism

Objective: The student will learn some of the characteristics of magnetism

Materials:

- 4-1 inch, 3 inch, 6 inch iron bar magnets
- 2 - Large Neodymium magnets, 2- small Neodymium magnets
- Compass
- Plastic battery holders
- Aluminum foil – minimum size is 4" x 6" (from home)
- Steel paper clip (from home)
- Plastic ruler (from home)
- Wood block – minimum size is 4" x 6" x ¾"
- Steel sewing needle or a steel straight pin (from home)
- Plastic cups (from home)

Procedure:

PART A – Iron bar magnet

1. Take one of your bar magnets and observe what happens when you touch a variety of objects with the North pole of the bar magnet. Record your observations in **Table 10.1.1.**

Material	Attraction/repulsion/no effect
Plastic battery holders	
Block of wood	
Aluminum foil	
South pole of bar magnet	
North pole of bar magnet	
Steel paper clip	

Table 10.1.1

2. Why are some materials attracted or repelled while others are unaffected? Summarize the results you observed.____

3. Now let us test to see if the magnetic field penetrates different materials. Complete **Table 10.1.2**. Determine if magnetic field will travel through the substance. Place your compass so that the compass is lined up with magnetic north. See **Fig. 10.1.1**.

4. Place your material that you are checking up close to the magnet. Place your iron bar magnet on the opposite side of the material that you are checking, and move the iron bar magnet around. See **Fig. 10.1.2** and **Fig. 10.1.3**. Determine if the magnetic field is present on the other side of your material. The compass North arrow would point towards the N arrow if the object shielded the magnetic field. If the object doesn't shield the bar magnet, the compass North pole will point away from the North pole of the bar magnet. Record your observation in **Table 10.1.2**.

Name____ Date__________________________

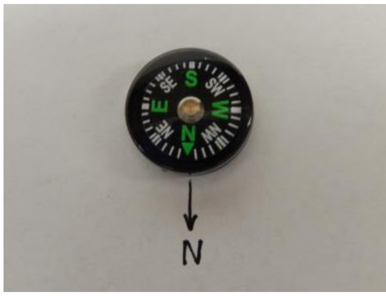

Fig. 10.1.1

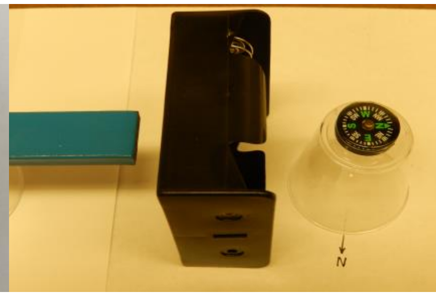

Fig. 10.1.2

Fig. 10.1.3

Material	**Does magnetism travel through material?**
Aluminum foil	
Plastic battery holder	
Block of wood	
Paper cup full of water	
Faraday cage	

Table 10.1.2

5. Record where the North-seeking end of the compass points to on the bar magnet. This is called the South Pole of the magnet. The opposite end of the magnet is referred to as the North Pole of your magnet. Label bar magnet poles N and S if not already labeled.

6. Explain what is meant by the North and South Pole of magnet.______________________

PART B – Neodymium Magnets

7. Carefully put your two-neodymium magnets together if they are not already. Repeat step 5 to determine the North Pole and the South Pole of your neodymium magnets. Label the North Pole of both magnets.

8. Summarize your conclusions about how the poles interact with another pole.__________

9. Is it possible to get an isolated North Pole and an isolated South Pole by braking a magnet in half? Explain why.

   ____

PART C – Floating a Bar Magnet

10. This is a simple and clean way to make a compass and get a feeling for the sensitivity of magnetic forces. The magnetic field due to the earth in this room is about 0.5 Gauss. The magnetic field due to your bar magnets is about 100 to 1000 Gauss. The largest magnetic field recorded in the Laboratory without destroying the equipment is about 1 Million Gauss. Now take your 1-inch smallest bar magnet and place it lengthwise so it lies along the bottom of your small plastic cup. Place the cup with the magnet in a bowl of water with enough depth so the cup floats in the water. Watch the cup slowly rotate until it stops. In what direction does the North-South poles of the bar magnet align when it comes to rest? Explain.____

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PART D – Making a Magnet (Optional)

11. Take a sewing needle and carefully scratch the pointed end of the needle along the North pole face of a strong magnet with the body of needle aligned with magnetic field lines. Scratch the needle 15 – 25 times in this manner. Take care to be sure that you are stroking and scratching the needle in the same direction. Be careful that you do not stick yourself with the needle during this procedure.

12. Determine if your needle is now magnetic by using it as a compass indicator. One ancient Chinese method of floating a magnetic needle is to stick the needle in a cork and float the cork in a bowl of water. It will rotate to align with Earth's magnetic field. A second method is to simply float a dry needle on water relying on surface tension to keep it afloat. In the latter method you must hold the needle and gently lower it into the water by using your fingers or tweezers to lower it just above the surface and then let it go. You may have to try this several times to get it to work.

13. After allowing the needle to float on the surface of the water for a short period of time, compare the orientation of the needle with the compass. Where does the pointed end of the needlepoint?
    Explain____

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Activity 10 – 2: Magnetic Field

Objective: The student will observe and map the magnetic field of a magnet. See **Fig. 10.2.1** for an example.

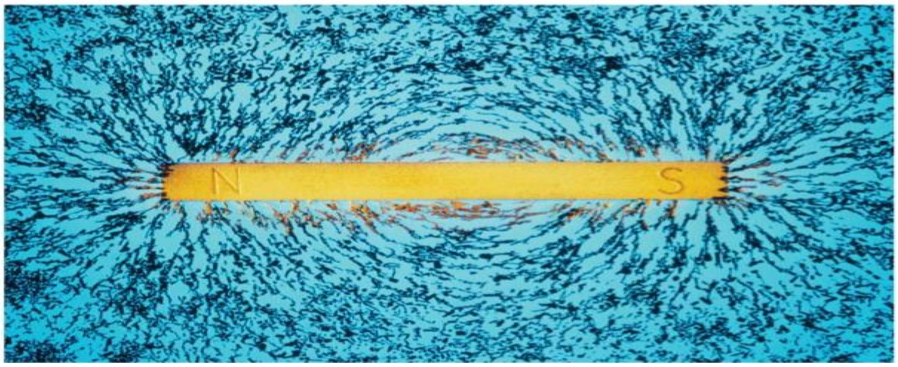

Fig. 10.2.1

Materials:

- Iron bar magnet
- Compass
- Scotch tape (from home)
- Sheet of paper (from home)

Procedure:

1. Place your sheet of paper on a table in which there is no magnetic material around or under the desk. Draw a 2 cm grid on the paper. From the previous activity you have determined materials that are nonmagnetic. Make sure there is nothing inside your desk producing a magnetic field.

2. Using your compass determine geographic north. Keep your compass away from your bar magnet while doing this. Next place the bar magnet as shown in **Fig 10.2.2** on the sheet of paper. Orient your sheet of paper so that the earths magnetic field is along the bar magnet. Make sure your paper has just as many squares at the ends than on the sides. The figure below does not show enough squares at the ends.

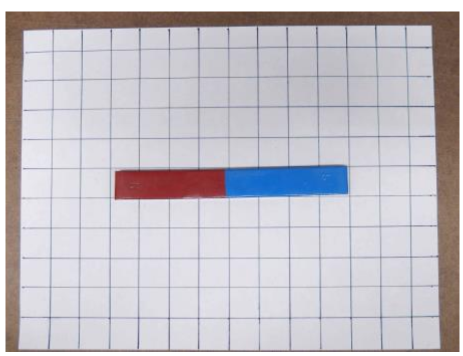

Fig. 10.2.2

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3. Draw an outline of the magnet. **Be sure the magnet is in this location at all times.** You may wish to use a little scotch tape to securely fasten the magnet down in this location. Use a pencil to mark the location of the magnet in case it moves.

4. Place the small compass over an intersection of the grid as shown in **Fig 10.2.3.** Draw a short line with a pencil under the compass pointing from S to N with an arrow at N

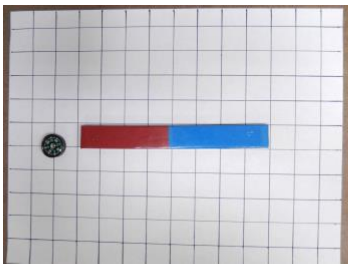

Fig. 10.2.3

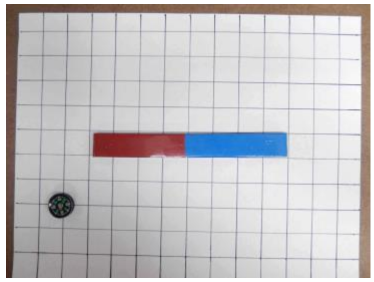

Fig. 10.2.4

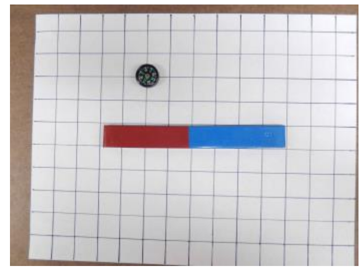

Fig. 10.2.5

5. Now move the compass to another intersection, such as the one in **Fig. 10.2.4, Fig10.2.5**. Repeat steps 4 and 5 until you have covered every intersection on the grid.

6. On the paper, mark the north pole of the magnet. Mark the location of the south pole of the magnet. How do you know which pole is which?______________________________

7. These lines that you have drawn are examples of magnetic lines of force. They indicate the strength and orientation of the magnetic field. Based upon your diagram, where is the magnetic field strongest? How do you know it is the strongest at the ends?____________

8. Where is the magnetic field weakest?____

9. Where is the magnetic field most uniform?_____________________________________

10. Is the magnetic field the same on top as on the bottom? Explain.____________________

11. Submit a copy of your diagram with your lab report.

Name_____________________________________ Date_______________________

Activity 10 – 3: Strength of the Magnetic Field around the Magnet

Objective: Learn how the strength of the magnetic field with varies with distance

Materials:

- Computer with internet access (from home)
- Sheet of graph paper (from home)

Procedure:

1. We will be using the computer to perform this activity. Go to the web site http://phet.colorado.edu/ and choose to search for magnetism. We will be using the simulation **Magnet and Compass**,(http://phet.colorado.edu/en/simulation/magnet-and-compass). Choose the **Run** now and then **Open** option, or **Download** option.

2. You will see a screen that looks like **Fig. 10.3.1**.

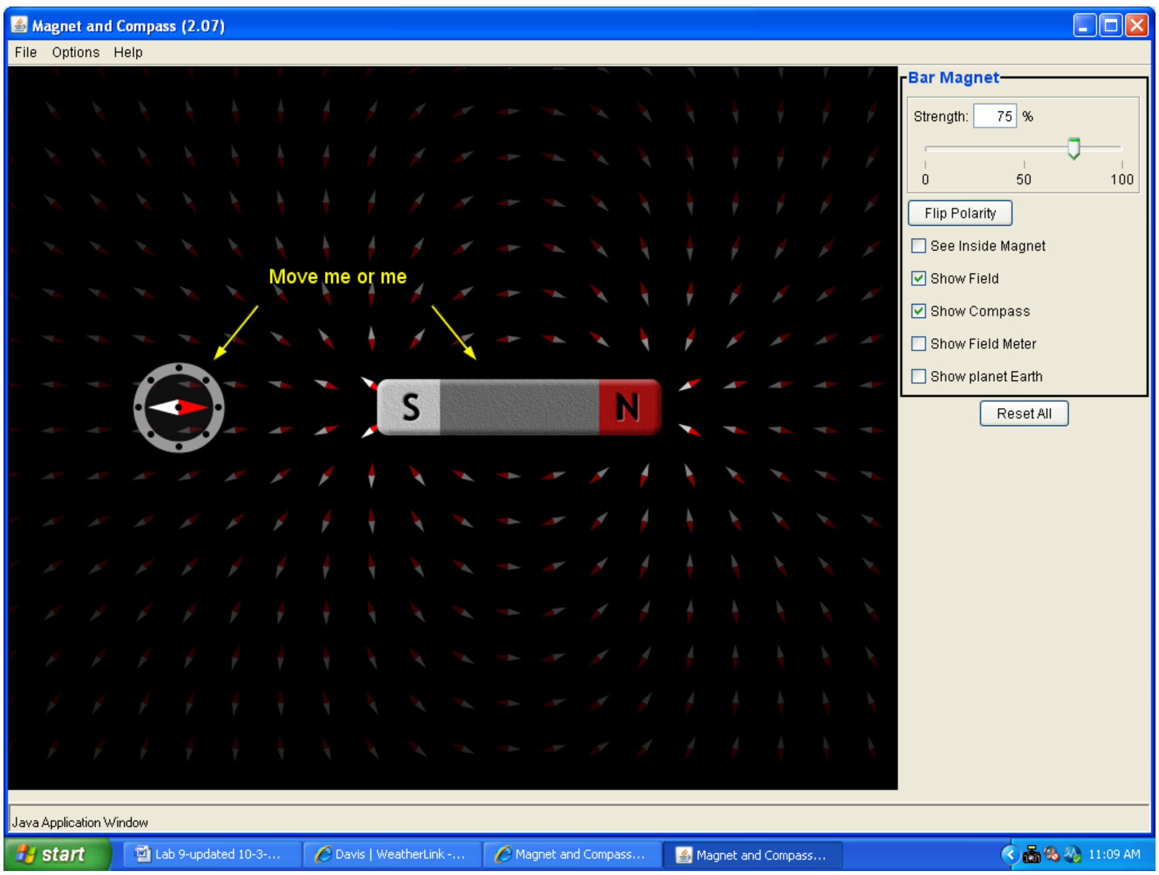

Fig. 10.3.1

3. Change the **Strength** of the magnet to be **50%**, unclick the **Compass Option**, and click the **Show Field Meter**.

