

Name _____ Date _____ Partners _____
TA _____ Section _____

Lab 1: Electrostatics

“It is now discovered and demonstrated, both here and in Europe, that the Electrical Fire is a real Element, or Species of Matter, not created by the Friction, but collected only.”

--Benjamin Franklin, 1747

Objective:

To understand electrostatic phenomena in terms of the basic principles of electric charges.
Distinguishing positive and negative charges.
Properties of conductors and insulators.

Equipment:

Braun electroscope, polar electroscope, Faraday cage
Fur, Saran Wrap, 2 rubber balloons, tissue paper
Electrophorus

Introduction

Electrostatic theory, while profound, is quite simple. Many otherwise mysterious phenomena can be understood by applying a few simple principles:

1. Electrical charges come in two types: *positive* (+) and *negative* (-).
2. Like charges repel. Opposite charges attract.
3. Electrical charges cannot be created or destroyed, but may be separated and moved.
4. If an object is observed to be electrically neutral, equal amounts of + and – charges are present. If it is positively charged, a surplus of + charges are present. If it is negatively charged, it has a surplus of – charges.
5. There are two types of materials:
 - a. *Insulators*: electrical charges are frozen in place in the material.
 - b. *Conductors*: electrical charges may freely move throughout the volume object like a gas in a container.

Franklin himself thought of these charges arising from an excess or deficiency of a single electric fluid. Today, we understand the charges are due to particles of protons (+) and electrons (-). *Usually*, it is the electrons (that is, the negative charges) that move around; however, it is often useful to think of positive charges moving as well. A negative charge moving to the left is equivalent to a positive charge moving to the right.

Triboelectricity

First, you must move some electrons around to produce a net electric charge. You can do this with the *triboelectric effect*.¹

1. Vigorously rub an inflated balloon with your hair.²

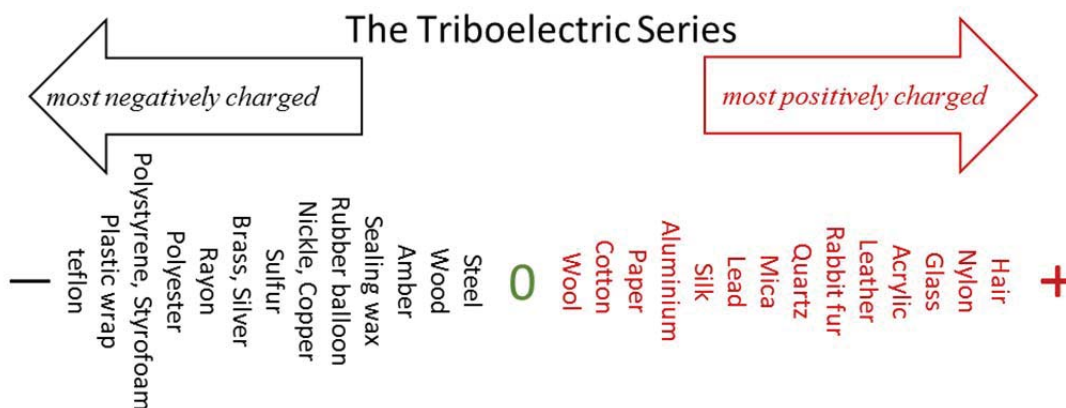


Fig 1

2. Tear off a few small pieces of tissue paper. Hold the balloon next to the chaff and observe the effect.
3. Touch the balloon to the electroscopes and observe the effect.

Some materials (such as hair) have a slight tendency to give up electrons. Other materials (such as rubber) can pick up a few extra electrons. Hence, if you rub a balloon with hair, electrons will be transferred, and a net electric charge will appear on each. When Ben Franklin did this, he declared the hair to have a “positive” charge and the rubber to have a “negative” charge.³ Today, following Franklin’s convention, we declare electrons to have a negative charge.

The Triboelectric Series ranks different materials by their tendency to give up or absorb electrons.



For any two materials brought in contact, you can estimate the sign and relative strength of the triboelectric effect by the relative position of materials on the series. For instance, hair is to the right of rubber on the series; hence, when rubbed against glass, silk will acquire a negative charge. Rub silk against silk and nothing happens.

¹ *Tribo* is from the Greek term for rubbing.

² If you are follicly challenged, use the fur.

