DC-CIR

Direct-current Circuits

revised August, 2021

Learning Objectives:

During this lab, you will:

1. Learn how to use a digital multimeter (DMM) to measure currents, potentials, and resistances.
2. Explore and obtain a basic understanding of direct current (*DC*) circuits.
3. Learn how to read circuit diagrams.
4. Test the limits of Ohm's law.
5. Review how to estimate the uncertainty in a quantity that is calculated from quantities that are uncertain.

A. Introduction

This experiment should provide you with a basic understanding of the properties of DC circuits. The voltage and current measurements in DC circuits are roughly constant in time, in contrast to alternating current (*AC*) circuits in which they vary periodically.

You will not have covered DC circuits in the course lectures before attempting this lab. *Don't worry about this*; all of the background information you need is supplied below. Also, physics is fundamentally an experimental science; experiments are often performed first and then a theory is developed to explain the results rather than the reverse. One of the things you should learn how to do is perform a good experiment when you *don't* understand the underlying theory. This is the rule, not the exception, in science.

Many of the physics labs this semester include elements designed to train you in general laboratory skills and are not simply meant to reinforce material taught in the lectures. This is done not primarily to train you as a laboratory scientist but to demonstrate appropriate methods of testing any hypothesis that someone may put to you. The DC Circuits lab includes several tasks that *should* be a review of skills you learned in your previous physics laboratory course. You will have to make appropriate plots of a set of data, perform a linear regression, estimate errors and use error propagation techniques to determine how errors in measurements lead to errors in factors calculated from the data. Most of these tasks will be performed with the research-quality data analysis software package, *Origin*. If you have forgotten how to do any of these procedures or have never seen them, you can refer to the appendices of this manual for help (***or ask your instructor***).

There is no paper due for this lab. There is instead a worksheet (*plus a few graphs*) that you must fill out and submit to Canvas a week after doing the lab. The worksheet can be found in Appendix XI. ***You should not fill out this worksheet as you do the lab.*** Your work should instead be entered into your lab notebook and only transferred to the worksheet once you have more carefully considered the answer to each question. You may want to refer to the worksheet as you do the lab to be certain you gather the necessary data; this is fine, but note that issues that must be addressed for the worksheet are indicated in this manual by underlining. (***Underlining will also be used to indicate issues that must be addressed in papers for upcoming labs.***) Where plots are required, you should save them as pdf to the L: drive so that you can access them later and attach them to your worksheet.

B. Principles

A simple electrical circuit consisting of a battery, $\mathcal{E}$, with some internal resistance, r, and an external resistor, R, is illustrated in Figure 1. The conducting wires through

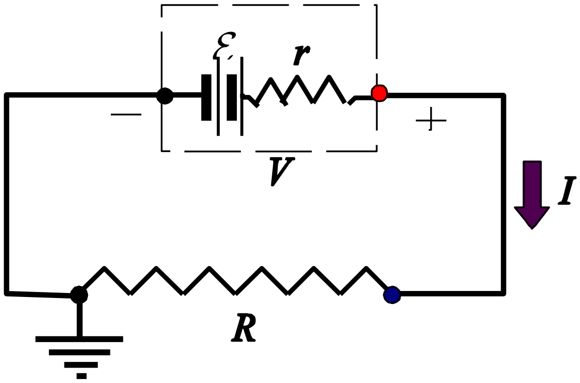

Figure 1: A simple circuit.

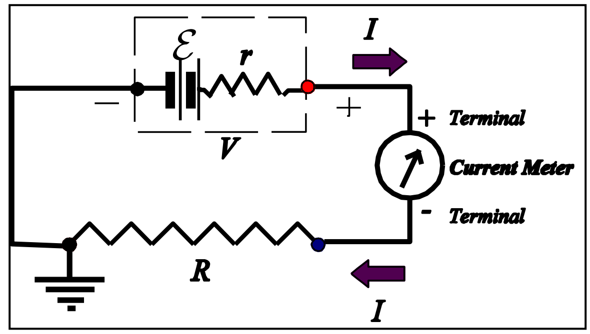

Figure 2: Measuring current

which the current flows are represented as solid straight lines.