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4. Move the magnetic B field meter to the end of the magnet labeled **S**, and we will be making readings from the **S** end of the magnet, and off the N end of the magnet. Your screen should look approximate like **Fig. 10.3.2.**

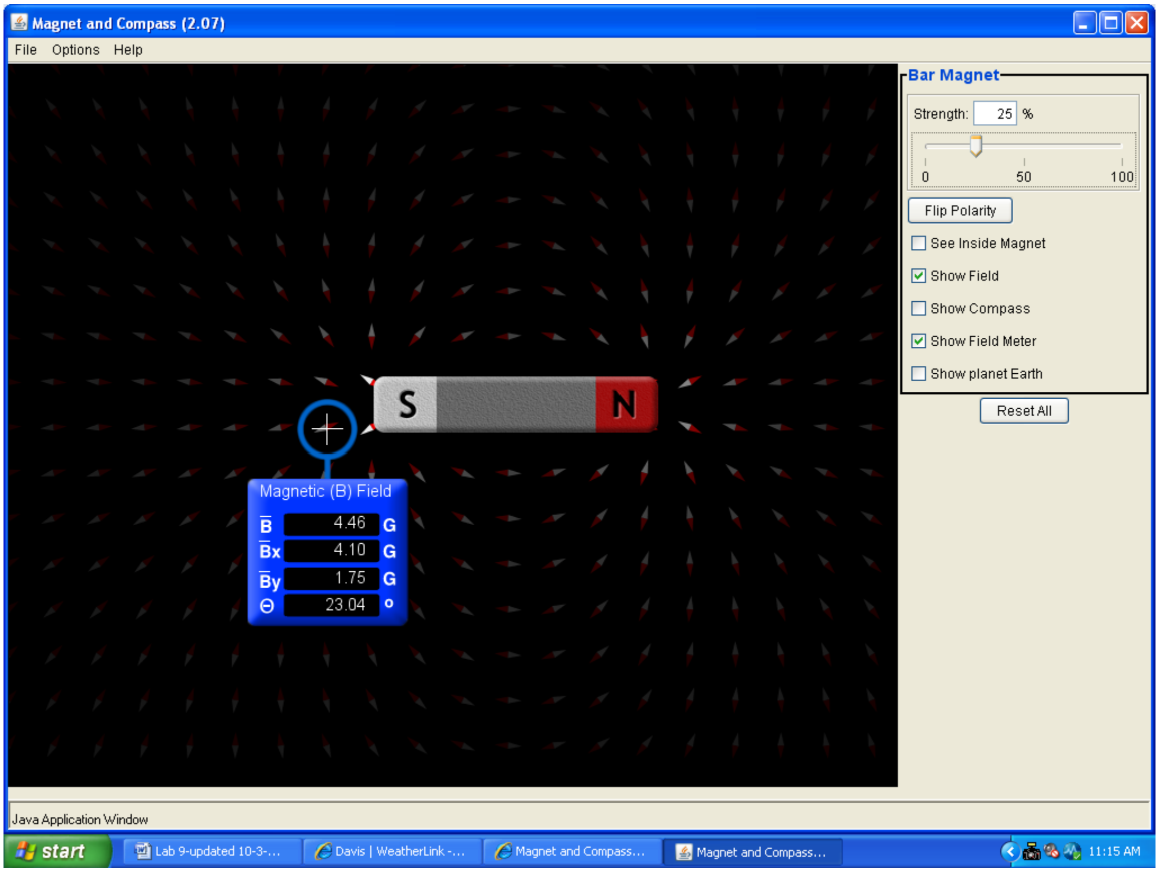

Fig. 10.3.2

5. Move the Magnetic B Field meter to the approximate center of one of the miniature compass indicators and observe the value of B. At this setting the B=4.46 Gauss and the x component is 4.10 Gauss and the y component is 1.75 Gauss. And θ is the angle in degrees between the x component and the horizontal. Record the value of B, and x which is the distance from the end of the magnet, in **Table 10.3.1**. As we have no units for the distance, we will make the distance x represent the number of compass indicators from the end of the magnet (1, 2, 3 etc.). The compass indicators actually form a grid as in the previous activity.

6. Record the value of the number of compass indicators x and B in **Table 10.3.1.**

7. Move your Magnetic (B) Field meter the next compass indicator horizontally away from the bar magnet. Record the values in **Table 10.3.1.**

8. Repeat step 7 for 7 more distances away from the magnet, along the same horizontal line.

9. Move the meter back to the original position and move it vertically downward away from the bar magnet and record the magnitude of B and y in **Table 10.3.1** for 7 distances.

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S Pole		**S Pole**		**N Pole**	
x	**B**	**y**	**B**	**x**	**B**

Table 10.3.1

10. Write an observation about how the magnitude **B** changed as you increased the distance **x**. Specifically, did the **B** values increase, decrease or remain the same when the distance increased.____

11. Write an observation about how the magnitude **B** changed as you increased the distance **y**. Specifically, did the **B** values increase, decrease or remain the same when the distance increased.____

12. Move your magnetic B field meter to the **N** end of the magnet and observe what happens as you move the magnetic B field meter horizontally away from the magnet. Record the values in Table **10.3.1.** Comment on how the magnitude of B and direction remained the same or changed at this end of the magnet compared to the other end of the magnet.____________________________

Name____ Date_________________________

Lab 11
Oersted and Ampere

Overview

One of the earliest pioneers in electrical and magnetic theory was Hans Christian Oersted, a Danish physicist and chemist. In 1820 he observed that a wire carrying an electrical current deflected a compass needle. Others had made similar observations, but Oersted systematically showed that the magnetic field circled the wire in a direction that depended on the direction of the electrical current in the wire. This magnetic field was an example of the **Right Hand Rule**, as shown in **Fig. 11.0.1.** (Diagram from http://hyperphysics.phy-astr.gsu.edu)

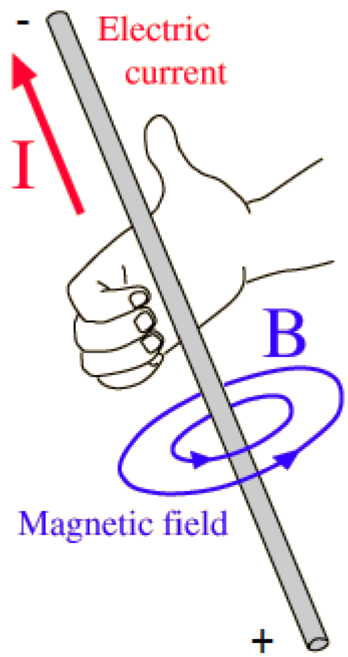

Fig. 11.0.1

The nominal current flows from the positive terminal to the negative terminal through the circuit. If you place the thumb of your right hand on the wire pointed in the direction of the nominal current, then your fingers curl around the wire in the direction of the magnetic (B) field.

Oersted's original discovery was reproduced and extended by Andre-Marie Ampere. Just two months after Oersted's initial discovery, Ampere provided an initial mathematical framework for the magnetic field in the form of Ampere's Law. When his law is applied to a wire with a constant current (one that does not vary with time), the result is

$$B = \frac{\mu_0 I}{2\pi R}$$

Where B is the magnetic field (unit: Tesla), I is the electrical current in the wire (unit: Ampere), R is the distance from the wire to the point where the field is being measured (unit: meters), and μ_0 is a constant, the magnetic permeability of a vacuum, defined as $4\pi*10^{-7}$ T*m/A. The magnetic field circles around the wire and shown and decreases in strength as you move away from the wire.

If we use the strength of the Earth's magnetic field (51.6 μT in Charlottesville, Virginia) as a benchmark, the magnetic field of a 20-Amp household current (AC) is comparable to the benchmark when you are only a hand's breadth away from the current-carrying wire.

Name____ Date_________________________

Activity 11 – 1: Oersted's Experiment

Objective: Observe the behavior of a magnetic compass in the presence of an electrical current.

Materials:

- Compass*
- Alligator Wires
- 1.5-Volt cell (from home)
- Wooden shims x2 (Popsicle sticks or very thin dowel rods or coffee stirrers, from home)
- Duct Tape or scotch tape (from home)

* The compass in the kit that you use for these activities is shown below in **Fig. 11.1.1.** It is a different than the one used in most of the photos shown later as examples of the activities in the Lab. You will be using a smaller compass but it works just as well. Your coils of wire will be slightly smaller.

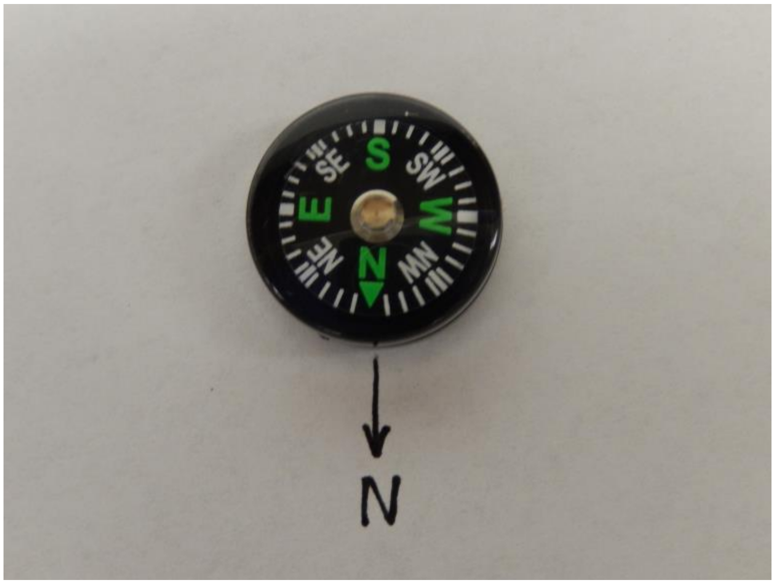

Fig. 11.1.1

Procedure:

1. Place the compass flat on a surface with no nearby sources of electricity or magnetism. Place the 1.5V cell in a battery holder.

2. Place the electrical wire across the top of the compass so that the wire crosses the center of the compass and the taped section makes a 45° angle clockwise from the north end of the compass. It may be necessary to use some duct tape to secure the wire across the face of the compass. See **Fig. 11.1.2.** Describe the movement (or lack) of the compass needle in the presence of the wire. Why does it move, or why not? ________________________
____

Name______________________________________ Date________________________

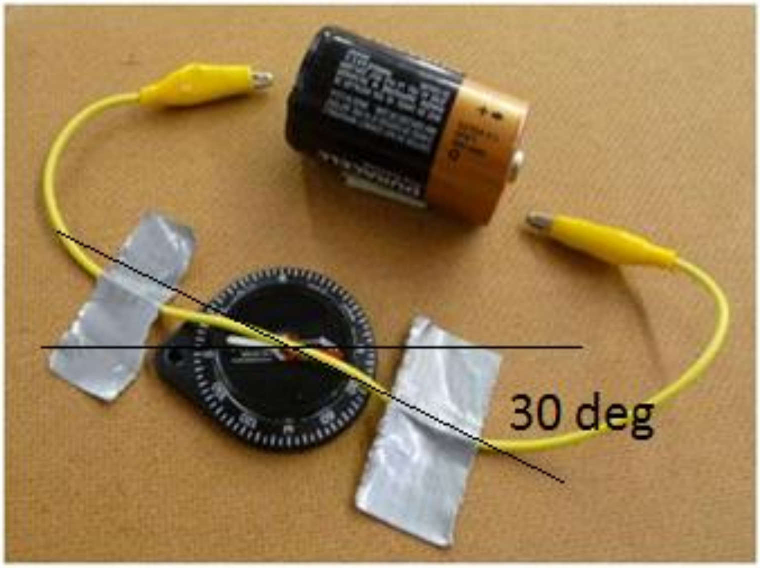

Fig. 11.1.2

3. Connect the end of the wire closer to the south end of the compass to the negative terminal of the 1.5-Volt cell. Briefly (!) connect the other end of the wire to the positive terminal of the 1.5-Volt cell. Describe the direction that the compass needle deflects in the space provided. Compare the direction with the direction of the magnetic field predicted by the Right Hand Rule. **(!) Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the wire. This will also drain the cell rapidly. Do not keep the wire connected to the cell for too long. It will only take less than 3 seconds to see the deflection.** ____________
____

4. Switch the direction of the current: connect the end of the wire closer to the south end of the compass to the positive terminal of the 1.5-Volt cell. Briefly (!) connect the other end of the wire to the negative terminal of the 1.5-Volt cell. Describe the direction that the compass needle deflects and comment on the relationship between the direction of the current in the wire and deflection. Compare the direction with the direction of the magnetic field predicted by the Right Hand Rule. ______________________________

Name____ Date_________________________

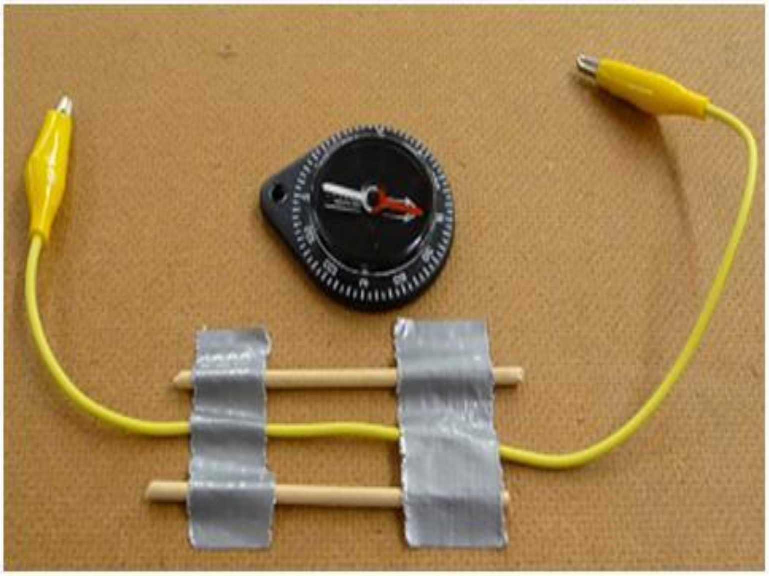

Fig. 11.1.3

5. Maintain the direction of the taped section of wire. Remove the compass from underneath the wire. Place one shim on each side of the wire, and put the compass on top of the two shims. The taped section of wire should make a 45° angle clockwise from the north end of the compass. Connect the end of the wire near the south end of the compass to the negative terminal of the 1.5-Volt cell. Briefly (!) connect the other end of the wire to the positive terminal of the 1.5-Volt cell. Describe the direction that the compass needle deflects in the space provided. Compare it to the direction that the compass needle deflected in #3. Compare the direction with the direction of the magnetic field predicted by the Right Hand Rule. ____