³ An unfortunate choice in retrospect. Electrical currents would be a little more intuitive if Franklin had declared the rubber (and hence, electrons) to be positive.

4. If silk is rubbed against Styrofoam, would you expect a stronger or weaker effect? What type of charge would appear on the Styrofoam? What charge on the silk? How would the magnitude of the charges compare?

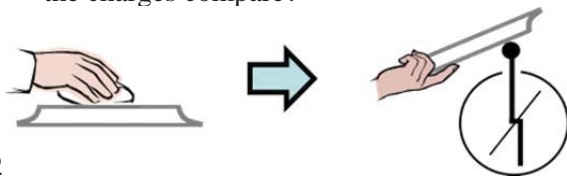


Fig 2

5. What would be the sign of the charges on each of the following items if they were rubbed against each other:
- Cotton _____ Nylon _____
 - Fur _____ Rubber _____
6. Why are artificial fabrics typically more prone to static cling?

Try this with several different materials on your table and your own hair. Observe the effect with the electroscope.

Charging an Electroscope by Contact

As you have discovered, an electroscope is used to detect an electric charge. You will be using two different electroscopes. While the Braun electroscope is more sensitive to small charges, its reaction time is slow due to the relatively large mass of its needle. Be patient with it.

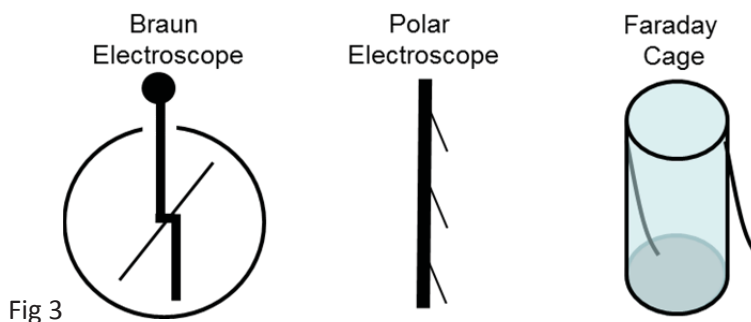


Fig 3

1. Verify that there is no charge on each device by touching them with your finger. This is called **grounding** the device. Any excess charge on the device will dissipate through your body to the ground.⁴
2. Charge one side of the balloon by rubbing it with your hair.
3. Gently rub the balloon along the top of the Braun electroscope to transfer some charge, then remove the balloon.

Note: Charges on insulators tend to be sticky, so it may take a fair amount of rubbing to transfer a significant charge.

4. Using the principles above, explain why is the needle deflected?

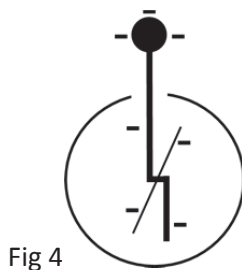


Fig 4

⁴ The human body is essentially a bag of salt water and therefore a fairly good conductor.

The Electrophorus and Electrostatic Induction

The electrophorus is a simple device for easily generating and transferring electrostatic charges. It consists of an insulating plate (the Styrofoam plate) and a conductive plate (the aluminum pie pan) with an insulated handle.⁵ The cartoon below illustrates how to use the electrophorus to charge the metal plate.

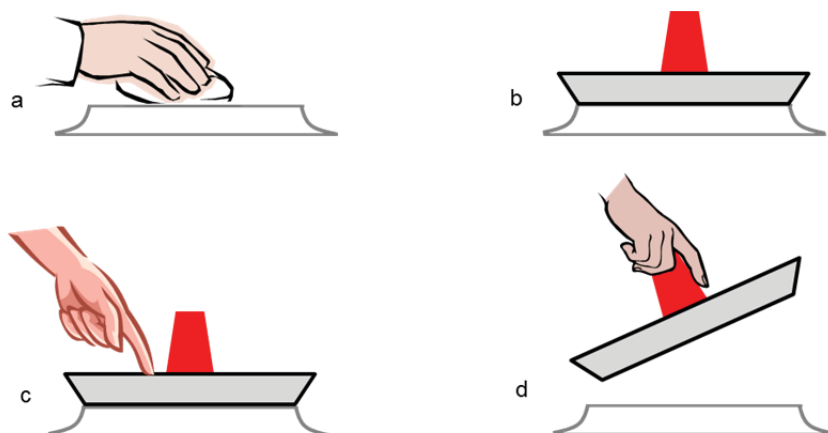


Fig 5

Charging an electrophorus

- a. With the insulating plate inverted, rub the surface with an appropriate material⁶ to produce a large negative charge on the plate.
 - b. Place metal plate on top.