B.1. Current

Current is the rate of flow of charge past any point in a circuit. By convention, current is in the direction positive charge carriers *would* move ***if*** they carried the current. In reality, it is negatively charged electrons that carry the current within most circuit elements and they move opposite to the direction that the current flows. Current as we've defined it flows from positive to negative voltages, + to -, or from regions of higher potential to regions of lower potential (*potential will be defined later*).

Current is represented in circuit diagrams such as Fig. 1 by the symbol I next to an arrow which shows the direction of the current. The value of the current may be positive or negative; a negative value simply means that the actual direction of the current is opposite to the direction indicated by the arrow.

The unit of current is the *ampere* (A) or *amp.* One amp is one coulomb of charge per second. A current of about 1 ampere flows through a normal 100 watt incandescent light bulb. The electron beam that creates the image in a cathode ray tube, *CRT*, of a television set or computer monitor is about 1 microampere. The digital multimeters, DMMs, used in this experiment can measure currents over this entire range, microamps to several amps.

One must measure the current ***through*** a circuit element, not *across* it. It is generally necessary to "break" a circuit to insert a current meter into the path. This is shown in Fig. 2, which is identical to Fig. 1 except that a meter has been added to the circuit to measure the current flowing ***through*** the resistor R. The meter could also have been inserted on the other side of the resistor. The current flowing into the resistor is the same as the current flowing out of it. In fact, the same current flows through all circuit elements that are connected in series, *i.e.*, without *branches* to multiple circuit elements.

DMMs can be connected without regard for the direction of the current flow and will simply display a negative sign if the current is flowing from the negative to the positive terminal.

It is important that the current meter have a resistance much less than R or it will have a significant effect on the current you are trying to measure. An *ideal* current meter would have zero resistance; real DMMs used as current meters will have resistances of a fraction of an ohm.

B.2. Voltage

The voltage or potential difference between two points is defined as the negative of the line integral of the electric field between those points. Since electric field is the electric force per charge and since the line integral of a force is the work done by that force, voltage is just the work (*or energy*) per charge required to move a charge between two points in a circuit.

Only differences in voltages between points are defined by fundamental equations, there is no absolute scale. However one often picks a reference point defines it as 0 volts and uses it to measure other voltages in the circuit. In theoretical problems, the reference point is typically chosen as $V = 0$ at infinity. Such a choice is not practical in a laboratory since you can't connect a wire to infinity, so another reference must be chosen. This reference point is called either *common*, *ground* or *Earth*. The latter two terms are strictly correct only if the reference is the Earth itself. The third prong in a standard 110 V outlet and the larger of the two rectangular prongs actually are connected to the Earth and many of the power supplies you will use this semester really do produce a certain voltage with respect to the potential of the Earth. However people tend to be sloppy with these terms. In a circuit diagram, a common is indicated by a small upside-down triangle "∇" connected at some point to the circuit. Figs. 1 and 2 include an Earth ground, indicated by a short series of horizontal lines cut to fit inside an imaginary symbol for a common.

One measures the potential difference ***across*** a circuit element. You can do this without breaking the circuit by putting the two voltage probes of a DMM on either side of the circuit element. Figure 3 shows a voltage meter connected ***across*** the resistor *R*. The DMM will simply display a negative sign if you connect its positive terminal to a lower potential than its negative terminal. An ideal voltmeter would have infinite resistance so that none of the current originally flowing through *R* is diverted into the voltmeter. A real voltmeter must have a resistance much larger than any *R* to which it will be connected. DMMs when used as a voltmeter typically have a resistance in the range of 10^6-10^7 Ω (1-10 MΩ.).

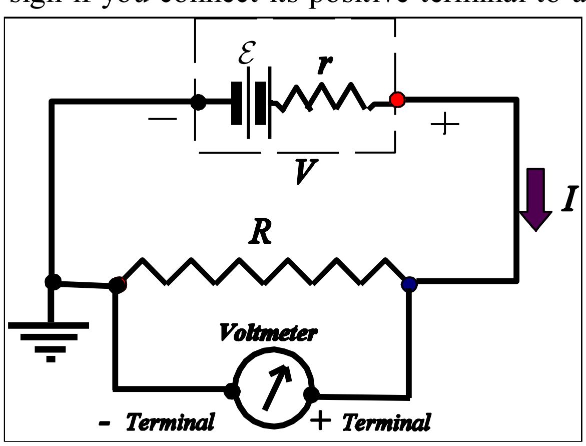

Figure 3: Measuring voltage.

