PHY152H1S – Practical 3: Introduction to Circuits

Don't forget:
- List the NAMES of all participants on the first page of each day's write-up. Note if any participants arrived late or left early.
- Put the DATE (including year!) at the top of every page in your notebook.
- NUMBER the pages in your notebook, in case you need to refer back to previous work.

Note that the activities below have numbers which refer to numbers in the Electricity and Magnetism Modules 2 and 4 at http://faraday.physics.utoronto.ca/Practicals/ .

Background

When water flows through a garden hose, we can characterize the rate of flow as the volume of water passing any cross section of the hose per time. Units for this flow could be m^3/s. Similarly, for a conducting wire electric charge can flow down the wire. We call the rate of flow of electric charge the *current*, which is the charge Q passing a cross section of the wire per time *t*. In SI units this is Coulombs per second or C/s. 1 C/s is also called an *ampere*, A. Conventionally the current is given the symbol *I* or *i*, so the definition of current is:

$$I \equiv \frac{\Delta Q}{\Delta t}$$

In order for water to flow in a hose a source of pressure is required. Similarly, for a current to flow in a wire a source of *voltage* is required. Common voltage sources are batteries, electric generators, and power supplies. In this Module we will be using a battery.

Note: the battery you will be using in the Activities is filled with acid. Do not lay it on its side or turn it upside down.

Activity 2.1 (20 minutes)

Banana Sockets
Wires

Mounted on a plastic frame is a light bulb and two *banana sockets*. On the bottom of the light bulb are two metal contacts which are connected to wires. The other ends of the wires are connected to the banana sockets, which are a convenient way to attach wires with a corresponding plug. The figure on the previous page shows the bulb, wires and sockets.


The figure to the right traces the conductors from the banana sockets through the light bulb. If you are viewing this in color, the conductors are in red.
A. Examine the mounted light bulb and identify the parts that
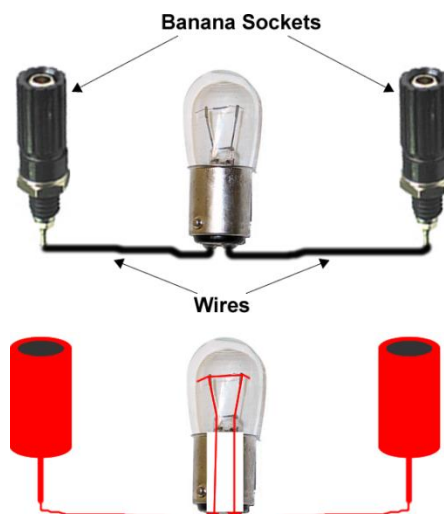
are indicated in the above figures. Connect a wire from each terminal of the battery to each of the banana sockets. The light bulb should light. It is good practice to use a red wire to connect to the red terminal of the battery marked +, and a black wire to connect to the black terminal of the battery marked -.

B. Here are four possible models for how the current flows in the wires when the light bulb is lit:
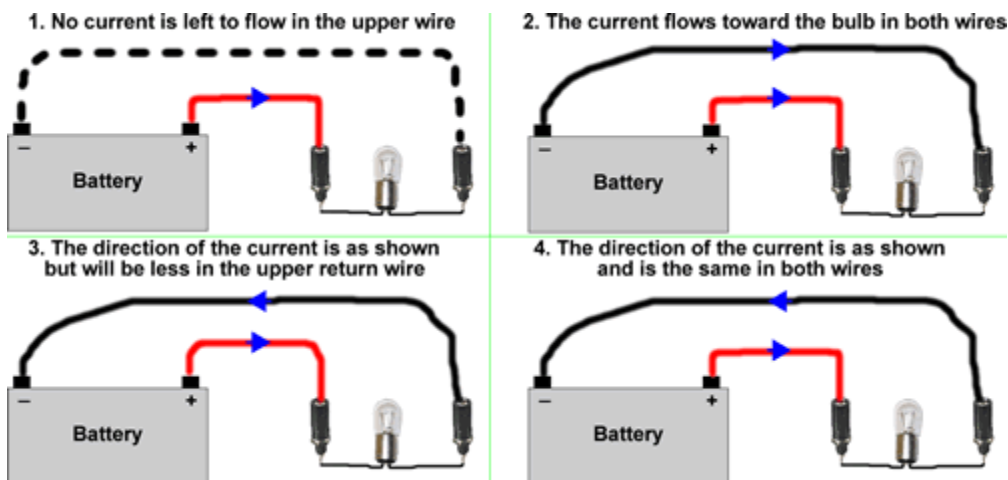
Which case is most correct? Why?