Remember: Charges on insulators are sticky. Relatively few will leap to the metal plate even when in contact.
 - c. Touch the metal plate to remove excess charge.
 - d. Remove the metal plate with the insulated handle.
1. Experimentally determine the sign of the final charge on the metal plate. What happened when you touched the top of the metal plate?

⁵ We use the term *electrophorus* because that sounds much more impressive than *random picnic supplies*.

⁶ Refer to the triboelectric series above.

2. What happened to the charges on the metal plate when placed on the charged plastic plate?

3. What happened to the charges on the plate when you touched it?

4. For each step, add + and – symbols to the cartoons in Fig. 5 to illustrate the distribution of charges on the plates. Discuss these distributions with your lab partners and finally with your TA

Charging the Electroscope by Induction

1. Ground the polar electroscope.
2. Charge the metal plate of the electrophorus.
3. Slowly bring the charged metal plate close to, but not touching, the top of the polar electroscope.
4. Holding the metal plate steady, briefly touch the electroscope.

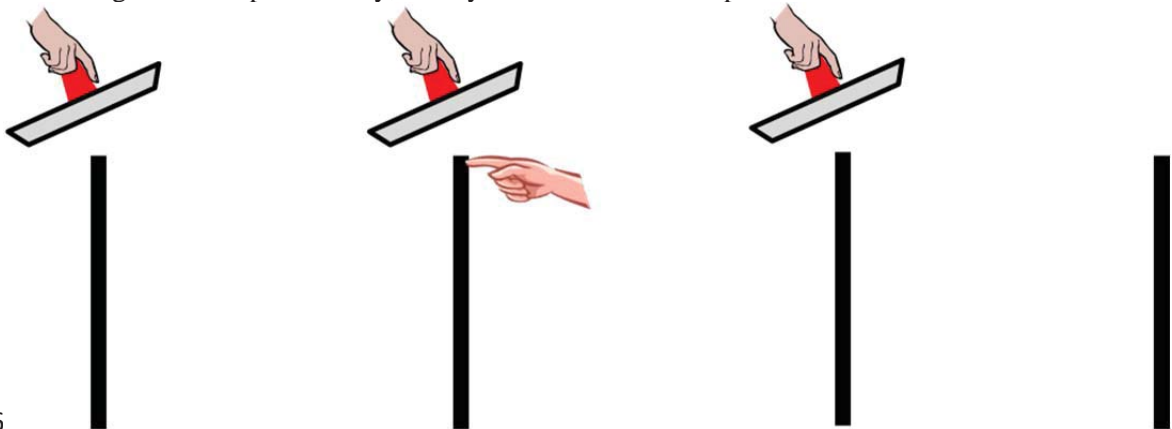


Fig 6

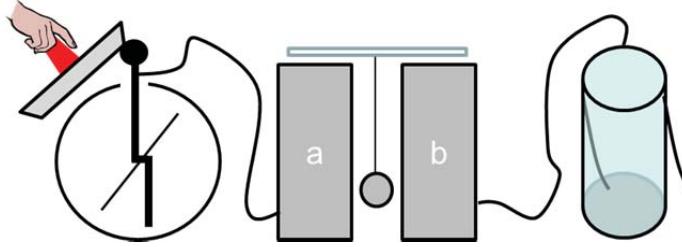
4. Exactly where on the cage does the charge reside? Applying the principles above, think of an intuitive explanation for this and discuss it with your TA.

5. What is the electric field inside the cage?

6. Have one member of your group wrap a cell phone with foil. Have another member make a call to the wrapped phone. Explain the result.

Franklin's Bells

1. Attach an electroscope to each side of the Franklin Bells (that is, the soda cans) as shown below. Each bell should be about 0.5 cm from the clapper. Ground each electroscope to ensure the system is neutral.



2. Using the electrophorus, transfer enough charge to the electroscope for the bells to start ringing.
3. When the motion stops, briefly ground one of the electroscopes with your finger.
4. Using the principles from the introduction, explain what you observed.⁷

⁷ With one bell attached to a lightning rod and the other grounded, Franklin used his bells to detect approaching electrical storms; thus letting him know when he could perform his experiments. This is illustrated on the cover.