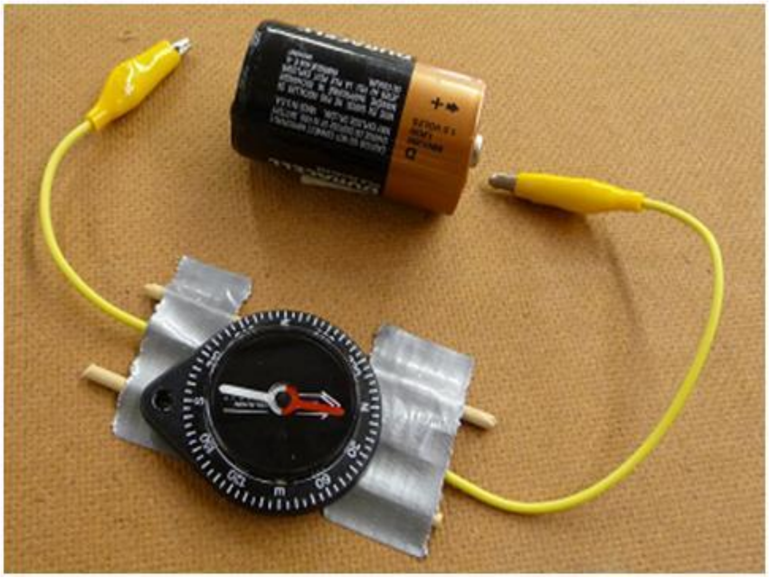

Fig. 11.1.4

6. Switch the direction of the current: connect the end of the wire closer to the south end of the compass to the positive terminal of the 1.5-Volt cell. Briefly (!) connect the other end

of the wire to the negative terminal of the 1.5-Volt cell. Describe the direction that the compass needle deflects in the space provided. Comment on the relationship between the direction of the current in the wire and deflection. Compare the direction with the direction of the magnetic field predicted by the Right Hand Rule. Compare this result to result #4. ____

7. Wrap the wire around the compass tightly to form a loop that starts at the center on the backside of the compass, loops around through the center on the front side, and loops back through the center on the backside again. Then rotate the compass until the loop forms a 45° angle clockwise from the north end of the compass needle. Tape the wire on the table and use one hand to hold down the wire against the compass, as well as making sure the compass stays level. Use the other hand to clamp the end of the wire closer to the south end of the compass to the negative terminal of the battery holder. Briefly (!) touch the positive terminal with the other end of the wire. Describe the direction that the compass needle deflects in the space provided. Comment on the relationship between the direction of the current in the wire and deflection. Since a wire that runs across the top of the compass deflects the compass one way and a wire that runs under the bottom of the compass deflects the compass the other way, shouldn't the two fields cancel out? Provide a brief explanation in support of your answer. ___________________________________
____

Fig. 11.1.5

Name____ Date________________________

Activity 11 – 2: Solenoid

Objective: Observe the behavior of a magnetic compass in the presence of an electrical current in a coil of wire.

Materials:

- Compass
- Enameled Wire 1.0 m (26 gauge enamel-covered copper wire)
- Iron rod
- 1.5-Volt cell (from home)
- Pencil (from home)
- Duct tape (from home)

Write your observations and answer questions for each of the following:

1. Place the compass flat on a surface with no nearby sources of electricity or magnetism. Turn compass until the red end of the pointer is pointed 0°. Note that the compass in **Fig. 11.2.1** is different from the one in the class kit, but that shouldn't matter. Describe the direction that the compass needle points in the space provided. ____________________
____

Fig. 11.2.1

2. Remove the enamel from the ends of the 1.0 m of magnet wire by scraping with a flat blade like a knife or box-cutter. (Alternatively, you can scour the enamel off with steel wool). Wrap the magnet wire tightly around the iron rod approximately thirty times to produce a coil or solenoid. Take the iron rod out of the coil. Place the coil so that one end is at the 90° heading on the compass. Connect one end of the coil to the positive terminal of the 1.5-Volt cell. Briefly (!) connect the other end of the coil to the negative terminal of the 1.5-Volt cell. **(!) Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the**

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wire. This will also drain the cell rapidly. Do not keep the wire connected to the cell for too long. It will only take less than 3 seconds to see the deflection. Describe the direction that the compass needle points in the space provided. _____________________

____

3. Without moving the coil, turn the 1.5-volt cell around and connect the other end of the coil to the positive terminal of the 1.5-Volt cell. Briefly (!) connect the first end of the coil to the negative terminal of the 1.5-Volt cell. Describe the direction that the compass needle points in the space provided. How do you predict the direction of the magnetic field generated by the current in the coil? ____________________________________

____

4. Place the iron rod in the middle of the coil. Repeat steps #2 and #3. Note that in **Fig. 11.2.2**, an iron nail is used instead of an iron rod, but that shouldn't matter. Describe the direction that the compass needle points in the space provided. Comment on whether the magnetic field is stronger or weaker with the iron nail in the coil. How do you tell? _____

____

Fig. 11.2.2

Name____ Date_________________________

Activity 11 – 3: Wire Swing

Objective: Observe the behavior of a wire with an electrical current in the presence of a magnetic field.

Materials:

- Neodymium magnet
- Alligator Wires
- Enameled Wire 0.3 m (26 gauge enamel-covered copper wire)
- Skinny Wooden Rod / Coffee Stirrer
- Battery holder
- 1.5-Volt cell (from home)

Procedure:

1. Strip the enamel from both ends of the magnet wire for 5cm on each end. Bend the wire in the shape of U. Then bend the ends of the wire outward. The bent part should be completely free of enamal. See **Fig. 11.3.1**.

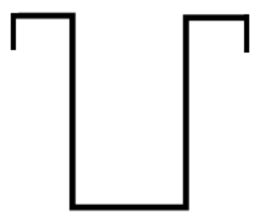

Fig. 11.3.1

2. Clamp the two wires onto the wooden coffee stirrer. See **Fig. 11.3.2**. Their separation should match the width of the U-shaped wire you made in step 1. Hook each end of the wire onto the exposed metal part of each alligator clamp. The wire should swing freely.

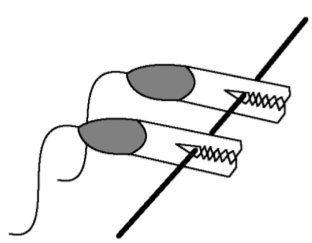

Fig. 11.3.2

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3. Fix the coffee stirrer onto the class kit as is indicated in the picture. Place the neodymium magnet under the wire swing so that one pole is facing up. Prop the magnet with some books so that the bottom of the wire swing just clears the magnet. See **Fig. 11.3.3**.

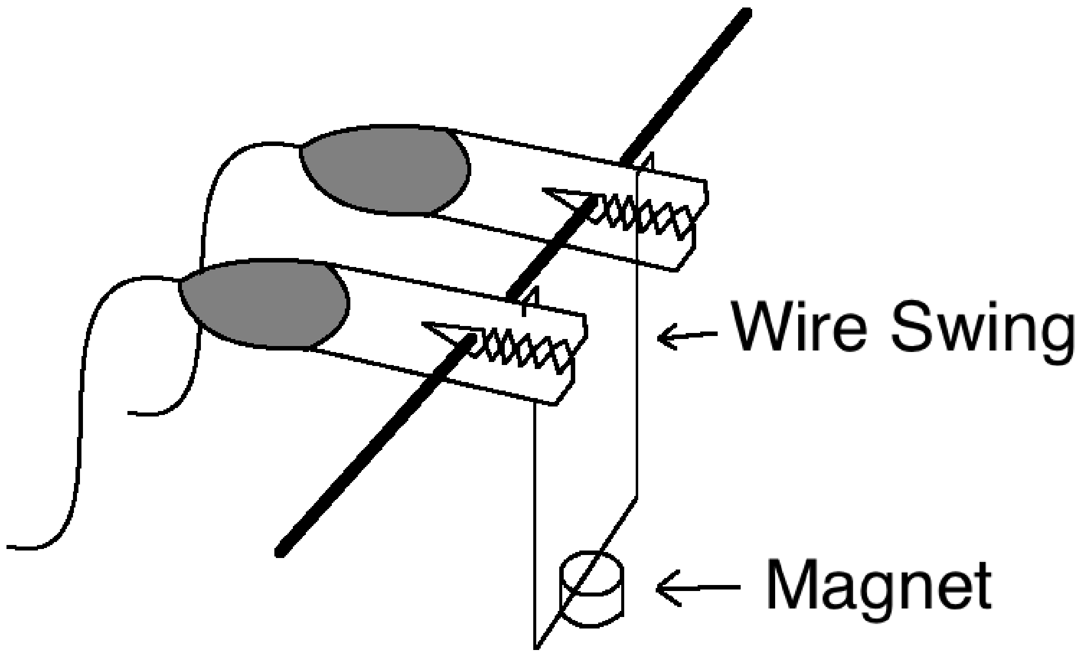

Fig. 11.3.3

4. Place the D-size battery in the battery holder. Clamp one wire to the negative end of the battery. Let's call it A and the other wire B.

5. Briefly (!) connect wire B to the positive terminal of the 1.5-Volt cell. **(!) Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the wire. This will also drain the cell rapidly. Do not keep the wire connected to the cell for too long. It will only take less than 3 seconds to see the deflection.** Describe the direction that the wire swing moves in the space provided. Note the direction of the force on the swing in relation to the direction of the current and the direction of the magnetic field. ___________________________________
____

6. Reverse the direction of current flow by swapping the leads connected to the battery. In what direction does the swing move? Comment on why the direction has changed. _____
____

7. Flip the magnet over. Connect wire A to the negative terminal of the 1.5-Volt cell. Briefly (!) connect wire B to the positive terminal. In what direction does the swing

Name____ Date_________________________

move? Comment on why the direction has changed. ______________________________
____

8. Reverse the direction of current flow by swapping the leads connected to the battery. In what direction does the swing move? Comment on why the direction has changed. _____
____

Name_______________________________________ Date________________________

Lab 12
Electromagnetism

Overview

Ampere's law for an isolated wire suggested that if the wire were looped, then the magnetic field would be strengthened inside the loop. As the diagram (all images are from http://hyperphysics.phy-astr.gsu.edu) to the left shows, each portion of the wire has a magnetic field that points to right inside the loop and to the left outside the loop. The next step was to continue the loop in the form of a helix. Each successive loop of the helix reinforced the field in the interior of the coil. The result is called a solenoid.

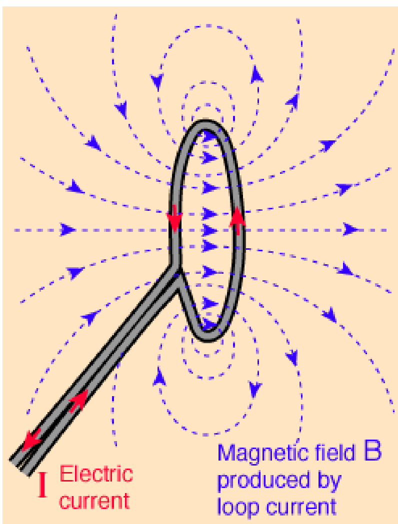

Fig. 12.0.1

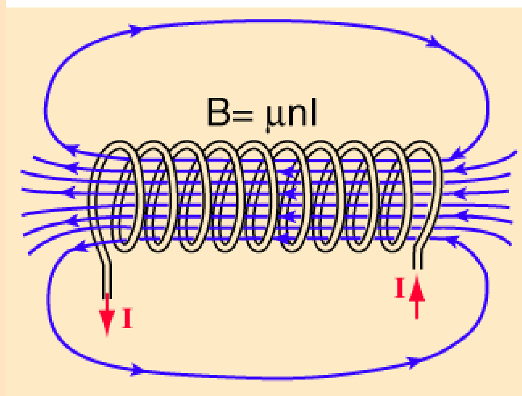

Fig. 12.0.2

The strength of the magnet field inside the coil of wire depends on the number coils per unit length (n) and the current (I) through wire where μ_0 is a constant, the magnetic permeability of a vacuum, defined as $4\pi*10^{-7}$ T*m/A.

$$B = \mu_0 n I$$

The solenoid can become an electromagnet by inserting a piece of soft iron inside the coil. Or, as will happen in this lab, wrapping wire around piece of soft iron. When the electric current produces a magnetic field, the magnetic domains of the iron tend to line up with induced magnetic field. This amplifies the overall magnetic field. Instead of μ_0, the magnetic permeability of a vacuum, the electromagnet uses the magnetic permeability of iron that is approximately 200 times μ_0.

The magnetic permeability of soft iron is small compared to the magnetic permeability of other materials such as permalloy (8,000) and mumetal (20,000), not to mention the newer rare earth magnets.

Name____ Date_________________________

Activity 12 – 1: Semi-quantitative Paperclip Pickup Experiment I

Objective: Investigate the effect of changing the voltage (current) on the strength of an electromagnet.

Materials:

- Alligator Wires
- Iron rod (7.5 cm long and 0.95 cm in diameter)
- Enameled Wire 3.0 m (26 gauge enamel-covered copper wire)
- 1.5-Volt cells x3 (from home)
- Steel wool or a blade to scrape the ends of the enameled wire (from home)
- Transparent adhesive tape (from home)
- Small paper plates or bowls x2 (to hold paperclips, from home)
- About 100 Paper clips (from home)

Fig. 12.1.1

Procedure:

1. Wrap the wire around the iron rod and secure it with transparent tape. Leave at least 10 cm of wire free for connection to the cell(s). Scrape the end of the wire so that the copper is exposed with steel wool. Alternatively, a scalpel or knife blade may be use under appropriate guidance.