C. You are supplied with a *clamp meter*, which measures the current in a wire that goes between the jaws of the clamp. Appendix 1 describes how to use this meter. Use the meter to measure the current in one place along one of the wires. As you slightly move the position of the clamp the measured current will change a bit. Quantify this by guessing the error ΔI to one significant figure.[1]

D. Use the clamp meter to check your prediction of Part B. Were you correct?

Activity 2.2 (5 minutes)

Instead of drawing a picture of an electric circuit, we can schematically represent it with a *circuit diagram*. Here are a few elements of circuit diagrams.

Wire	
Wires that are joined	

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[1] Although one can carefully repeat the measurements of the current and calculate the standard deviation to get a value for ΔI, that will not be necessary here. This is a general principle: do things the simple way first. If you later discover that you need a more careful determination you can always go back and do so.

Wires that are not joined	
Light Bulb	
Battery	

For the Battery, the positive terminal is on the right and the negative terminal is on the left. Here is a mnemonic for remembering this: a + symbol has more line in it than –, and the longer line of the battery is the + terminal.

Draw a circuit diagram of the circuit of Activity 1.

Activity 2.3 (10 minutes)

In Activity 1 the light bulb had two conducting contacts on the bottom. Most light bulbs only have a single contact on the bottom, and use the conducting side of the base for the other contact.

Using the supplied unmounted flashlight light bulb, the battery, and only *one* wire can you make the light bulb light? You may not cut the wire.

If you do achieve this, please ask one of your TAs to observe the lit bulb and initial your notebook.

Activity 2.5 (10 minutes)

Meters that measure currents are called *ammeters*. Conventional ammeters, as opposed to the clamp meter you used in Activity 1, must be inserted in *series* into the circuit. The circuit diagram symbol for a conventional ammeter is shown to the right.
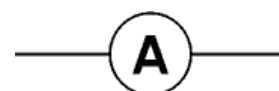
Here is the circuit diagram for using a conventional ammeter to measure the current in a wire of the same setup you investigated in Activity 1.
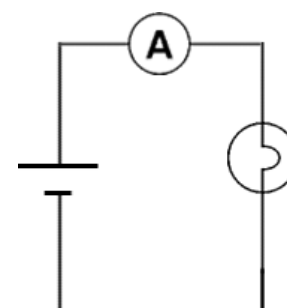
You are supplied with *multimeters* which can be used as conventional ammeters. Details on how to do this are in Appendix 2.A.

Wire the circuit and measure the current in the wire. Check your measurement using the clamp meter. Do they give the same results for the magnitude and direction of the current? How do the values compare to the results of Part D of Activity 1?

Activity 2.6 (10 minutes)

Voltmeters measure voltages of, say, batteries. The circuit symbol for a voltmeter is shown to the right.
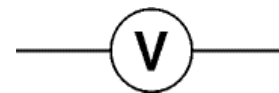
Voltmeters are typically wired in **parallel**. So the circuit diagram that measures the voltage of the battery while the light bulb is being lit is shown to the right.
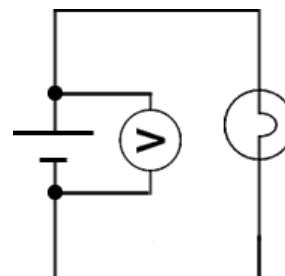
Instructions on how to use a multimeter as a voltmeter are given in Appendix 2.B. Use a multimeter to measure the voltage of the battery. The rated voltage is written on the front of the battery. How do the two values compare?