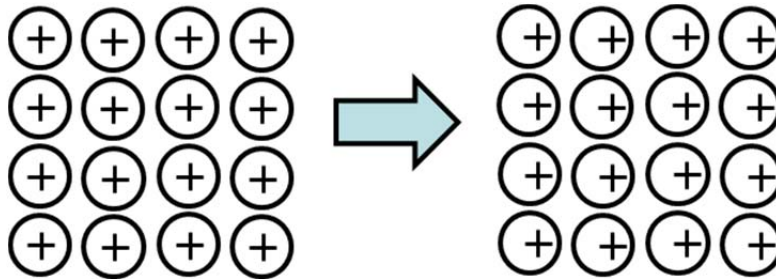
"I was one night awaked by loud cracks on the staircase. . . I perceived that the brass ball, instead of vibrating as usual between the bells, was repelled and kept at a distance from both; while the fire passed, sometimes in very large, quick cracks from bell to bell, and sometimes in a continued, dense, white stream, seemingly as large as my finger, whereby the whole staircase was inlightened (sic) as with sunshine . . ."

Wisely, Franklin also invented fire insurance.

Induced Polarization of Insulators

1. With the silk, recharge the glass rod.
2. Hold the rod close, but not touching the hanging wooden dowel. What is the effect on the rod?

Even though electrical charges are not free to move through the insulating wood (unlike a conductor), the wood can still be slightly polarized. Model each atom in the wood as a positive nucleus surrounded by a negative shell of electrons. In the presence of an external electric field, the electrons will be slightly pulled one way and the nuclei are pulled the other way. This polarizes each atom, and hence the entire object, by having just a little more positive charge on one side, and a little more negative charge on the other.



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Lab 2: Building and Analyzing Simple Circuits

Freddy: Throw the third switch!

Igor: Not the third switch???

*Freddy: **THROW IT, I SAY! THROW IT!***

-- Young Frankenstein

Objective:

To learn how to build simple circuits and analyze them with a multimeter.

Equipment:

2 multimeters

Vernier circuit board

Two batteries

Two battery holders

4 banana cables

Package of alligator jumpers

Introduction





The simplest electronic circuits contain three measurable parameters.

1. **Potential (V)**, measured in **Volts (V)**. Potential can be naively understood as the electrical pressure that pushes charges through the circuit.
2. **Current (I)**, measured in Coulombs/second or **Amperes (A)**. Current measures the rate at which charges move through the circuit.
3. **Resistance (R)**, measured in **Ohms (Ω)**. It measured how strongly particular circuit elements resist the flow of charge. An ideal conductor has zero resistance. An ideal insulator has infinite resistance. Resistance is defined by the expression:

$$R \equiv \frac{V}{I} \quad (2.1)$$

Note: This is the definition of resistance. This is not Ohm's law. That will be defined later.

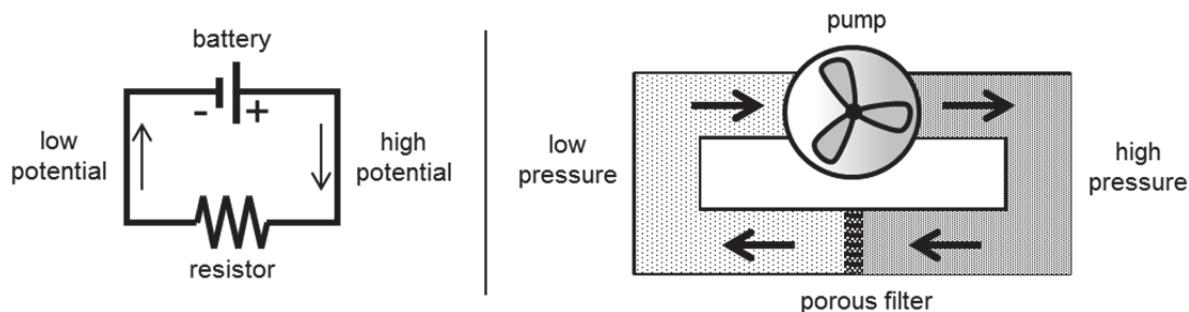
In this lab, you will assemble and analyze some very simple circuits using only the following elements:

- A conductive wire. For our purposes, the resistance of a wire is essentially zero.
-  A resistor.
-  A battery or dc voltage source. The long line indicates the positive side of the battery.
-  A switch.
-  Ground.