2. Place ~100 paper clips on a paper plate. Connect one alligator clamp lead to each end of the electromagnet wire. You may try connecting the ends of the electromagnet directly to the cells but the connection may be erratic and intermittent depending on how well the ends were cleaned of enamel.

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Fig. 12.1.2

3. Place the end of the electromagnet directly over and touching the pile of paper clips. Connect the leads, picking up a number of paper clips. Transfer the magnetically attracted paper clips to the other plate and disconnect the leads. Count the number of paper clips transferred and enter your data in **Table 12.1.1**. Do this for a total of 3 trials.

# of cells	Trial 1	Trial 2	Trial 3	Average
One cell				
Two cells				
Three cells				

Table 12.1.1

4. Add a second 1.5 V cell in series with the first cell. Since the resistance of the electromagnet will not significantly change, the current through the electromagnet should be twice the current through the electromagnet with just one cell, assuming that the cells have the same voltage. Repeat the experiment of transferring paper clips for 2 more trials. Enter your data in **Table 12.1.1**.

5. Add a third 1.5 V cell in series with the first and second cell. Since the resistance of the electromagnet will not significantly change, the current through the electromagnet should be three times the current through the electromagnet with just one cell, assuming that the cells have the same voltage. Repeat the experiment of transferring paper clips for 2 more trials. Enter your data in **Table 12.1.1**.

6. Determine the average number of paper clips transferred. Graph the average number of paper clips (y-axis) versus the number of cells (x-axis).

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7. Use Excel to plot the average number of paper clips picked up vs. the number of cells used. Include your graph here.

8. Does your graph support the solenoid equation, $B = \mu_0 n I$? Explain why or why not. ___
____

Name____ Date_________________________

Activity 12 – 2: Semi-quantitative Paperclip Pickup Experiment II

Objective: Investigate the effect of changing the number of coils on the strength of an electromagnet.

Materials:

- Alligator Wires
- Iron rod (7.5 cm long and 0.95 cm in diameter)
- Enameled Wire 3.0 m (26 gauge enamel-covered copper wire)
- 1.5-Volt cells x3 (from home)
- Steel wool or a blade to scrape the ends of the magnet wire (from home)
- Transparent adhesive tape (from home)
- Small paper plates or bowls x2 (to hold paperclips, from home)
- About 100 Paper clips (from home)

Procedure:

1. Use the electromagnet that was prepared for the previous exercise. There should be approximately 90 turns of magnet wire around the iron core. See **Fig. 12.2.1**.

Fig. 12.2.1

2. Place ~100 paper clips on a paper plate. Connect one alligator clamp lead to each end of the electromagnet wire. You may try connecting the ends of the electromagnet directly to the 3 cells but the connection may be erratic and intermittent depending on how well the ends were cleaned of enamel.

3. Place the end of the electromagnet directly over and touching the pile of paper clips. Connect the leads, picking up a number of paper clips. Transfer the magnetically

attracted paper clips to the other plate and disconnect the leads. Count the number of paper clips transferred and enter your data in **Table 12.2.1**. Do this for a total of 3 trials.

# of turns	Trial 1	Trial 2	Trial 3	Average
90 turns				
80 turns				
70 turns				
60 turns				
50 turns				

Table 12.2.1

4. Remove 10 turns of wire from the electromagnet by unraveling the wire from the iron rod. The unwrapped wire will just hang loose from the rod. Repeat the step above capturing paper clips and counting them for five new trials. Since the length of the wire has not changed, the current through the wire should remain the same. Repeat the experiment of transferring paper clips for 2 more trials. Enter your data in **Table 12.2.1**.

5. Remove an additional 10 turns of wire and repeat the paper clip pickup. Continue the process for two more sets of trials. Repeat the experiment of transferring paper clips for 2 more trials. Enter your data in **Table 12.2.1**.

6. Use Excel to plot the average number of paper clips picked up vs. the number of cells used. Include your graph here.

7. Does your graph support the solenoid equation, $B = \mu_0 nI$? Explain why or why not. ___
____

Name____ Date_________________________

Activity 12 – 3: Simple loudspeaker

Introduction:

A simple loudspeaker consists of a magnetic, a coil of wire, and a membrane that can vibrate back and forth to produce sound. See **Fig. 12.3.1**. A solenoid (coil) will produce a magnetic field that will attract another magnet when the current flows one way and will repel the same magnet when the current flows the other way. If a flexible membrane is attached to the coil (or in the lab, then the magnet) then the membrane will move back and forth with the changes in the current. If the current changes are rapid enough, the membrane will produce sounds audible to the human ear.

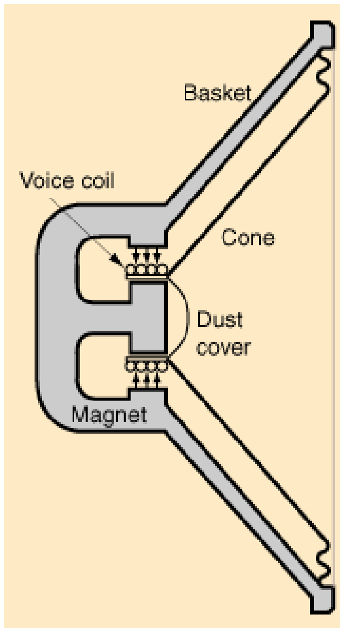

Fig. 12.3.1

Objective: Build a simple loudspeaker from magnets and a coil of wire.

Materials:

- Enameled Wire 1.0 m (26 gauge enamel-covered copper wire)
- Neodymium Magnet (the large one)
- 3.5 mm Audio Jack Plug
- Disposable Clear Cups x2 (from home)
- Needle or pin (from home)
- Steel wool or a blade to scrape the ends of the magnet wire (from home)
- Cell phone, computer or mp3 player (from home)

Procedure:

1. Wrap the wire between your two fingers to make a coil of about 3 cm in diameter. It should just slightly larger than the neodymium magnet. Secure the coil by winding the ends around the coil on opposite sides of the coil. Leave at least 10 cm of wire free for connection to the cell(s). Scrape the end of the wire so that the copper core is exposed.

2. Flip a clear cup upside-down. Place the coil at the center of the bottom of the cup. Draw a line on the bottom of the cup to mark the diameter of the coil. Then use a needle or a pin to poke a small hole through the cup on each end of the line. **See Fig. 12.3.2.**

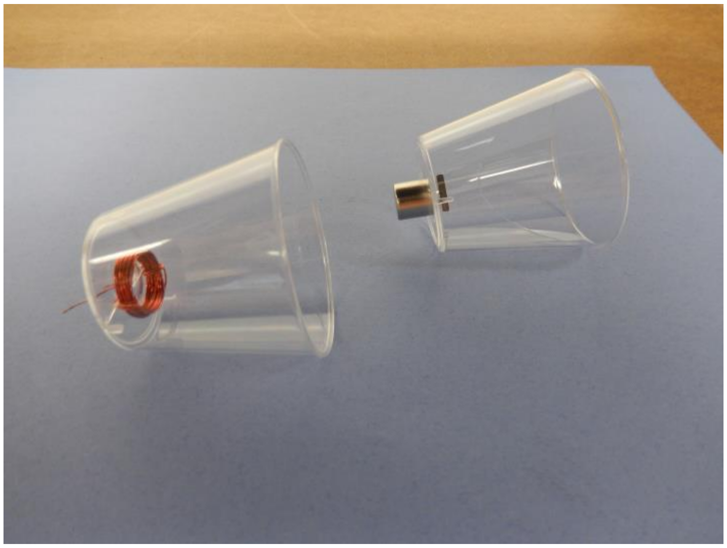

Fig. 12.3.2

3. Pick up the cup. Put the coil inside. Thread the two ends of the coil through the two holes. On the outside of the cup, tie a knot with the wire ends that stick out of the holes on the cup. Pull on the two ends until the knot is tight and the coil is secured against the inside bottom of the cup.

4. Tape the neodymium magnet at the center of the bottom of the other cup. Push the second cup into the first cup. Tape the rim of the second cup to the rim of the first cup in order to make sure they fit snuggly to each other. **See Fig. 12.3.3.**

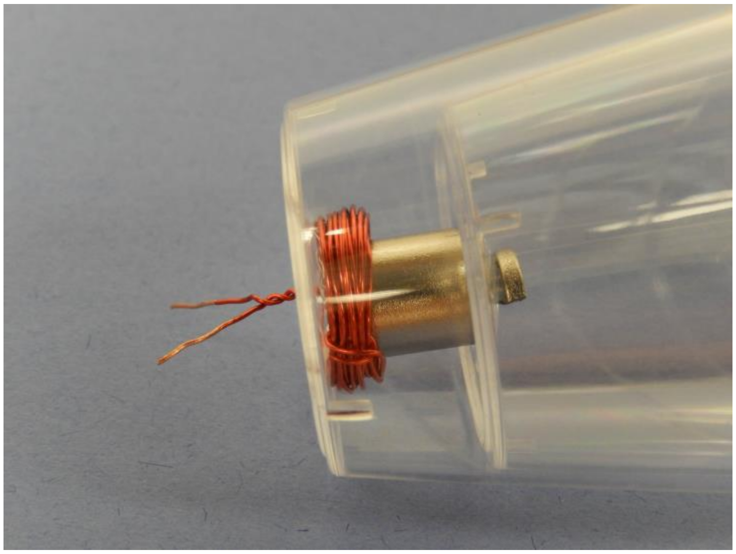

Fig. 12.3.3

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5. See **Fig. 12. 3.4** for an illustration of the 3.5mm audio jack plug. Hook one end of the wire to Terminal C. Hook the other end of the wire to Terminal A. Make sure the copper core of the wire is exposed to the terminals.

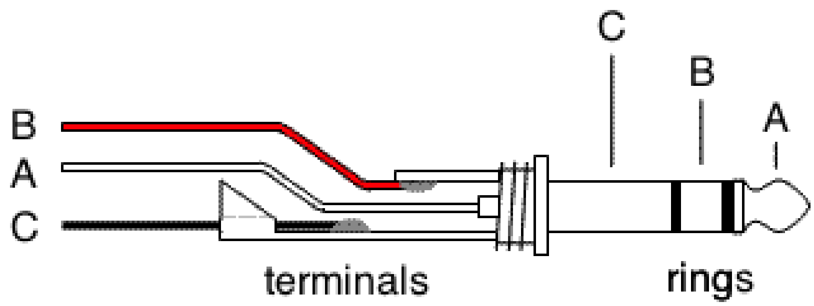

Fig. 12.3.4

6. Connect the plug to an audio jack from your phone, Ipad, computer or an mp3 player. Turn up the volume to the maximum. What do you hear from the clear cups? Why isn't your sound system as good as the one in **Fig. 12.3.5**? ______________________________
____

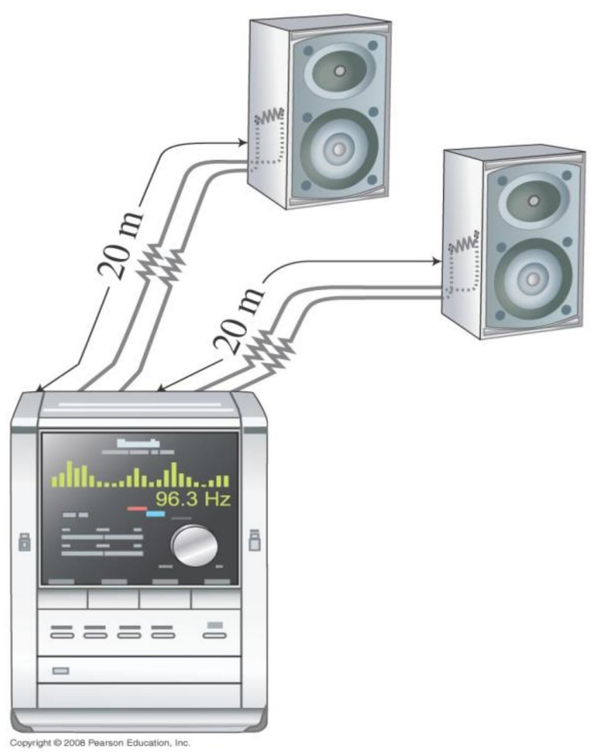

Fig. 12.3.5

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Home Lab 13
Faraday's Experiment and Lenz's Law

Overview

Michael Faraday was the first to appreciate the intimate connection between electricity and magnetism. In 1831 Faraday did the famous experiment that showed a changing magnetic field was able to induce an electric current in a coil of wire.

Faraday's experimental setup had two coils wound around a piece of iron. The first coil was simply an electromagnet. The secondary coil was connected to a very sensitive current detector, called a galvanometer. See **Fig. 13.0.1**. Prior to the experiment, Faraday had reasoned that since Oersted's experiment was a conversion from electricity to magnetism, the reverse could be achieved. Faraday expected that when the electromagnet was on, it would produce a current in the secondary coil. However, the steady magnetic field of the electromagnet produced no induced voltage or current in the galvanometer.