Disconnect the battery from the circuit and use the voltmeter to measure its voltage. How does it compare with the voltage when it was in the circuit?

Please disconnect all wires from all the circuit elements and turn off the meter when you have completed this Activity.

Activity 2.7 (15 minutes)

Rewire the circuit that lights the 6V 6W light bulb with the ammeter in the circuit again. In the circuit diagram to the right we have indicated a number of points in the circuit. Use the voltmeter to measure the voltage difference between **1** and **2**, **2** and **3**, **1** and **3**, **4** and **5**, etc. If the meter reads a very small voltage difference between two points, you should decrease the scale of the reading by rotating the upper knob: when the scale is too small the meter will read **-1**; in this case increase the scale of the reading.
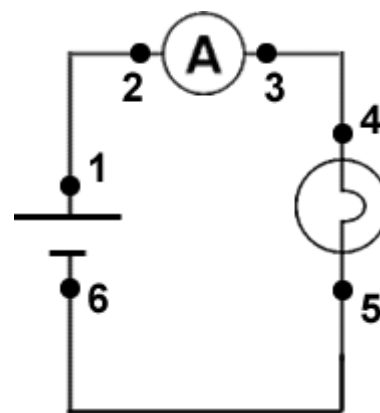
Do you see a pattern? What is the voltage "drop" across the light bulb? What about across the ammeter? One of the wires? Summarise your findings. Can you explain them? Why did we use the word "drop" above?

Activity 4.5 (25 minutes)

For a garden hose a pressure difference Δp generates the flow of the water. We shall give the symbol w to the volume of water per time passing a cross-section of the wire in m^3 / s. The hose has a resistance R to the flow of the water and we can define the resistance as:

$$R \equiv \frac{\Delta p}{w} \qquad (1)$$

This resistance is approximately constant for a given hose.

Similarly, a voltage difference ΔV causes the electric current I to flow in the wire, and the wire has a resistance R to the flow:

$$R \equiv \frac{\Delta V}{I} \tag{2}$$

Just as for the hose, for a given conductor the resistance is usually approximately constant. Equation 2 is called *Ohm's Law*. The unit of resistance is *volts / ampere*, which is called an *ohm* Ω. (Ω is the Greek letter *omega*.)

The circuit diagram symbol for a resistance is:

A. A hose of length L and area A is shown. How would you expect the resistance of the hose to the flow of water to depend on its length? How might the resistance depend on its area?

B. A wire of length L and area A is shown. How would you expect the resistance of the wire to the flow of electric charge to depend on its length? How might the resistance depend on its area?
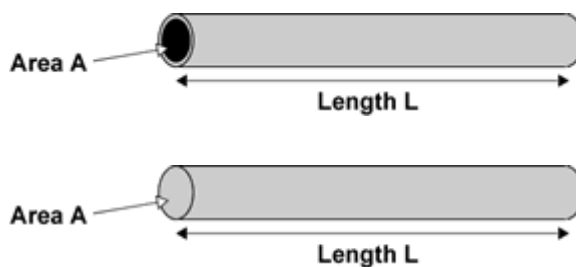
C. A perfect ammeter and a perfect wire both have zero resistance. In Activity 2.7 you measured a number of voltage differences between points 1, 2, 3, 4, 5 and 6. From that data, what is the actual resistance of the ammeter? Of the wires? Calculate the resistance of the *6V 6W* and the *6V 1W* light bulbs.

For the light bulb, you will need to know that as it heats up its, resistance changes. Thus when doing measurements of a light bulb in a circuit, be sure to give it a few seconds to reach equilibrium.