We will also define symbols for a voltmeter \textcircled{V} , ammeter \textcircled{A} , and ohmmeter $\textcircled{\Omega}$ since these may also be included in circuit diagrams.

A simple loop

The simplest possible electric circuit contains three elements: a battery, conductive wires, and a resistor.



A useful analogy to this circuit is a hydraulic system. The pipes represent the wires, the pump the battery, and a dense filter the resistor. The flowing water is analogous to the electric current.¹ Much as a pump produces the pressure to push the water through the filter, the battery produces the potential to push the current through the resistor. Even as the water in the pipes is does not disappear but returns to the pump, whatever current flows out of the battery must flow back in.

This analogy applies to more complicated circuits as well. Keep it in mind as you work with circuits in this and future labs.

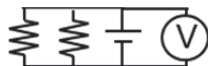
Series and Parallel design

In a series design, the circuit elements are placed one after the other along the wire. For example, below we have 2 batteries, a switch, and 3 resistors arranged in series:

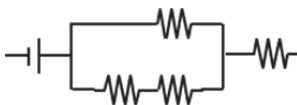


¹ Note that I speak of the current, not the electrons. Electrons, being negative, move in the opposite direction of the current. You can blame Ben Franklin for this absurdity.

In parallel design, the ends of each element are connected to the same two wires. Below, we elements arranged in parallel:



However, circuits will not always fit neatly into these two categories. For example:



We will deal with such circuits later in the semester.

The Multimeter

The Digital Multi-Meter (DMM) is *the* go-to device for measuring the important properties of almost any electrical circuit, whether it's a motherboard for the latest super-computer or an old string of Xmas lights. Generally, they can measure **voltage** (ac or dc), **current** (ac or dc), **resistance** and **continuity**². Depending on the particular model, other quantities may also be measured such as: capacitance, frequency, inductance, temperature, diode tester, transistor tester, battery tester, alien life detector³, . . . Basically, anything that strikes the fancy of the meter's designer (and the wallet of the purchaser).

Our DMM's are very well engineered devices that are designed to withstand common abuse without failing and uncommon abuse without failing catastrophically. So, be careful with these meters, but don't be paranoid. You will be using two DMM's in this lab. The specific instructions in the text refer to the EZ DM-332, but the operation of the second meter is very similar.

Activity 1: Measuring Potential, the Voltmeter

In class, you have learned how electric fields create the forces that cause charged particles to move. However, in practice one rarely actually measures the electric field. Instead we measure the **electric potential** (also called **voltage**). You will study the theory explaining potential in your class and how this relates to the field. For now, we will naively define potential as the pressure on charged particles which causes them to flow.

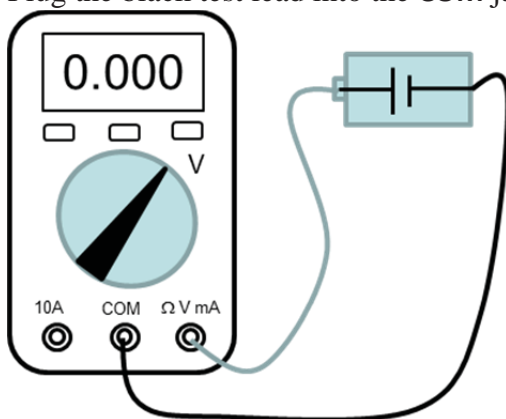
There are many sources of electric potential: an electrical generator, a solar cell, even a charged rubber comb. But the easiest source to think about is a battery $\text{---}|$.

- Turn the dial to **4** on the voltage **V** setting. This will allow you to measure up to 4 V. On the left side of the display, you will see either a --- (for dc measurements) or a \sim (for ac measurements). Press the $\text{---} \sim$ button (upper right on the meter) to switch between these settings. Today, we will limit ourselves to dc measurements, so leave the meter on --- .

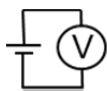
² We will define continuity in a bit.

³ No, wait. That last one is only on a tricorder. I get them confused sometimes.

- b. Plug the black test lead into the **COM** jack. Plug the red lead into the **V** jack.



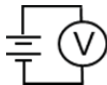
- c. Insert batteries into the individual battery holders. By placing the probe leads to the ends of each battery, measure the potential of each.