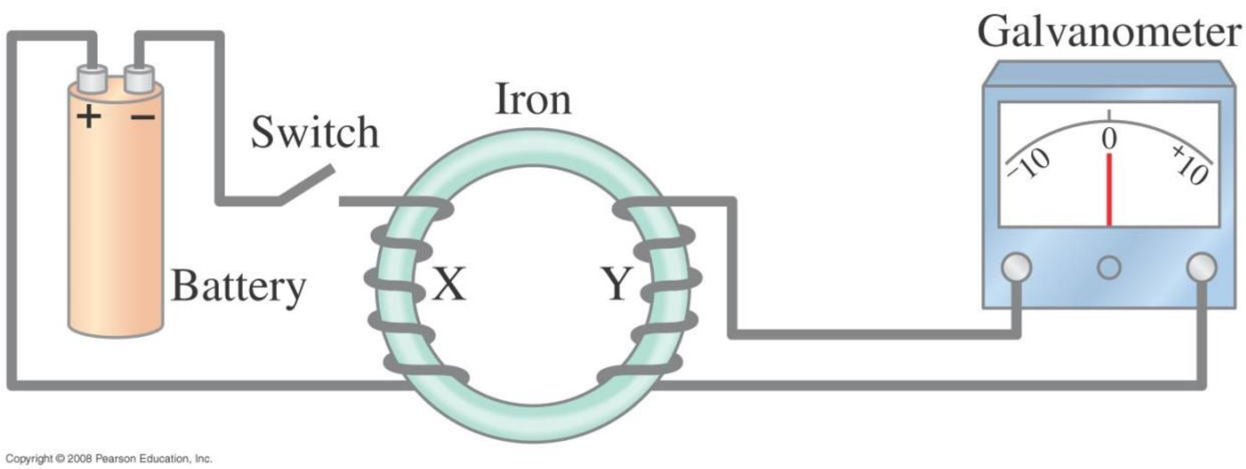

Fig. 13.0.1

Instead, he found a momentary current in the secondary coil in the split second right after connection was made from the battery to the first coil. When he disconnected the battery, there was another split-second current in the secondary coil flowing in the opposite direction. Faraday found that the faster the disconnection or connection, the bigger the current in the galvanometer. Also, the direction of the current always reversed. If connecting the battery deflected the galvanometer needle to the right, then disconnecting the battery deflected the needle to the left. See **Fig. 13.0.2 (a) – (c)**.

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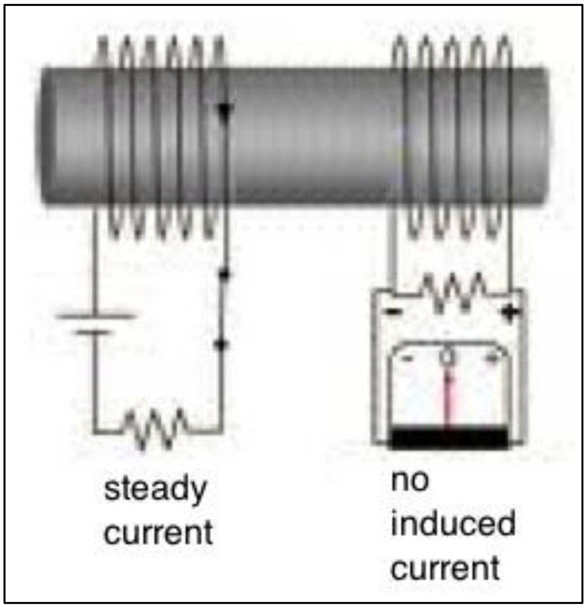

Fig. 13.0.2 (a)

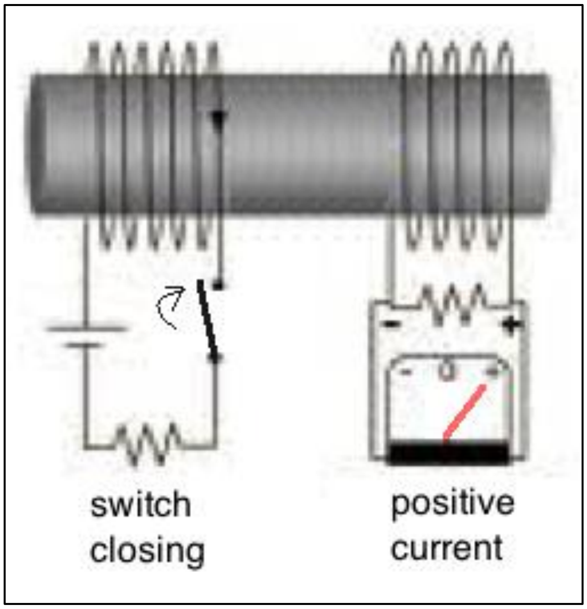

Fig. 13.0.2 (b)

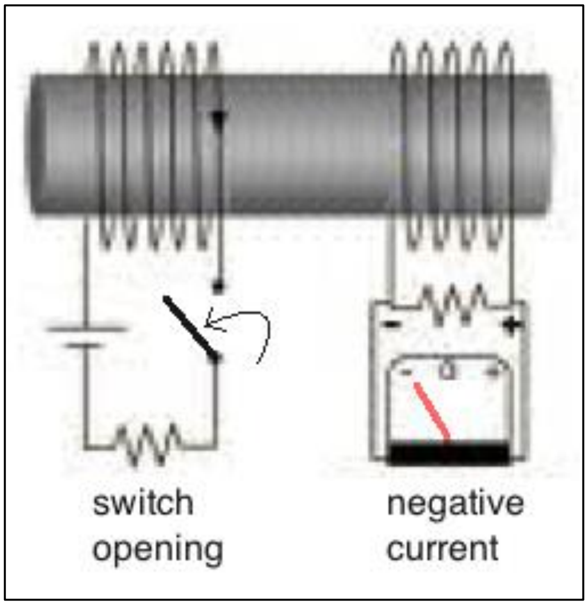

Fig. 13.0.2 (c)

Lenz generalized Faraday's experimental observation as follows: the induced voltage or current will always give rise to a magnetic field that opposes the change that produced it. The overall effect will be similar to friction – no matter in what direction the object moves, friction always opposes the motion. See **Fig. 13.0.4**. This phenomenon is the basis of magnetic braking, which we will cover in activity 3.

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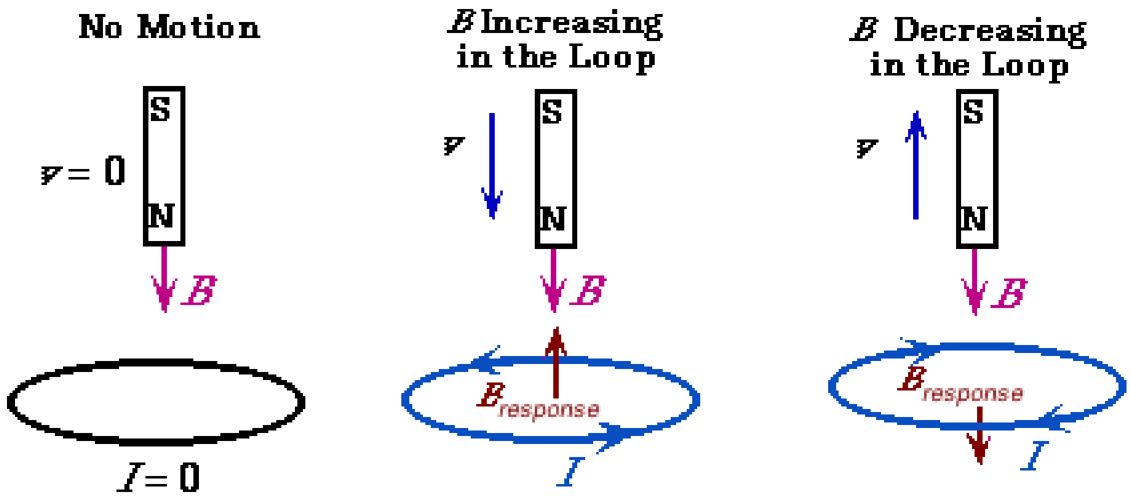

Fig. 13.0.4

Faraday's Experiment is monumental in the history of physics. It completed the missing link converting magnetism into electricity, and opened up a new world where radios, cell phones, generators, and household consumption of electricity became possible. A century after Faraday, the same experiment inspired Einstein to develop special relativity to account for paradoxical observations of Faraday's Experiment in different reference frames. In a word, Faraday's Experiment is like the proverbial golden goose, and it should be introduced to physics students in a way that preserves its historical significance.

An excellent JAVA applet that illustrates the effect of moving a magnet near a coil can be found at http://phet.colorado.edu/en/simulation/faraday

Name____ Date_________________________

Activity 13 – 1: Faraday's experiment

Objective: Investigate the effect of changing the current in a coil on the current in a second coil

Materials:

- Iron rod
- Enameled wire 3.0 m
- Enameled wire 1.0 m
- Compass
- Multimeter
- Alligator Wires
- 9-Volt battery (from home)
- Steel wool or a blade (to scrape the ends of the magnet wire, from home)
- Scotch tape (from home)

Procedure:

1. Find the enamel coated #26 copper wire from the class kit. Wrap 3.0 m of it around one end of the iron rod leaving approximately 5 cm of wire free at each end. Secure the coil using transparent tape. Use steel wool or a knife blade to scrape insulation away from both free ends of the coil.

2. Wrap 1.0 m of it around the other end of the iron rod leaving approximately 5 cm of wire free at each end. Secure the coil using transparent tape. Use steel wool or a knife blade to scrape insulation away from both free ends of the coil. Use alligator clamps to connect the free ends to the multi-meter. The multi-meter should be set to the 20uA scale. **See Fig. 13.1.1**

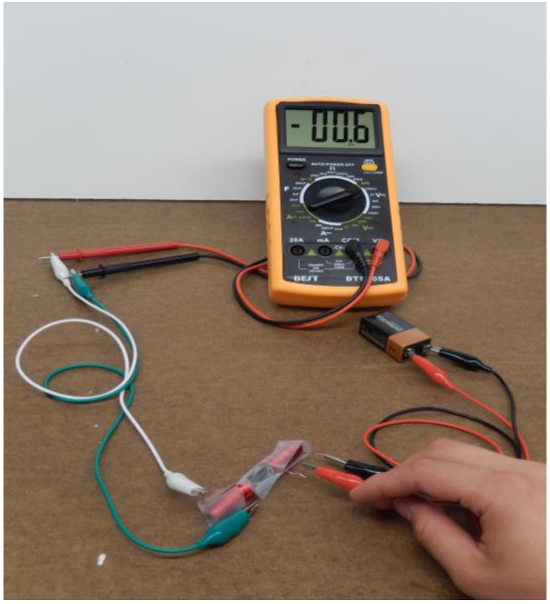

Fig. 13.1.1

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3. **Write your observations and answer questions for each of the following:** Connect one end of the first coil to the (-) side of the 9-Volt battery. Briefly connect the remaining free end of the first coil to the (+) side of the 9-Volt battery. **Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the wire. This will also drain the cell rapidly. Do not keep the wire connected to the cell for too long. It will only take less than 3 seconds to see the effect.** What is the reading on the multi-meter immediately when the circuit is closed? Provide a brief explanation for the reading or lack of reading. _______________________
____

4. While the free end is connected to (+) side of the 9-Volt battery, continue watching the multi-meter. **Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the wire. This will also drain the cell rapidly. In this case, we want to keep the connection time under 30 seconds.** What is the reading on the multi-meter when the circuit is closed for a little while (about 10 s)? Provide a brief explanation for the reading or lack of reading. _______
____

5. Disconnect (+) side of the 9-Volt battery. Continue watching the multi-meter. What is the reading on the multi-meter immediately when the circuit is opened? Provide a brief explanation for the reading or lack of reading. ____________________________________
____

Name____ Date_________________________

Activity 13 – 2: Faraday's experiment with a transformer an LED

Objective: Demonstrate Faraday's experiment using light-emitting diodes to indicate current.

Materials:

- 9-Volt battery snap
- Transformer
- Alligator Wires
- Multimeter
- Red light-emitting diode (LED)
- 9-Volt battery (from home)

Procedure:

1. The transformer used in this activity is shown below in **Fig. 13.2.1 (a)**. **Fig. 13.2.1 (b)** is the schematic symbol of the transformer. There are 2 input leads on one side and 3 output leads on the other side. The bottom side has two holes in the metal support that can be used to mount the transformer on a surface. Let's call the 2 input leads on the left side A and B. Call the 3 leads on the right side C, D, and E, as is shown in **Fig. 13.2.1 (a)**.

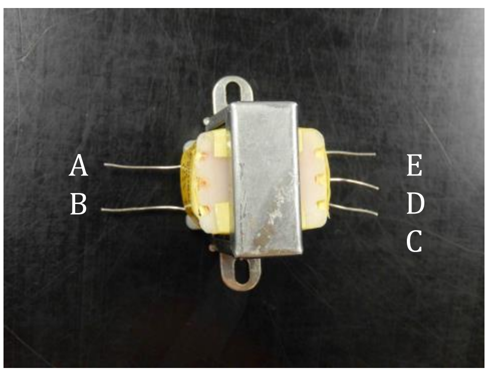

Fig. 13.2.1 (a)

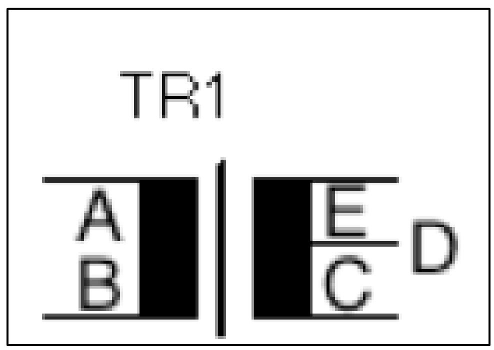

Fig. 13.2.1 (b)

Using wires with the alligator clips clamp the wire from C onto the positive end of the multi-meter. Clamp the wire from D onto the positive end of the multi-meter. Switch the scale of the multi-meter to 200mV. Put the battery snap onto the 9V battery. Clamp the wire from A onto the negative end of the battery snap. Turn on the multi-meter. See **Fig. 13.2.2** for a schematic diagram of the setup. The actual components are shown in **Fig 13.2.3**.