B.3. Resistance

The voltage across a circuit element *may* be related to the current flowing through it by the equation

$$V = IR \tag{1}$$

where *R* is the *resistance* of the element. Resistance is measured in ohms (Ω). (*We usually assume that the wires in a circuit have negligible resistance compared to that of the actual circuit elements. A typical wire or connection between wires in this lab may have a resistance of a hundredth of an ohm.*) Eq. 1, with the added condition that *R* is a constant, independent of the current in the circuit, is *Ohm's Law*. You will investigate several circuit elements to discover whether or not they obey Ohm's Law.

In a circuit diagram, a resistor is represented as a short section of a triangular wave (Fig. 1). There are many different types of commercial resistors available. You will use mainly cylindrical carbon resistors. Common sizes range from fractions of ohms to millions of ohms (MΩ). Most carbon resistors are marked with colored bands to indicate their resistance and their precision (or *tolerance*). The colored bands include the colors in the optical spectrum and have the values listed in Table 1. Read the bands starting from the end of the resistor that has one of the colors listed in Table 1. The first two bands give a number from 10 to 99 and the third band gives a power of ten by which this should be multiplied. Thus, a resistor banded yellow, violet, orange has a nominal resistance of 47

$\times 10^3\ \Omega$ or 47 kΩ. (*If the third band is gold, this indicates a power of 10^{-1}; silver represents 10^{-2}.*)

Value	Band		Value	Band
0	black		5	green
1	brown		6	blue
2	red		7	violet
3	orange		8	gray
4	yellow		9	white

Table 1 Resistor Color Codes

If a 4th band is present, it indicates the precision or tolerance of the nominal value. The convention for tolerance is given in Table 2. You need not worry about tolerances for this lab experiment.

Band	no band	silver	gold
Tolerance	20%	10%	5%

Table 2: Resistor Tolerances

B.4. Power

A resistor *resists* the flow of current. Charges lose energy moving through a resistor, with the electrical energy being converted to heat. The power loss is the charge per time passing through the resistor (*the current*) times the energy loss per charge (*the voltage drop*). This gives the energy loss per time, or power,

$$P = IV = I^2R = V^2/R \qquad (2)$$

where the third and fourth terms in Eq. 2 are easily derived from the second term using Ohm's Law, Eq. 1. Although all three definitions of P are equivalent, generally one of them is more convenient to use in any given situation.

The power that a resistor can dissipate without being damaged may be indicated only by its size. The small, color-coded resistors that you will use this semester may dissipate ⅛, ¼, ½, 1 or 2 watts. Large-power resistors may dissipate tens or hundreds of watts.

B.5. Batteries and Circuits

If electrical energy is lost as charges move through a resistor, something must be supplying that energy to keep a DC current flowing. The source of energy can be either a battery or a power supply. In the case of a battery, the energy comes from electrochemical reactions and the voltage it produces is often referred to as an *electromotive force*, *EMF* or $\mathcal{E}$. The potential energy of a positive charge increases inside the battery as charges are moved electrochemically from the negative terminal of the battery to its positive terminal. The charges' energy or potential then decreases as they travel outside the battery from the positive terminal around the circuit back to the negative terminal. (*Note that this description assumes positive charge carriers. We know this is usually wrong, but it seldom matters in practical circuits.*)

A battery is made up of one or more cells. A single cell typically supplies 1.5 volts. Each cell is represented in a circuit diagram such as Fig. 1 by a short, thick line (the *negative* or - plate) and a longer, thin line (the *positive* or + plate).

A real battery has *internal resistance* r so that, when the battery is providing current, the external potential difference V available at the terminals will be less than the internal EMF by a factor Ir. This will not be a problem as long as $r \ll R$, although it can cause a battery to get warm as it delivers current. *We shall omit the internal resistance from diagrams unless it plays an important role in the circuit.*

A power supply produces a *DC* voltage using alternating current, *AC*, supplied by the local electric utility company. How this works is not a concern right now, but you will encounter many of the important principles behind this process through the course of this semester.