Battery 1: _____ Battery 2: _____

Electric potential is always a relative measurement. One does not measure the absolute potential of some point a , but rather the difference in potential between point a and some other point b . Thus, *a voltmeter is placed in parallel with the circuit element* whose potential you wish to measure. *A voltmeter's resistance is practically infinite*, and very little current moves through it. Note what happens when you reverse the leads.

- d. Attach the batteries in series. What is the potential across the pair of batteries?



Potential in series = _____

- e. Attach the batteries in parallel. What is the potential between the positive and negative sides?



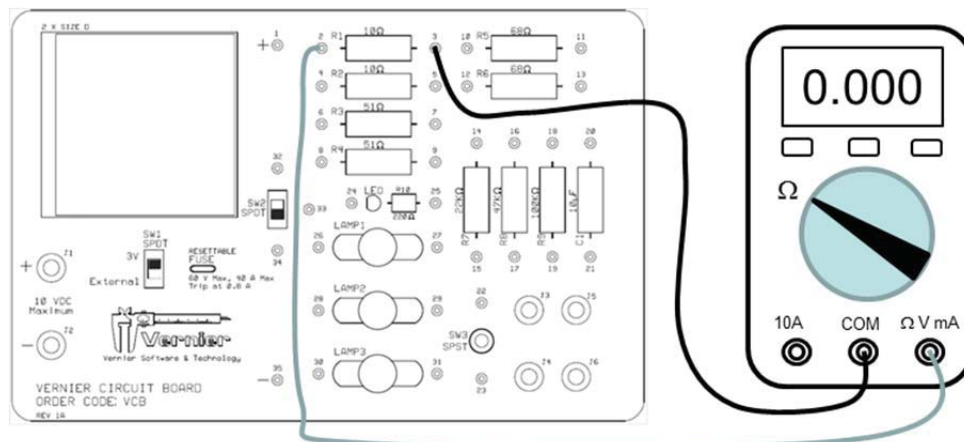
Potential in parallel = _____

Note: As long as the resistance of a wire is negligible, the potential everywhere along a single wire will be constant.

Activity 2: Measuring Resistance, the Ohm Meter

Electrical resistance is a kind of friction inhibiting the flow of charge.

- Plug the black test lead into the **COM** jack. Plug the red lead into the Ω jack.
- Turn the dial to **400 Ω** . At this setting, you can measure resistances up to 400Ω .



- c. Touch the leads to each side of R1 on the circuit board. Verify that the resistance is 10 Ω .
- d. Do the same with the rest of the resistors. Increase the range as needed by rotating the dial to 4k Ω , 40k Ω , etc.

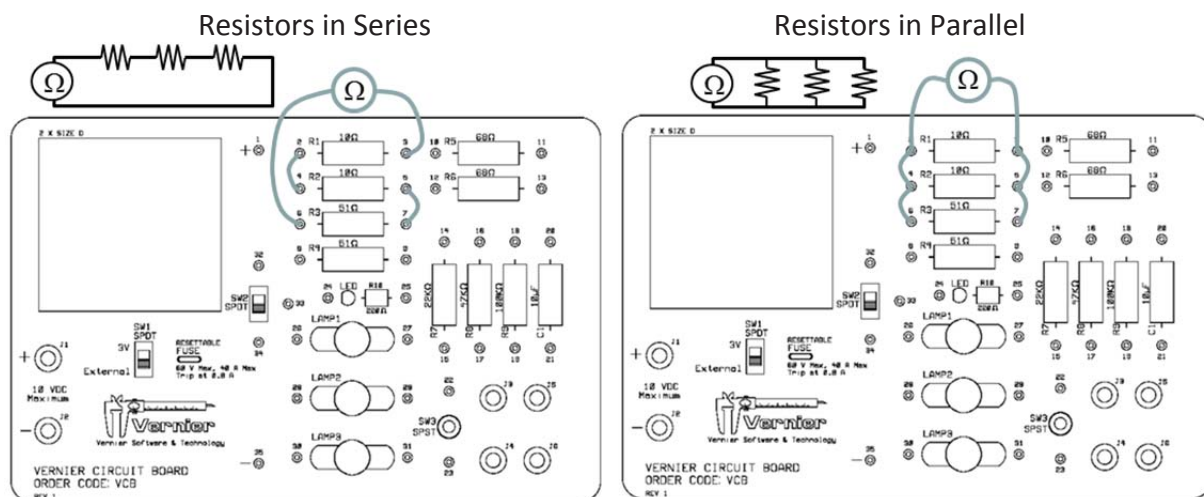
The Ohm Meter works by applying a known voltage to the leads and measuring the resulting current: $R=V/I$. For this to work, ***the resistor you are measuring must be isolated from the rest of the circuit***. If an external voltage is applied to the leads, you will not get a correct reading (and you *might* damage the meter).