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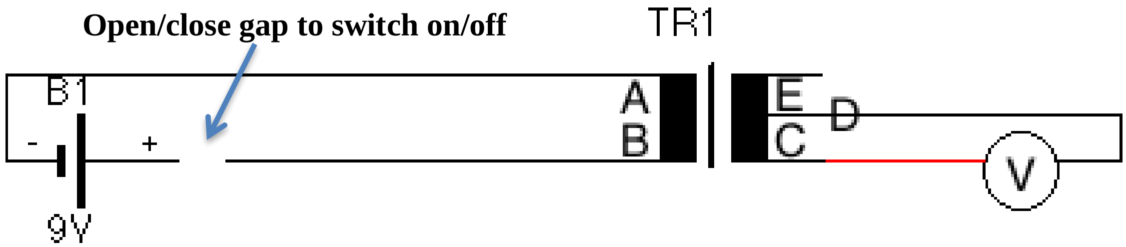

Fig. 13.3.2

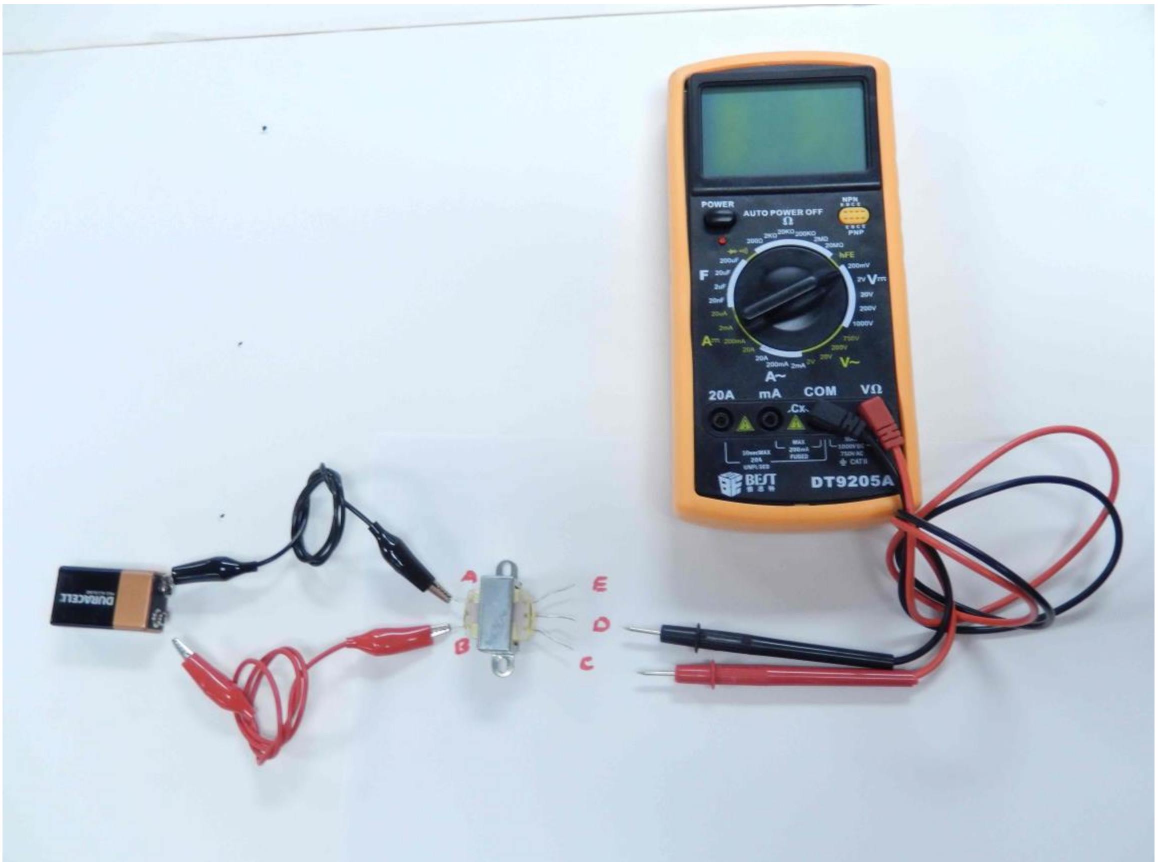

Fig. 13.3.3

2. Take the wire from B and touch the positive end of the battery snap for 10 seconds. **Warning: The wire will get hot very fast because the cell is essentially shorted, which means there will be a large current through the wire. This will also drain the cell rapidly. Do not keep the wire connected to the cell any longer than seconds.** Observe how the reading on the multi-meter changes over time and note the sign of the reading. Explain. ____

3. Immediately after 10 seconds disconnect the wire from the positive end of the battery snap. Observe again how the reading on the multi-meter changes over time and note the sign of the reading. Why is the voltage higher when you disconnect the wire and why is it positive? ____

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4. Now use the wire from E instead of the wire from D, and repeat steps 3 through 5. Record your observation in the space below. Note the difference from before, and provide an explanation (hint: refer to the schematic of the transformer). ______________
____

5. Replace the multi-meter with the red LED. Identify the positive and negative leads by observing their different lengths. See **Fig. 13.3.3.** Usually the shorter end is the negative side of the LED and the longer length is the positive side. (Same convention as electrolytic capacitor leads; refer to Lab 9 Activity 2). Using a wire with alligator clips clamp the negative side of the LED to the wire from D. Clamp the positive side of the LED to the wire from C. Keep the polarity as shown in **Fig. 13.3.3.** Also see **Fig. 13.3.4.**

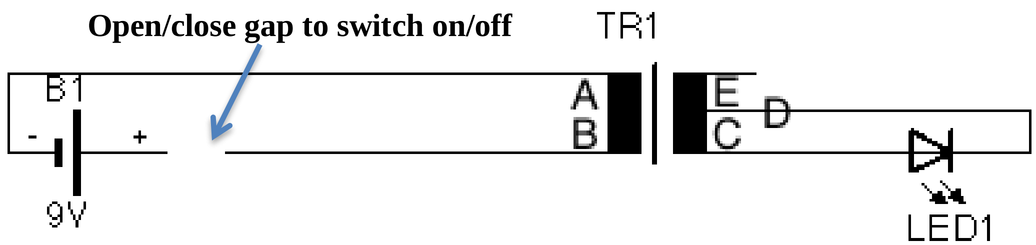

Fig. 13.3.3

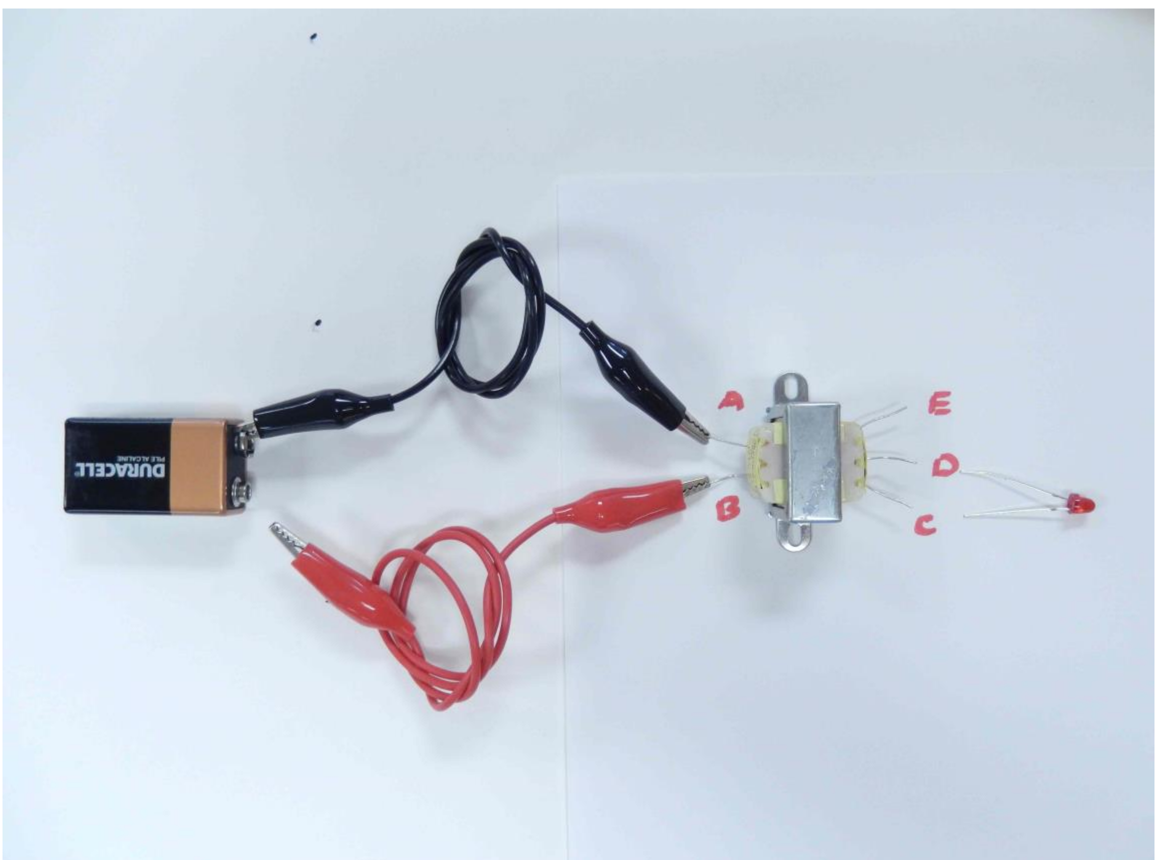

Fig. 13.3.4

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6. With the wire from A still clamped to the negative end of the battery snap, connect the wire for 10 seconds from B to the positive end of the battery. What is your observation of the red LED starting from when you make the connection as a function of time? _______
____

7. Now disconnect the wire from the positive end of the battery. What is your observation of the red LED? Explain. ____

Name____ Date________________________

Activity 13 – 3: Magnetic braking

Objective: Investigate the effect of a non-ferrous metal in the presence of a moving magnet

Materials:

- 2 large and 1 small neodymium magnets
- ¼ inch thick aluminum plate or 10-20 layers of aluminum foil. The plate works better. (from home)
- Thread (~70 cm, from home)
- Scissors (from home)
- Pendulum support (such as a ring stand with cross piece, from home)

Procedure:

1. Tie the thread to an appropriate support so that the pendulum can swing freely. The path of the pendulum must be free of the influence of nearby ferromagnetic materials. Attach the thread to the wooden rod as shown in **Fig. 13.3.1.** Attach the two large magnets together and trap the support thread between the large magnet and small magnet as shown in the **Fig. 13.3.1.** You may enlarge the figure see it better. Adjust the magnets so the magnets are about 1 mm above the aluminum (but do not touch the aluminum plate). Using scissors cut the thread below the magnet so that no thread is visible.

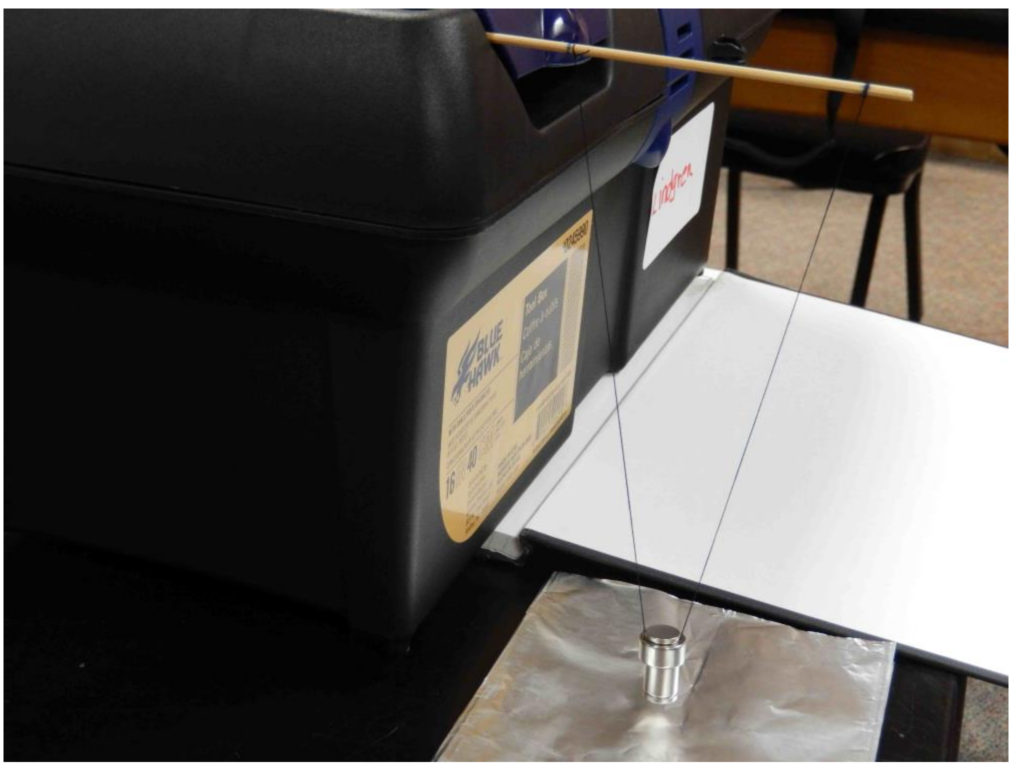

Fig. 13.3.1

Name____ Date________________________

2. Remove the aluminum. Pull the magnet over a fixed distance and release the magnet. Count the number of swings until the magnet/pendulum bob stops. What force is acting on the magnet/pendulum bob while it is in motion? _____________________________

3. Return the aluminum plate so that it is directly under the lowest point of the pendulum swing. Pull the magnet over the same fixed distance and release the magnet. Count the number of swings (if any) until the magnet/pendulum bob stops. Describe all forces acting on the magnet/pendulum bob while it is in motion. Include the direction of the forces in your description. Provide an explanation for why the magnet/pendulum bob stops sooner. ____

4. With the magnet/pendulum bob stopped at its lowest point, pull the aluminum plate along the tabletop from underneath the suspended magnet/pendulum bob. Describe the motion of the pendulum bob as the aluminum plate is pulled away. Provide an explanation for why the magnet/pendulum bob follows the plate. _______________________________

Name____ Date________________________

Activity 13 – 4: Magnet into a coil of wire

Objective: Observe the behavior of a coil of wire (solenoid) when a magnet is moved within the coil.