C. Apparatus

This experiment requires a Pasco circuit board, various resistors, a small light bulb, and two digital multimeters (*DMMs*). *You should read Appendix X about the Pasco boards before attempting this lab.*

Whenever you use a DMM be certain that the probes are plugged into the proper inputs (*black wire into the common input and the red wire into either the current input or the volts/ohms input*) and that you've properly set the function and scale (*volts, current or ohms*; *AC or DC*; *with a scale that won't be overloaded by the expected signal*) before connecting the meters to the circuit. A mistake can destroy a DMM. For example, consider what happens if you leave a DMM on its amps function while trying to measure a voltage. An ideal current meter has an input resistance that is nearly zero for measuring current so as not to affect the current being measured. Thus Ohm's Law suggests that a current $I = V/0$ = "HUGE" will flow through the DMM. This won't actually happen only because something will blow up first (*hopefully just a fuse, sometimes followed by the Lab Director*).

For each type of measurement that you make, estimate its uncertainty. Be reasonable in your error estimates. Assuming that errors have a Gaussian distribution (*bell curve*), your error estimates should be for about 1 standard deviation from the mean and not for the maximum or minimum error that you might ever make. (*This means that about ⅔ of the data points that you acquire should fit within your error bars with the other ⅓ outside this range.*)

The manufacturer of the DMMs specifies their accuracy as ± 0.5% of the reading and ± 1 of the last digit. This last term means that the last digit displayed on the meter may not be trusted to more than one unit, *i.e.* a reading of 10.12 could be 10.11 or 10.13 and may flicker between these readings. The ± 0.5% contribution may be more or less important than the ± 1 digit term; you may be able to ignore one or the other. You must use your own judgment to decide which of these terms is more important for each of your own measurements or whether you must include both of them.

D. Ohm's Law

D1.) Before placing the resistor in the Pasco board, **use a 100 Ω resistor and <u>measure the value of the resistor with a DMM on its OHMS function</u>**. You will need to **use the banana plug cables at your station to make connections between the resistor and the DMM**. Banana plugs are the connectors that fit in the jacks on the bottom of your DMM. You'll also need alligator clips from your parts box. These will slip onto the other end of the banana plug cables and let you clip onto individual resistors or onto the Pasco board springs. ***Check the website or Canvas for detailed photos of this equipment.***

D2.) Construct the circuit shown *schematically* in Figure 4 (next page). Circuit *diagrams* illustrate a circuit so that its function can be readily understood. A circuit *layout* is given in Figure 5. The circuit layout may be more useful in actually constructing the circuit since it gives a physical position for each component on the Pasco board. (*Circuit diagrams are more universally understood than the Pasco board layouts; you should use diagrams (rather than layouts) in your lab papers when you want to graphically describe a circuit.*) ***A photograph of this setup is posted on the Lab web site.* You should use the wires included in your parts box to make connections between springs on the Pasco board.**

You will use the batteries on the Pasco board to provide a 3-volt source; to

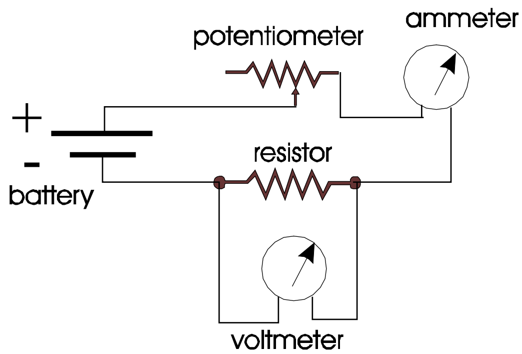

Figure 4: Circuit diagram for Part D.

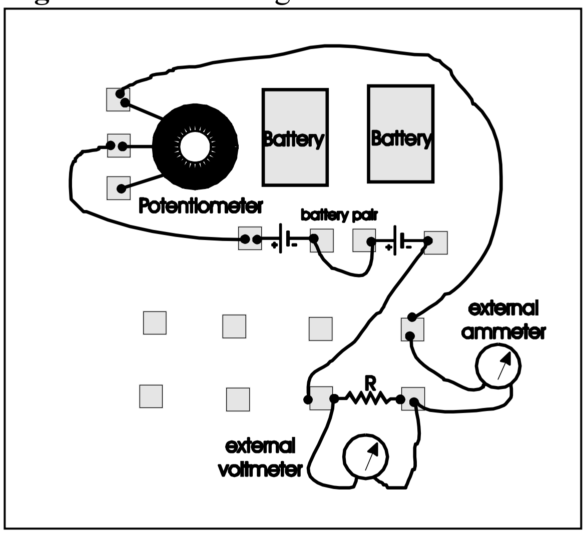

Figure 5: Circuit layout for Part D.

do this, connect the - spring terminal of the left 1.5 V battery to the + spring terminal of the right 1.5 V battery. *However, do not complete this connection until the DMMs are properly set up as described below*.