Continuity

- e. Turn the dial to \bullet .
- f. Touch the leads together. You should hear a buzz, and the displayed resistance should be nearly zero.
- g. Touch the leads to each end of a single wire.
- h. Touch the leads across a 10 Ω resistor.
- i. Touch the leads across a 51 Ω resistor.

This is the continuity test, a variation on the Ohm Meter setting. As long as the resistance between the two probes is $<40 \Omega$, it will buzz. This is a great way to see if your wires are actually connected or is there a break somewhere in the middle. This is arguably the single most useful feature on a multimeter.⁴

⁴ Wondering if a fuse is blown? Is this light bulb any good? This is the setting you want.



Resistors in series

- j. Using the wires provided, place R1, R2, and R3 in series. Reference the figure above. Measure the combined resistance.

Resistance = _____

- k. What is the effective resistance of several resistors in series?

Resistors in Parallel

- l. Using the wires provided, place R1, R2, and R3 in parallel. Reference the figure above. Measure the resistance.



Resistance = _____

- m. Now place R1 and R2 in parallel. Measure the resistance.



Resistance = _____

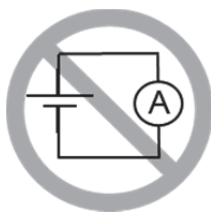
- n. How does the effective resistance of resistors in parallel differ from resistors in series?

Activity 4: Measuring Current, the Ammeter

The algebraic symbol used for current is I .⁵ The current setting on your meter is marked with an **A**. Note that your meter has separate ac \sim and dc --- ranges. In this lab we will only perform dc measurements.

To measure current, *an ammeter must be placed in series with the element* whose current you wish to measure. Since the ammeter itself must not affect the current being measured, *the resistance of the ammeter is nearly zero*.

CAUTION! If you touch the probes of an ammeter directly across a battery or power supply, the resulting current surge would likely blow a fuse and possibly damage the meter.

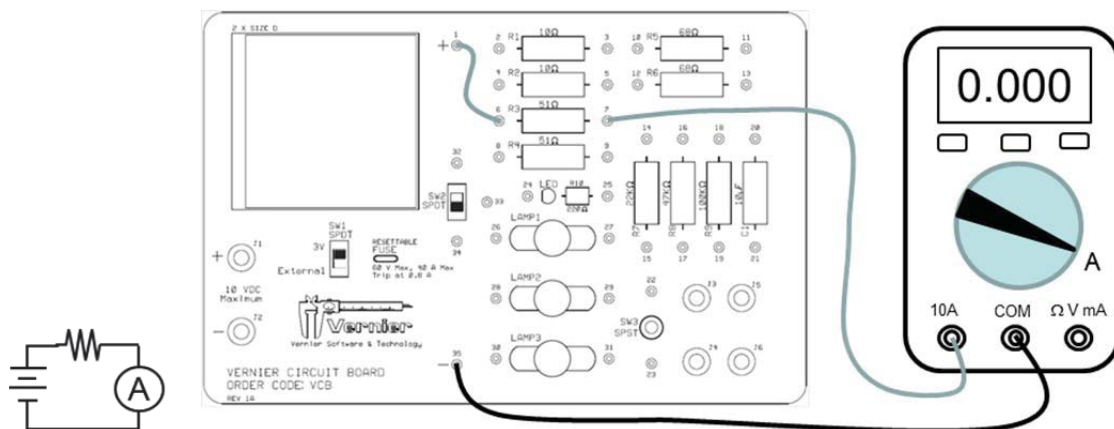


Turn the dial on the multimeter to the 40 mA dc setting. Leaving the black probe in **COM** jack, move the red plug to the **10A** jack.

Note: There are two jacks for the ammeter setting: **10A** and **mA**. The **10A** jack is a low precision setting that can handle currents up to 10 A. The **mA** jack is a more precise setting, but it can only handle currents up to 400mA. Always start your measurements using the 10A jack. If the measured current is safely below 400mA, you may *then* move to the **mA** jack.