Materials:

- Iron bar magnet
- Neodymium magnet (the large one)
- Multimeter
- Enameled Wire 1.0 m (26 gauge enamel-covered copper wire)
- 1.5-Volt cell (from home)

Procedure:

1. Wrap the 1-meter long 26-gauge wire into a coil with a diameter or 2 to 3 cm leaving about 5 cm free at each end. The best way to make the coil is to loop the wire around your index and middle fingers. You will get an elliptical loop. Then round it by pulling along the short axis of the ellipse. It will have about 12 turns. Use the free ends to secure the coil by wrapping them around the coil (in and out) several times. See **Fig. 14.4.1.**

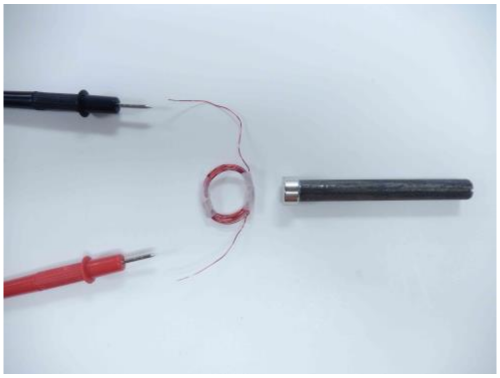

Fig. 14.4.1

2. Strip the enamel from both ends of the coil of magnet wire. Set the multimeter to the lowest voltage setting. Connect the multimeter leads to the two ends of the coil. Put the neodymium magnet in series with the bar magnet. Use the bar magnet as a handle to place the neodymium magnet in the coil. Write down the voltage reading when the magnets are at rest, including units in the space provided. ___________________________

3. Pull the magnet rapidly out of the coil. See **Fig. 14.4.2** Write down the largest voltage reading while the magnet is moving (pay attention to the unit and sign) in the space provided. ____

Name____ Date_________________________

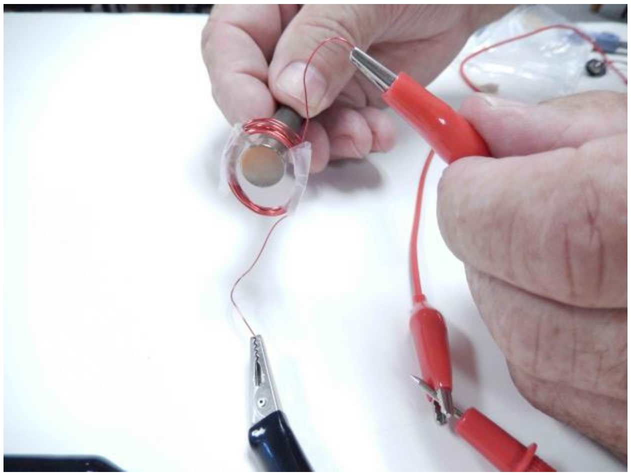

Fig. 14.4.2

4. Write down the voltage reading when the magnet stops moving. Explain. _____________
____

5. Now push the magnet through the coil in the opposite directions as when you pulled it. Write down the largest voltage reading (if negative then smallest) while the magnet is moving. Write down the voltage reading when the magnet stops moving. Explain. _____
____

6. Switch the north end of the magnet for the south end of the magnet and repeat the process. Again, use the bar magnet as a handle to manipulate the neodymium magnet. Move the magnet rapidly in and out of the coil. Note how the sign of the voltage reading is related to the direction of magnet movement. Explain. __________________________
____

Name ____ Date ____________________________________

Lab 14
Electric Motor

Overview

Electricity can do work, most noticeably by producing light or motion, such as in a light bulb or in a motor. The general formula for electric power is

$$P = V * I$$

where V is the voltage across an electrical component, I is the current through the component, and P is the power consumed. If the current goes in the opposite direction as voltage, the power consumption will turn out to be negative, which means the component actually outputs power, such as a battery does.

An electric motor works by running a current through a coil that is placed in a magnetic field. The current produces a pair of forces acting on the coil in opposite directions. See **Fig. 14.0.1**

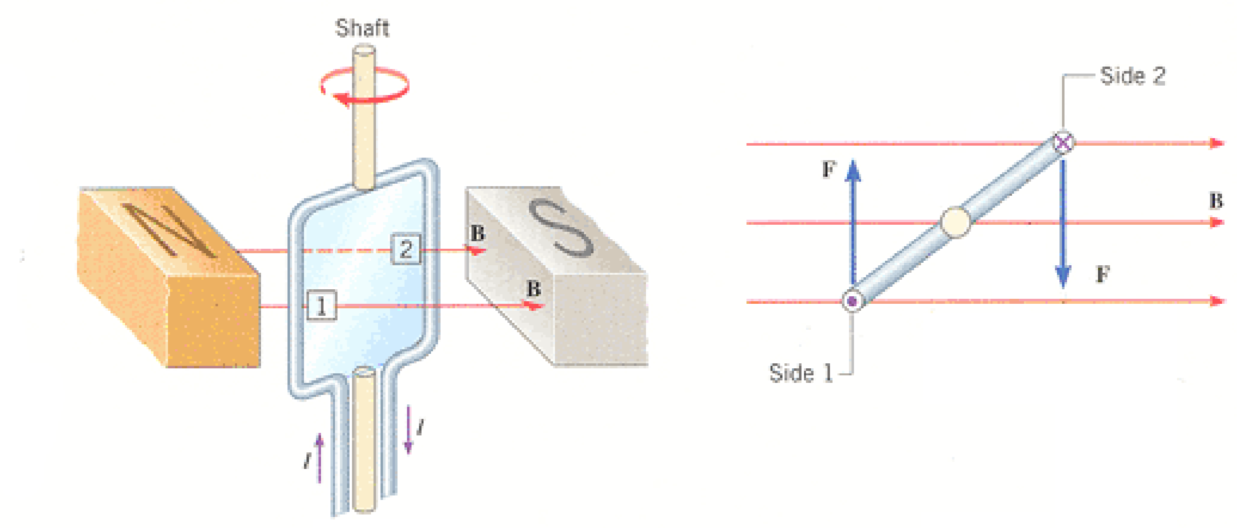

Fig. 14.0.1

If the current reverses direction every time the coil turns 180 degrees, the torque will remain in the same direction, thus spinning the coil continuously. This is achieved by means of a commutator that is essential to every DC motor. **See Fig. 14.0.2**

Name ________________________________ Date ______________________________

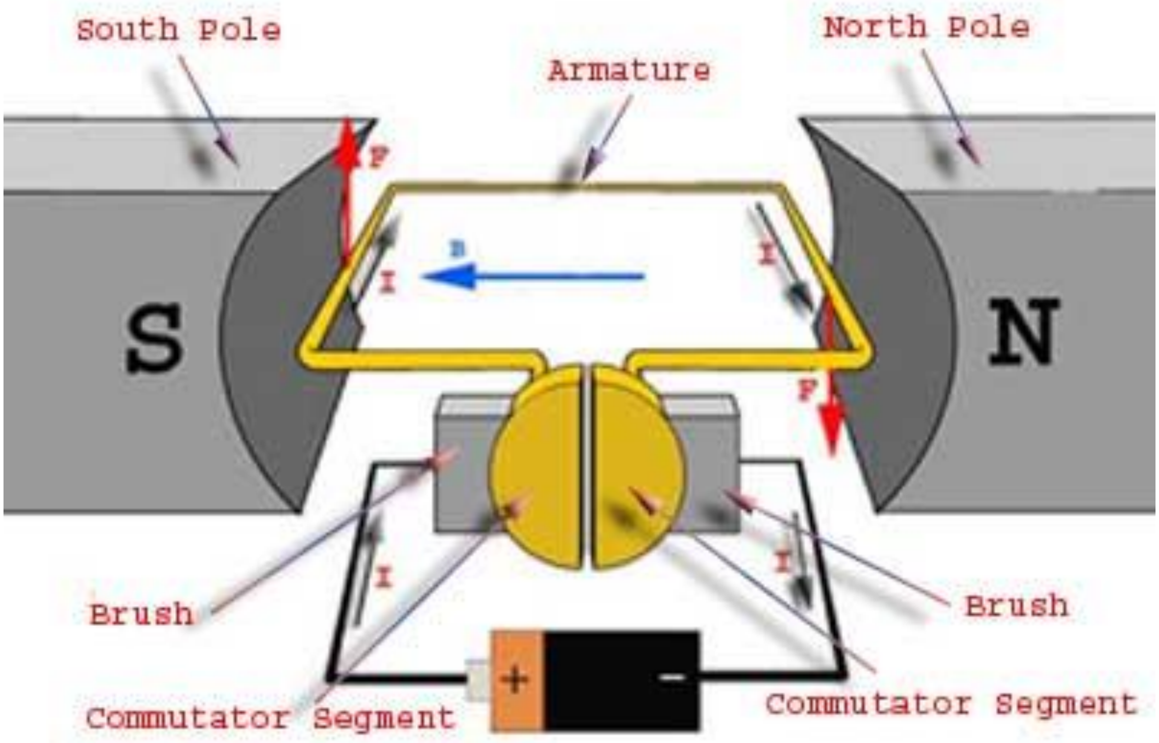

Fig. 14.0.2

Name ____ Date ____________________________________

Activity 14 – 1: Simplest Motor

Objective: Use the properties of a commutator to change a DC current into a semi-alternating current that drives a motor

Materials:

- Bare copper wire x2 (16 gauge ~15 cm long)
- Enameled Wire 1.0 m (reuse from lab 11 act 4)
- Rectangular magnet (~2.5 cm x 1.5 cm)
- Wooden Block with Groove
- Wide rubber band
- Scalpel or knife or steel wool (to remove enamel from wire, from home)
- 1.5-Volt cell (from home)

Procedure:

1. Using a pencil as a jig, make one and a half loop around the pencil with the 16-gauge wire to form a hoop with two long parallel legs of roughly equal length. Repeat with the other piece. The legs should be even and about 1 cm apart. **See Fig. 14.1.1**

2. Wrap the rubber band around the 1.5 Volt D cell. You may have to double-loop the rubber band to make sure it's taut. Then insert the two 16-gauge copper hoops under the rubber band against the battery terminals. Place the battery in the groove on the wooden block, and put the magnet on the battery. **See Fig. 14.1.2**

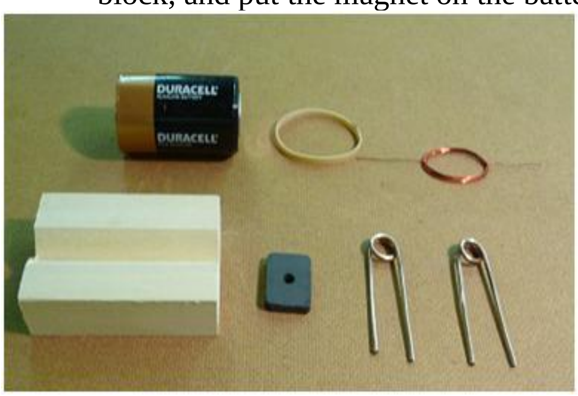

Fig. 14.1.1

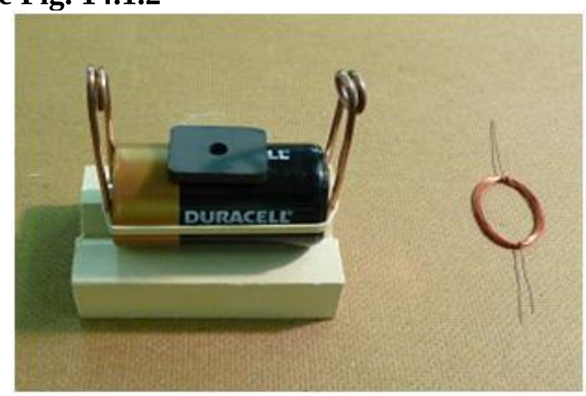

Fig. 14.1.2

3. (If you reuse the wire loop from lab 11 act 4, you can skip this step.) Wrap the 26 g wire in a coil with a diameter or 2 to 3 cm leaving about 5 cm free at each end. The best way to make the coil is to loop the wire around your index and middle fingers. You will get an elliptical loop. Then round it by pulling along the short axis of the ellipse. It will have about 12 turns. Use the free ends to secure the coil by wrapping them around the coil (in and out) several times.

4. Strip the enamel around the wire for about 3cm from one end. Strip the enamel only on one side of the wire for about 3cm from the other end. This is going to act as the commutator. See **Fig. 14.1.3**. The stripped copper wire has a bright copper color as opposed to the orange red enamel. (If you reuse the wire loop from lab 11 act 4, you have

to cut off one of the stripped ends of the wire and strip again only on one side of the wire to make the commutator work.)

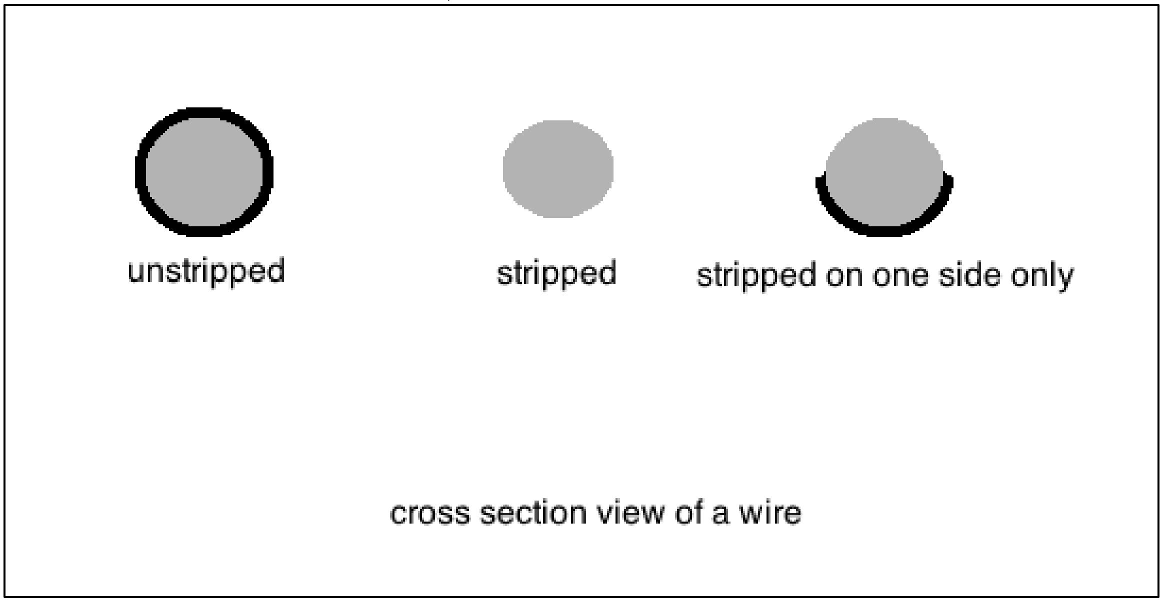

Fig. 14.1.3

5. Place the thin wire coil between the two thick wire hoops so that the coil is directly over the magnet. See **Fig. 14.1.4**. Try to align the two ends (axles) of the coil so that they are on a straight line. The coil should start spinning now. (It may be necessary to nudge the coil to get the motor started.) **WARNING: the coil gets hot with prolonged use.**

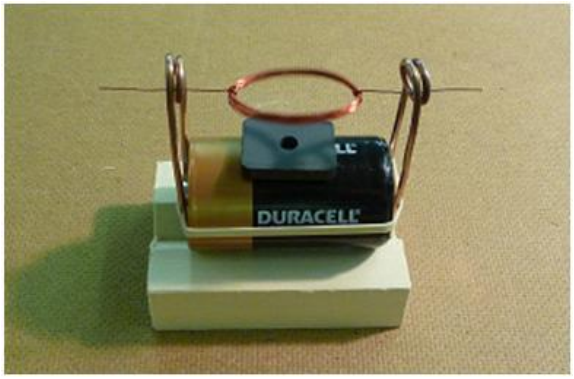

Fig. 14.1.4

6. If the coil is not turning, take it off the rack before it gets too hot. Then check the following:
    a. The two free ends of the coil should be in a straight line with each other and there should be no sag in the coil.
    b. The insulation may not be sufficiently stripped from one end or the other.
    c. The 16 g copper loops may not be in contact with the terminals of the D cell.