The potentiometer or *pot* on the Pasco board is used here as a 0 - 1000 Ω (or 0 - 1 kΩ) variable resistor to provide control over the current flowing through the 100 Ω resistor. The pot has three connections; one at each end of a resistor and a third to a *wiper* that can move continuously from one end of the resistor to the other. The connection to the wiper is indicated by an arrow in Fig. 4 and on the Pasco board. (*You need connections to the wiper and to one of the two ends of the pot to use it as a variable resistor.*)

You should expect a maximum current of 3 V / 100 Ω = 30 mA when the pot is adjusted to its minimum resistance (such that $R_{pot} \approx 0$). **Set the DMM you use to measure current to an *appropriate* DC scale before powering the circuit by completing the battery connection**. (*'Appropriate' means use the most sensitive scale possible without overloading the DMM, so as to obtain as many significant figures as possible. You can and should change the scales as necessary during the course of the experiment. You will normally be able to read 4 significant figures. DC scales are distinguished from AC scales on the DMMs with a little symbol next to the volts, V, or current, A mark. DC is indicated by a mark that is supposed to indicate a flat line signal '⎓', while AC signals are indicated by a short segment of a sine wave, '~'.*) **The maximum voltage that you can obtain is 3 V and you should set up the DMM used to measure this voltage appropriately.**

Also, be certain that the DMM probes are plugged into the proper jacks on the meters; it is common to use separate jacks for different functions. (*The Mastech DMMs use the second jack from the right, labeled COM or COMMON, for all voltage, current and resistance measurements. The far right V/Ω jack is used as the second input for voltage and resistance measurements. The second jack from the left is used for most current scales while the far left jack is used in conjunction with the 10 A scale for measuring large currents.*)

D3.) After all the other connections are made and the DMMs are turned on with the correct settings, **complete your circuit by joining the wires that connect the two batteries**. **Starting with the pot turned fully** (*this may take up to 10 turns*) **in the direction which gives <u>minimum current</u>** (*which should mean maximum resistance for the pot*), **<u>read the current that flows through the circuit and the resulting voltage across the 100 Ω resistor</u>. Then turn the pot all the way in the other direction** (*for the pot's minimum resistance and maximum current*) and **<u>repeat these measurements of current</u>**

<u>and voltage</u>. Now make three or four additional measurements with the pot and current set between these two extremes and plot your set of data points, *V vs. I*, using *Origin*, however, before doing so give some thought to where you should take these additional data points; should they be separated by equal intervals of current, equal turns of the pot, particular *simple* values of current or voltage, etc.? (*When making plots of data points, choose SCATTER mode so that you can see your data points. One of the best ways to construct such plots in Origin is to be certain that none of the data columns is highlighted. Then, when you select PLOT → SCATTER → SCATTER , Origin will open a window that lets you choose which column to use for the x-axis, y-axis, error bars, etc. Also, by convention, when someone says to plot quantity α vs. quantity β, this means that α should go along the y-axis while β goes along the x-axis.*)

Your Origin data should also include error bars based on your estimates of the uncertainties in determining *I* and *V* from your DMMs. Any data that you quote in your lab papers should include such error estimates. (*To put error bars in your plot, add two columns to your table of data using COLUMNS → ADD NEW COLUMN. You could type in error estimates by entering each one individually. Often it is better to enter a formula for these error estimates. Highlight each new column in turn, right click on its heading, choose SET COLUMN VALUES and enter a formula that describes your error estimate. When you make your plot you can then choose these columns to show their respective error bars. It is also recommended that you set the data points to circles rather than squares and to a '3 point' size rather than the default 8 point. This makes it easier to see the error bars. To change this setting, click on a data point or on the data point label on the upper right of your plot or choose FORMAT → PLOT PROPERTIES.)*