In terms of the resistances of the wires, ammeter, and light bulb we can represent the circuit as shown: in this representation the lines connecting the circuit elements have zero resistance.
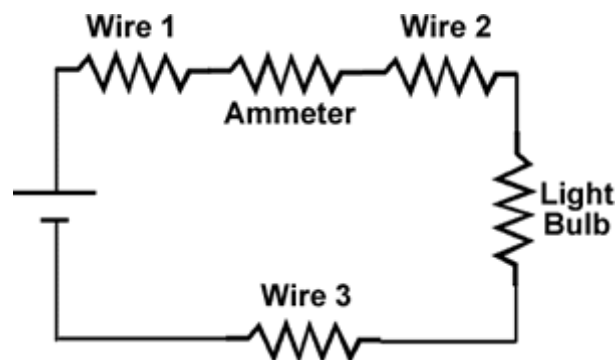
Activity 4.7 (If You Have Time)

You are supplied with two short wires which we will assume are perfect and have zero resistance. The plastic cylinder of the banana sockets of the mount for the light bulbs can be unscrewed so that a wire can be inserted into a hole in the conductor. Use the two wires to connect two of the *6V 6W* light bulbs together in parallel and place the combination in a circuit with an ammeter and the battery. On the left is a circuit diagram, and the diagram on the right represents the components as resistors.
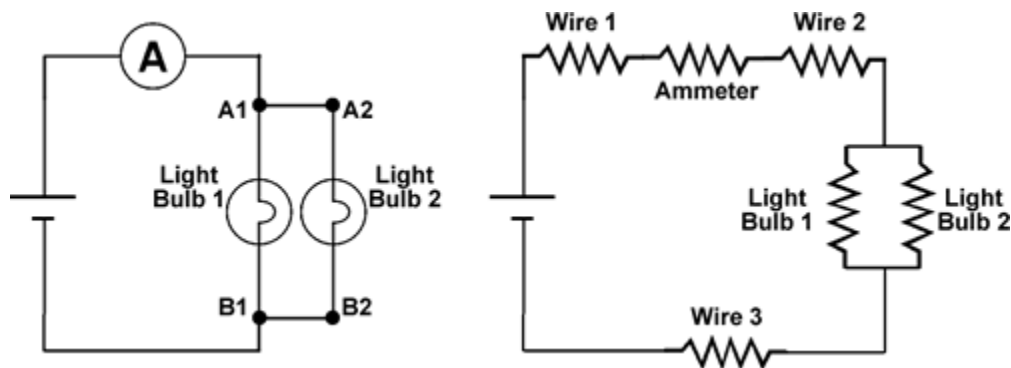
The current in the circuit may be over 1A. As discussed in Appendix 2, the inputs to the ammeter should be connected to **10A COM** and **10A** sockets.

A. The two short wires are the segments between points **A1** and **A2** and between **B1** and **B2**. When you measure the voltage across the two light bulbs, does it matter whether you connect the voltmeter across **A1** and **B1**, across **A2** and **B2**, across **A1** and **B2**, or across **A2** and **B1**? Why?
B. Say the resistance of each light bulb is R. Without using equations but using the reasoning of Part B of Activity 5, predict the effective resistance R_{eff} of the two bulbs together in the circuit.
C. Measure the effective resistance. Was your prediction correct?
D. If two different resistors R_1 and R_2 are wired in a circuit in parallel, what is the effective resistance R_{eff} of the two? You may need to do a derivation to answer this question.
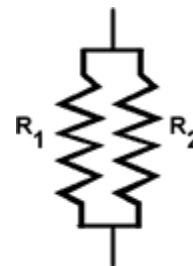
Appendix 1 – The Clamp Meter

A *clamp meter* measures the current in a wire that passes through the jaws of the circular clamp. For now we will treat how the meter does this as "magic"; in a later Module we will return to investigate how it works.

The jaws may be separated by pressing on the **Clamp Opening Handle**.

When the current is flowing in the direction shown, the reading will be positive; if the current is flowing in the opposite direction to that shown the reading will be negative. There is a small arrow on the inside of the jaws of the clamp indicating the current direction shown in the figure.