7. (Optional): The rpm of the coil can be determined using a stroboscope or photo gate, whichever is cheaper to get.

Name ____ Date ____________________________________

8. Raise the height of the hoops. Then add the second magnet on top of the first magnet. Describe what happens to the speed of rotation of the coil. Provide an explanation for the change. ____

9. Take the coil off and store it separately so that the cell will not discharge by itself. Note that as a classroom activity, the components (except for the 1.5-volt D cell) cost less than a $1 per set up and can be purchased at the local electrical store or at an electronics store such as Radio Shack.

Name ______________________________________ Date __________________________________

Activity 14 – 2: Motor as a Generator

Objective: Convert mechanical energy into electrical energy though an electric motor.

Materials:

- Motor
- Jumper Wires
- Alligator Wires
- Red LED
- Paper Clip (from home)

Procedure:

1. Take a good look at the motor. There are two slots on the motor for jumper wires. Use a paper clip to pry open the copper electrode underneath one of the slots, insert a jumper wire, and remove the paper clip. See **Fig. 14.2.1**. Then do the same on the other slot.

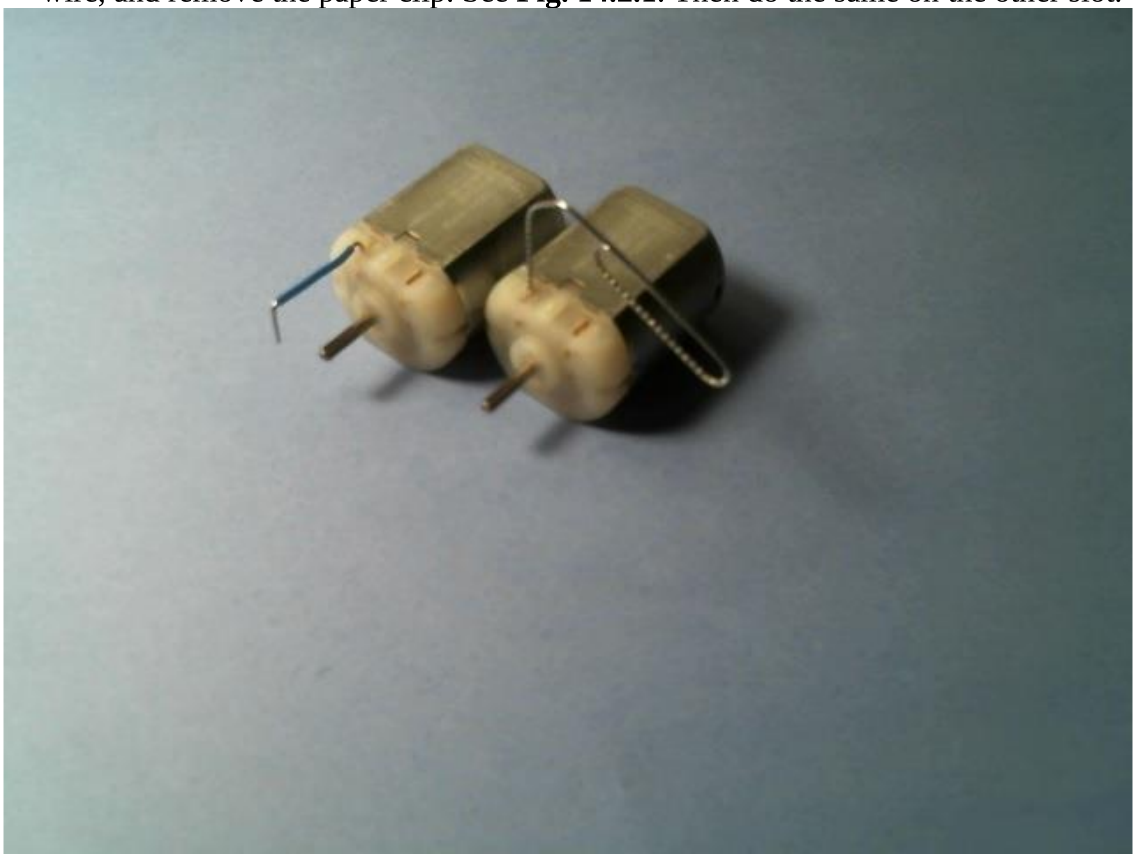

Fig. 14.2.1

2. Connect the jumper wires to the alligator wires, and then to the red LED. See **Fig. 14.2.2**. Which terminal on the motor is the positive end of the LED connected to? Write it down here.

____

Name ______________________________ Date ______________________________

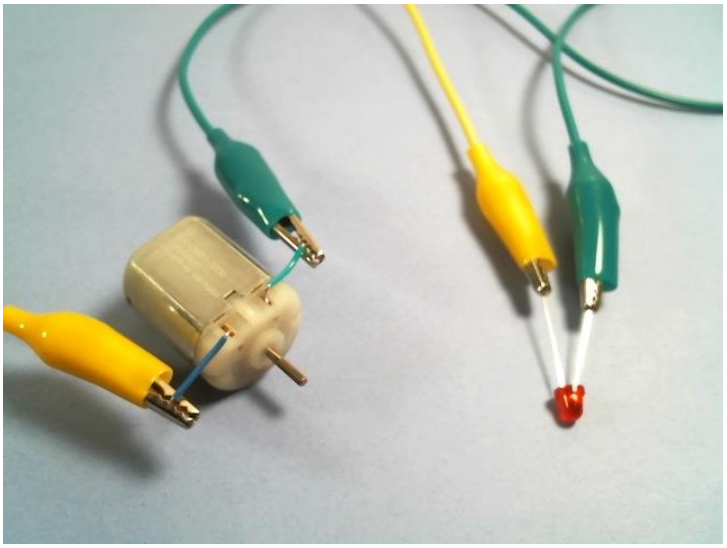

Fig. 14.2.2

3. Turn the motor shaft clockwise (clockwise as you look down the motor shaft into the housing) with a rapid twist of your fingers. What do you observe? How about turning it counterclockwise? ____

4. Switch the polarity of the LED and repeat step 3. Record your observation here. Explain why LED lights up or doesn't light up. LED lights up when motor is turned one way, but doesn't light up in the opposite way. ____

____

5. Describe how the mechanical energy released from your fingers eventually turns into energy in the flash of light. See **Fig. 14.2.3**.

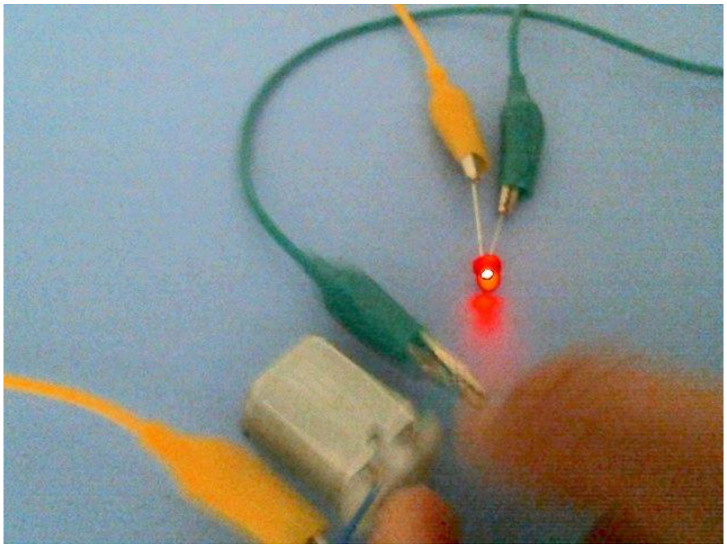

Fig 14.2.3

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Activity 14 – 3: Motor Efficiency

Objective: Measure the efficiency of a motor-generator pair, and infer the efficiency of a single motor.

Materials:
- Motor x2
- Rubber tube (1/2'' long, 1/16'' diameter)
- Jumper Wires
- Alligator Wires
- Multimeter
- Light Bulb
- Light Bulb Holder
- 9V Battery (from home)

Procedure:
1. Insert jumper wires into the slots on the motors. Connect the shafts of both motors through the rubber tube. See **Fig. 14.3.1**.

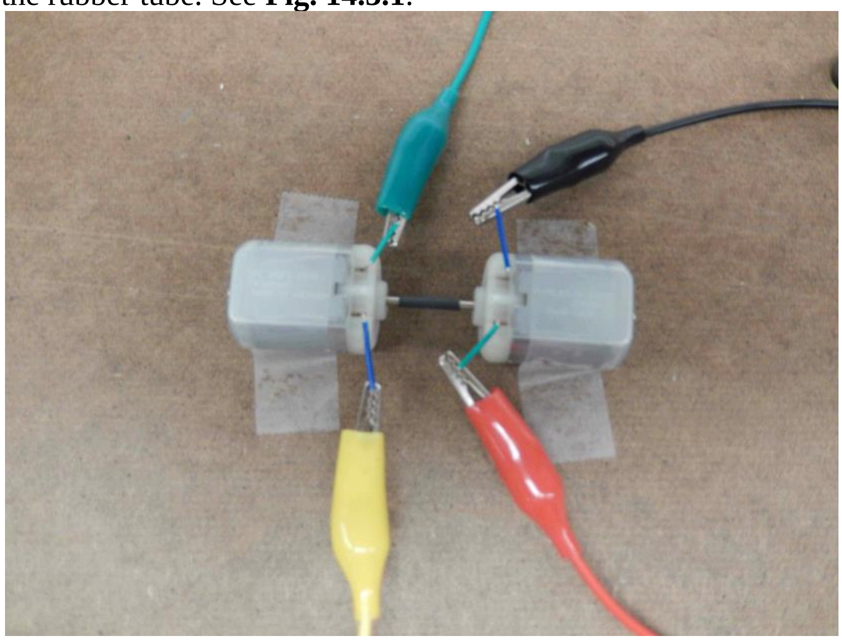

Fig. 14.3.1

2. Tape the motors onto the table. Put the light bulb in the holder. Connect one of the motors to the light bulb holder through alligator wire. Call it motor B. Connect the other motor to the 9V battery. Call it motor A. See **Fig. 14.3.2**.

Name ____ Date ___________________________________

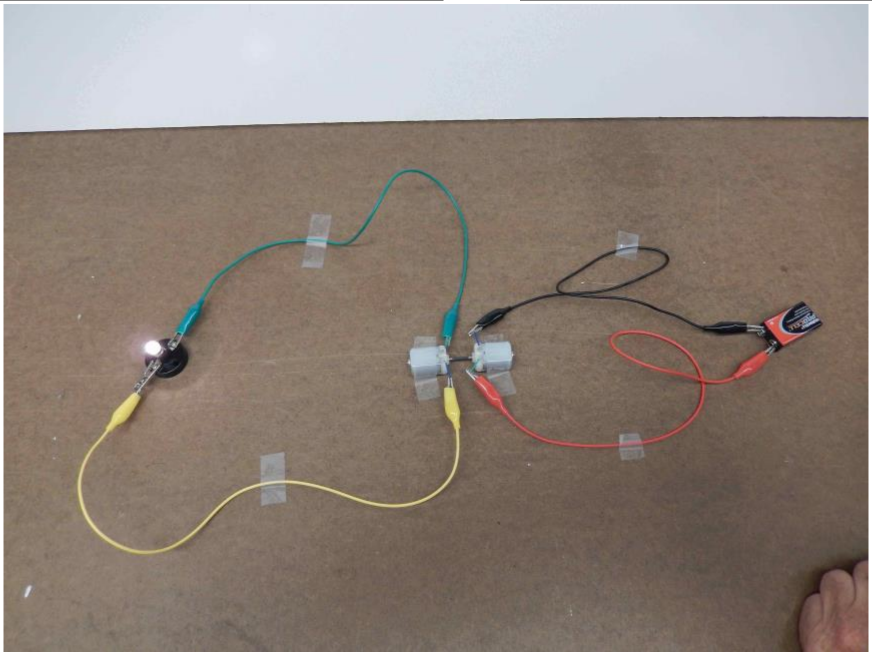

Fig 14.3.2

3. What do you observe when the circuit to motor A is closed? ___________________________

4. Take the multimeter and measure the voltage across motors A and B. Write down your measurements. ____

5. Switch the multimeter to 20A scale. Measure the current through motors A and B. Write down your measurements. ____

6. Calculate the power going into motor A and the power coming out of motor B. What is the ratio of output vs. input? ____

7. Assuming that, since the motors are the same, they have the same efficiency. What is the efficiency of a single motor? ____