D4.) Do a linear fit to your data to obtain the resistance from the slope of this plot (*and don't forget that if you plotted the current in mA rather than A, you have a factor of 1000 to contend with*). **<u>Attach to your worksheet a copy of this plot showing the linear fit, the linear fit parameters</u>** <u>(*slope & intercept plus errors in both of these quantities*)</u>, **<u>as well as a comparison to the DMM value for *R*'s resistance.</u>** (*Don't be shocked if the two measurements of resistance do NOT agree within error bars; there are subtle differences between the two measurements that can account for such discrepancies.*)

You should now have proven that Ohm's law holds, at least under the conditions of the experiment you have performed. The voltage across a resistor is linearly proportional to the current flowing through it and the proportionality constant is determined by the resistor you use.

D5.) (Optional) *If you have spare time and would like to exercise your brain, consider the following issue, which is not required work. Although a linear fit should look very good, a second order polynomial will probably fit the data even better. Consider how you would experimentally counter someone's hypothesis that Ohm's Law should read $V = a + bI + cI^2$ where a, b, and c are the constants needed to describe a resistor. Try a second order polynomial fit to your data with Origin. Examine the fit parameters, a, b & c, and consider how you could quantitatively demonstrate that a linear fit is sufficient. Your TA may offer extra credit for anyone who can demonstrate this point, attaching your analysis to your worksheet.*

E. Combinations of Resistors

In the following measurements of several resistors connected in series and in parallel, you will **measure their individual resistances using the ohmmeter function of a DMM**. This function operates on the principle of Ohm's Law. The DMM has a built-in power source (*a battery*) and can send a known current through a circuit element and measure the voltage across the element. The resistance is then given by $R = V/I$. You will examine how series and parallel combinations of these resistors behave when used in a simple circuit.

E.1. Series Resistors

E.1.1.) A simple application of Ohm's Law can be used to show that when resistors are connected in series, the combination of resistors is equivalent to a single resistor of value

$$R_{equiv} = R_1 + R_2 + R_3 + \ldots \qquad (3)$$

Pick out two 100 Ω resistors (*naming them* R_1*, and* R_2), **one 1 kΩ resistor** (R_3), and **one 47 Ω resistor** (R_4) from the components supplied to you, using the color codes from Table 1 for quick identification. ***Do NOT*** trust the labels on the parts box; remember that several generations of students have used these boxes before you, often returning parts to the wrong bin. **Using a DMM in ohmmeter mode, measure the resistance of each individual resistor.** (*Keep track of which 100 Ω resistor has which measured resistance.*) In your lab notebook, create a six-column table where the first column contains the resistor identification numbers 1-4 and enter the measured resistor values, with error **estimates in the second column. In the third column, enter the equivalent resistance predicted by Eq. 3 as each successive resistor is added to a series combination.** (*The first row of this column should just be the* ***measured*** *value of* R_1*, the second row is* $R_1 + R_2$*, etc. Use the actual, measured values, not the 'nominal' values 47 Ω, 100 Ω, 1 k Ω.*)

E.1.2.) Connect the four resistors in *series* on the Pasco board, as illustrated in Fig. 6, using the Pasco board batteries to supply power and two DMMs to measure the

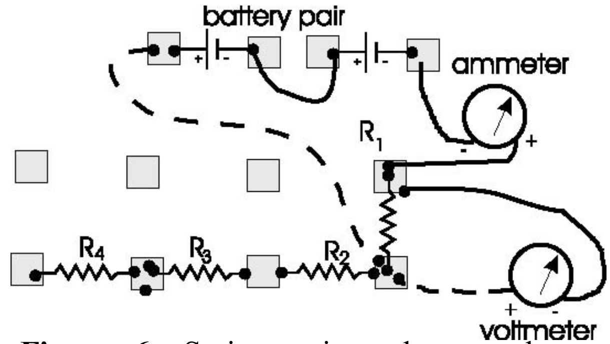

Figure 6: Series resistor layout, shown measuring only the first resistor.

voltage across and current through each series combination of your table (R_1 *alone,* $R_1 + R_2$*,* $R_1 + R_2 + R_3$*, etc.*) **These voltage and current values, with error estimates, should be entered in the fourth column and fifth columns, respectively, of your table**.