- Verify that the power supply is set to 3V. Connect the color coded wires to the Vernier Circuit Board. The switch SW1 should be set to External.
- Construct the following circuit using a 51Ω resistor. Refer to the above figure. Measure the resulting current.

⁵ . . . because *that* makes perfect sense.



Measured Current = _____

- c. Reverse the plugs going into the **COM** and **mA** jacks. Measure the resulting current.

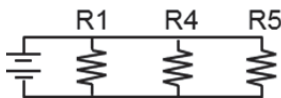
Measured Current = _____

Current flowing into the **COM** jack is positive. Current flowing out of the **COM** jack is negative.

Activity 5: Bringing it all together

- a. With the ohmmeter, verify the resistances of R1, R4, and R5.

R1 = _____ R4 = _____ R5 = _____

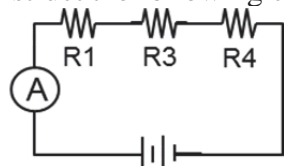


- b. Construct the following circuit.
 c. With a voltmeter, measure the potential across the power supply, and then measure the potential across each resistor.

$V_{\text{power supply}} =$ _____ $V_{R1} =$ _____

$V_{R4} =$ _____ $V_{R5} =$ _____

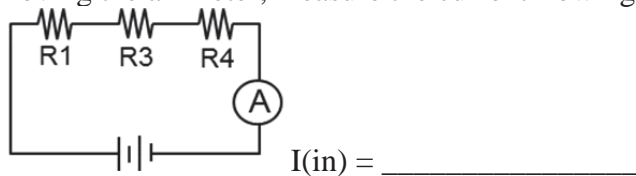
- d. Construct the following circuit.



- e. Measure the potential across R1, R3, and R4.

$V1 =$ _____ $V3 =$ _____ $V4 =$ _____

- f. How do these potentials relate to the potential of the power supply?
- g. Measure the current coming out of the power supply. $I(\text{out}) = \underline{\hspace{2cm}}$
- h. Moving the ammeter, measure the current flowing into the battery.



- i. Measure the current between the resistors. How are all of these currents related?
- j. Using the definition of resistance and the measured voltages, calculate the expected current through each resistor.

$I_1 = \underline{\hspace{2cm}} \quad I_3 = \underline{\hspace{2cm}} \quad I_4 = \underline{\hspace{2cm}}$

Activity 6: Grounding

While potential is always a relative measurement, it is useful to define a point of zero potential for a circuit. This point is called the **ground**. Exactly where we define the ground to be is arbitrary.⁶ One may select a particular wire in the device, the metal frame of the device (a chassis ground), or a metal rod driven deeply into the earth (an earth ground).⁷ If a circuit element is not somehow connected to ground (either directly or through a resistor), it is said to be “floating”.

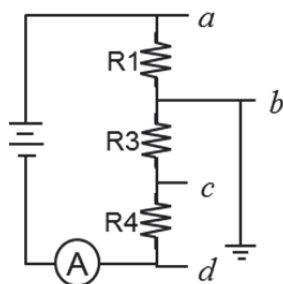
Note: The third socket of a standard North American electrical outlet is connected to a metal rod driven deeply into the earth.



For the circuit in the previous activity, declare ground to be the point between R1 and R3.

⁶ Similarly, the zero for gravitational potential energy is arbitrary.

⁷ By convention, grounding wires are green or bare, positive wires are red, negative wires are black.



- a. Connect the **COM** (or ground) probe of your multimeter between R1 and R3. Then measure the potential at points a , b , c , and d .

$$V(a) = \underline{\hspace{2cm}} \qquad V(b) = \underline{\hspace{2cm}}$$

$$V(c) = \underline{\hspace{2cm}} \qquad V(d) = \underline{\hspace{2cm}}$$

- b. Suppose that no part of the circuit may be more than 2 V from ground. Where should the ground be placed?

- c. Move the ground. Then measure the potentials to verify the circuit meets the requirement.

$$V(a) = \underline{\hspace{2cm}} \qquad V(b) = \underline{\hspace{2cm}}$$

$$V(c) = \underline{\hspace{2cm}} \qquad V(d) = \underline{\hspace{2cm}}$$