Here is a close-up of the controls of the meter. The **Function Select** knob has three positions:

1. **Off**
2. **400A**
3. **40A**

We will be using the **40A** function.

After turning the meter on it must be zeroed.
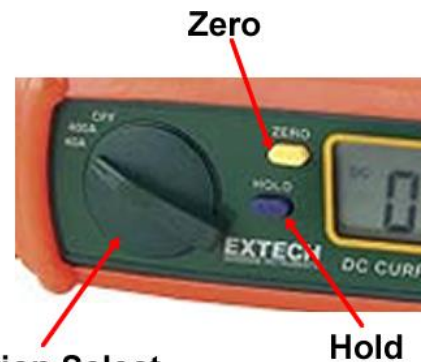
1. Place the meter close to the part of the wire whose current will be measured and orient the meter as it will be when it is clamped around the wire.
2. Press **ZERO**: The display will read *ZERO*.
3. Press on the **Clamp Opening Handle** to separate the jaws of the clamp, place the clamp around the wire, and release the handle.

The meter will now read the current in the wire in *amperes*.

To measure the current at a different location or with the meter at a different orientation:

1. Move the meter close to where it will do the new measurement, oriented as it will be when clamped around the wire.
2. Press on **ZERO**; the display will no longer read *ZERO*.
3. Press the **ZERO** button again: the display will read *ZERO*.
4. Clamp the meter around the wire and read the current on the display.

If it is difficult to see the display because of the orientation of the meter:

1. Press on the **HOLD** button. This will cause the reading to be held and the display will read *HOLD*.
2. Remove the meter and read the current on the display.
3. Press on the **HOLD** button to return the meter to normal operation. The display will no longer read *HOLD*.

Appendix 2 – The Multimeter

This module uses multimeters, which are devices capable of a number of different electrical measurements. With the flexibility of this instrument comes a price: at first glance there is a bewildering array of controls and inputs. This Appendix will guide you through this complexity to learn how to use the meter to measure DC currents and voltages.

Just as for the clamp meter, for now we will treat how the instrument actually works as "magic".

Note: typically a multimeter is capable of measuring currents and voltages in a number of different ranges. You should always begin measurements with the largest available range. This is because if the voltage or especially the current is much larger than the selected range you can easily blow a fuse inside the meter.

Note: particularly for current measurements, turn off the power to the circuit or disconnect the battery before putting the meter in the circuit.

Note: please conserve the batteries inside the meter. When you are finished using the meter turn it **OFF**.

Note: if the meter starts to beep, something is wrong! Please turn off the meter and the power to the circuit and investigate further.