To make these measurements, **start with the + battery connection and + voltmeter connection on the node between** $\boldsymbol{R_1}$ **and** $\boldsymbol{R_2}$ (*a node is where two or more electronic devices are connected or where a circuit terminates.*) **Measure the voltage across and current through one resistor alone (**$\boldsymbol{R_1}$**), then move these two connections to the next node to measure two resistors in series and continue in sequence until you have measured all four resistors in series.** (*The dashed lines in Fig. 6 represent the connections that must be moved, jointly, to each node of the circuit. Note that the resistors to the left of the battery and voltmeter connection in Fig. 6 are effectively isolated from the circuit. Also, since the DMM used as a voltmeter is always connected across the batteries, the voltage you measure shouldn't change if the batteries really do behave as ideal voltage sources. Do they?*)

E.1.3.) Calculate the equivalent resistance for each combination of resistors, $\boldsymbol{R_{equiv} = V/I}$ **(*where V and I are the values you just measured*) and enter these values in the sixth column of your table.** Compare the entries in your third and sixth columns to test the theoretical prediction for the behavior of resistors in series. This table should be included in your worksheet, along with a detailed error analysis for two resistors in series. (*Start your error analysis with the estimates of error in your measurements of R, V and I. Show how you eventually arrive at the error estimates for the values in the third and sixth columns. Although you really should do the error analysis for the other rows in this table if you want to compare experiment to theory, we are not requiring this in an attempt to reduce the workload.*)

E.2. Parallel Resistors

Later this semester, you will see in lecture how to use Ohm's Law to show that when resistors are connected in parallel, the total equivalent resistance R_{equiv} is given by

$$\frac{1}{R_{equiv}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \qquad (4)$$

(*A parallel connection means that the resistors are electrically joined to each other at both ends. The voltage drop across each resistor must then be the same but any current flowing into this arrangement is divided between the resistors.*)

E.2.1.) Create another six column table with the first two columns duplicated from your previous table. In the third column, enter the prediction of Eq. 4 for the equivalent resistance R_{equiv} for parallel combinations of R_1 alone, $R_1 + R_2$, etc. (*Be careful to enter R_{equiv}, not $1/R_{equiv}$.*)

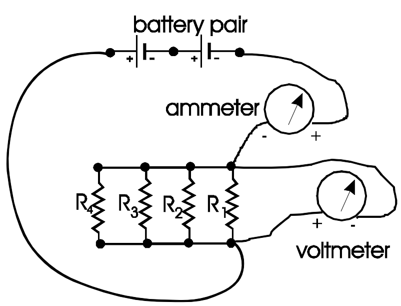

Figure 7: Four resistors in parallel.

Once again you need only work out the error estimates for two resistors in parallel.

E.2.2.) Remove all of the resistors except R_1 from the Pasco board, *keeping track of which is which.* **Restore the voltmeter and ammeter connections so that you can measure the voltage across and the current through R_1**, as shown in Fig. 7. The values of voltage and current should be copied into the fourth and fifth columns of your table. Then **insert R_2 in parallel with R_1 and measure the voltage across and current through this combination**. You can probably make this parallel connection by inserting R_2 into the same pair of springs that hold R_1. (Figure 7 shows the circuit schematic for the first three resistors connected in parallel. We are NOT supplying a circuit layout; figure out your own!)

Then **add R_3 in parallel with R_1 and R_2**, and **retake these measurements. Continue this sequence until all four resistors are connected in parallel.** (*Note that you can generally install at least 3 resistors between a single pair of springs, placing these resistors into adjacent loops of the springs. Additional resistors can be inserted into a neighboring pair of springs using two wires to join the sets.*)

Enter into the sixth column of your table the effective resistance, *V*/*I*, of each combination of resistors in parallel. Compare the entries in the third and sixth columns to confirm or contradict Eq. 4. **Include this table in your worksheet. Also attach a sheet in which you work out the detailed error analysis for the arrangement of two resistors in parallel.**

F. Where Ohm's Law Fails

Ohm's Law only applies to certain circuit elements and materials. There are many important situations in which ***V* does not depend linearly on *I*** and one cannot then describe the circuit element with a single number, a resistance, or measure it properly with an ohmmeter.

F.1. Incandescent Lamp

F.1.1.) Before constructing the circuit described below, **<u>use your DMMs OHMS function to measure the resistance of the light bulb mounted on the Pasco board</u>.** Then **construct the circuit shown in Figure 8, using the 3 V battery source, the bulb and the pot on the Pasco board. Use one DMM to measure the current flowing through the bulb and another DMM to measure the voltage across the bulb.** The pot is used to adjust the current flowing through the bulb; more resistance means less current. The object is to **determine whether or not the resistance of the bulb, defined as the voltage across it divided by the current flowing through it, remains constant as the current increases**, as demanded by Ohm's Law.

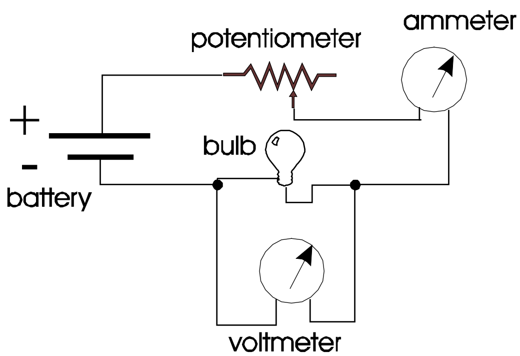

Figure 8: Incandescent lamp circuit.

F.1.2.) Begin with the pot set to allow maximum current so that the bulb glows brightly. Measure *V* and *I*. Then adjust the pot for minimum current and re-measure *V* and *I*. Once you have these readings, use them as endpoints to **take a set of 10 roughly evenly spaced (*in current*) data points of voltage as a function of current.** (*Don't space your points evenly in terms of turns of the pot or voltage; you should find that most of your data comes from one extreme of the pot position.*)

<u>F.1.3.) Calculate the resistance of the light bulb for each measurement, assuming that you can use Ohm's Law. Plot *R vs. I* using *Origin*.</u> <u>Does Ohm's Law apply to the bulb?</u> <u>How does the DMM reading of bulb resistance compare to the values in your plot; do they agree under any conditions?</u>

G. Power Limits

Every electronic component has limits on how much power it can handle. Resistors will no longer obey Ohm's Law if you try to run too much current through them.

G.1.) <u>What is the maximum voltage that you should be able to supply to a 100 Ω, ¼ watt resistor?</u> (*See Eq. 2.*) After answering this question, **connect a 100 Ω resistor to the output of the special *ELIMINATOR* power supply** set up in one corner of the lab. **Use a resistor from the container near that power supply**, not from your own box. Monitor the voltage across the resistor and the current through it using the two DMMs at that station. Note that, as long as Ohm's Law holds, the V and I readings should be related by a factor of 100.

G.2.) Set the power supply to 5 V, wait about 15 seconds and carefully touch the resistor to see if it is hot. Then turn the power supply quickly to full scale, about 25 volts (*5 times the rated voltage or 25 times the rated power*). Leave it there until it is obvious that Ohm's Law no longer applies. This should provide a dramatic demonstration that a resistor turns electrical energy into thermal energy. Don't worry about a little smoke and a few flames, but if the fire alarm goes off, everyone must evacuate the building! You may keep your resistor as a souvenir. You might also note the odor; the next time you smell this from your computer you will know what is happening inside the case.

Here's something to think about – if you were to grab each of the power supply connections with one of your hands and we were to turn it up to 25 volts, would you also glow bright red and burst into flames? Probably not. You are welcome to try this personally or on your lab partner. There's 1 bonus point for anyone who tries this and discovers otherwise. You might first want to locate the fire extinguisher mounted in the lab area.

G.3.) How are you different from a 3 cent, 100 Ω resistor (*at least in terms of its electrical properties*)? To help you answer this question, **check your own resistance directly with your DMM, holding one of the probes in each hand.** **How much voltage would it take across your body to dissipate through you the same power that caused the resistor to fail** (*at 25 volts*)? Since you are so much larger than this resistor, any sensation you would feel due to such a voltage is probably not directly related to thermal processes but rather to interference with nervous system signals necessary for things like keeping your heart beating. Don't try this!

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