2.A – Measuring DC Currents

The figure below shows the multimeter set up to measure a DC current with a maximum value of 10 amperes.
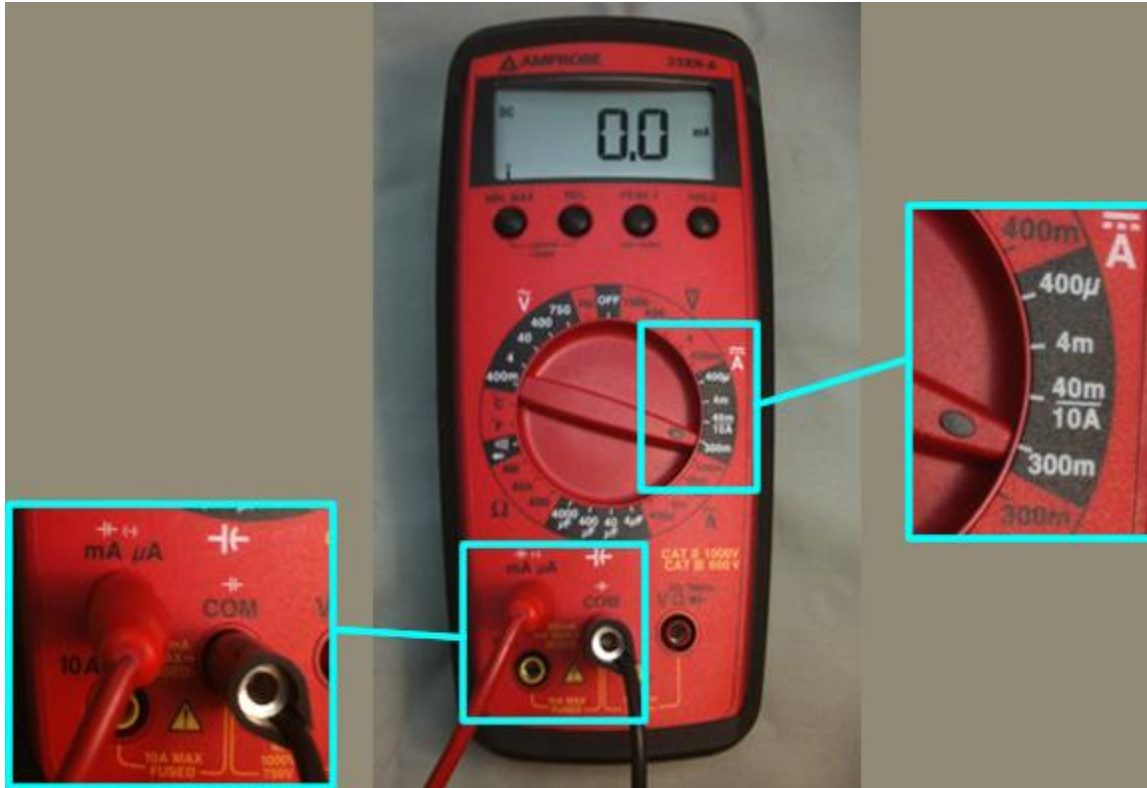

Note that:

1. The red wire is connected to the **10A** input on the meter.
2. The black wire is connected to the **COM** input on the meter. This is the common input which is paired with the various other inputs depending on what you are trying to measure.
3. The rotary knob points to **40m/10A**. When the red wire is connected to the **10A** input as here, this measures a 10 ampere maximum DC current. The icon below is the symbol used by the meter for DC currents.

$$\overline{\overline{\text{A}}}$$

If the current flows through the meter from the **10A** input to the **COM** one, the display will be a positive number. If the current is flowing the other way, it will be negative.

If you are sure that the current that you wish to measure is less than 300 mA, then you may set up the meter as shown on the next page. If you are not sure, first do a 10A measurement as just described.

Note that:

1. The red wire is connected to the **mA μA** input on the meter.
2. The black wire is connected to the **COM** input on the meter. This is the common input which is paired with the various other inputs depending on what you are trying to measure.
3. The rotary knob points to **300m**. This selects a maximum current of 300 mA.

You should always begin with the **300m** range selected. If the display reads a current less than 40 mA, you can then select the **40m** range. Similarly, the **4m** range has a maximum of 4 mA, and the **400μ** range has a maximum of 400 μA.

If the current flows through the meter from the **mA μA** input to the **COM** one, the display will be a positive number. If the current is flowing the other way, it will be negative.

2.B – Measuring DC Voltages

The figure on the next page shows how to set up the meter to measure DC voltages.

Note that:

1. The red wire is connected to the **V Ω** input. This input can measure either voltage or resistance. Here we will measure DC voltage.
2. The black wire is connected to the **COM** input. This is the common input which is paired with the various other inputs depending on what you are trying to measure.
3. The rotary knob points to **1000**. This selects a maximum range of 1000 V. The icon shown to the right is the symbol used by the meter to indicate DC voltages, and the **1000** that is selected with the rotary knob in the above figure is in the group of ranges indicated by this symbol.

You should always begin with the **1000** range selected. If the voltage is less than 400 V, you can then turn the rotary knob to the **400** position. Similarly, there are ranges for 40 V, 4 V, and 400 mV.

If the voltage at the **V Ω** input is positive relative to the voltage of the **COM** input, the display will be a positive number. If the **V Ω** voltage is negative relative the **COM** one, the display will be a negative number.