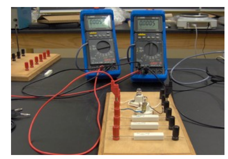
Series and Parallel Resistances and Ohm's Law
Pandemic Version 2021-Revision 2

Please refer to the instructions regarding mx55 interface initialization on the lab website before starting the experiment. You will acquire data with the program "OhmsLaw" which you will see a script link to on your unix desktop. The data will be written to your I directory (under /root/I) with a file of your choosing (use less than 9 characters, no spaces or unusual characters) in ".csv" format. The data will need to be copied into the spreadsheets shown on the web to do the analysis. Be sure to read the instructions in the program when you start it.

On the μA scale on the ammeter, you may not see zero current when the power supply is off. The reading you will see should be very low. You are seeing the wires act as an antenna. This is normal.

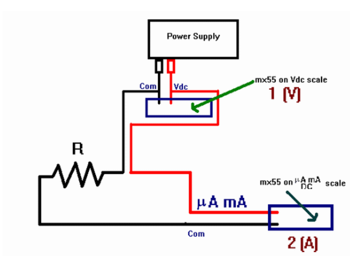
Experimental Note: meters are set to low input impedence for this lab.



In this lab, you will verify several aspects of resistance. As far as resistance goes, you will investigate several Ohmatic and non-Ohmatic resistors. You will then verify the addition formulas that we obtain in class for resistances in series and parallel.

Part I: Resistances.

The fundamental circuit diagram for this portion of the lab is shown below.



Here, we will use a variable voltage supply to vary the applied voltage to a resistance. You need to be a bit careful when making connections with analog meters (such as the voltmeters we are using) since you need to observe polarity. Basically, you want to connect red terminals to each other and black terminals to black terminals. The conventional current goes from red to black. The physical current goes from black to red.

Connections for the ammeter can be more complicated. Here, you need to connect the red end to the higher potential and the black (or common) to the lower potential. As a general rule, current flows through an ammeter but across a voltmeter: if a voltmeter were removed, the circuit will function. If an ammeter is removed, the circuit will not function. As a note, if you sometime pick up an ammeter which does not seem to function properly than a good guess is that a fuse across the lead has been blown. In the lab today, I will connect the volt meter and the ammeter for you. You will be responsible for making the other connections (I will connect the 100 Ω resistor as an example for you to start with.

The lab power supplies

For DC operation, the black switch should be set to Volts or Amperes. This refers to the reading that is present on the meter above the word "Power". Use the black and red terminals for DC operation and green terminals for AC operation. We use black and red today.

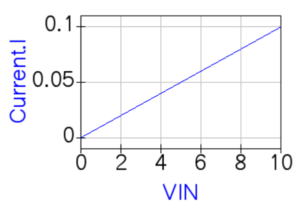
Warning: some of the resistors can become warm. Do not touch hot resistors!

Please note: an important part of this lab is to make completed circuit diagrams for your experiments which you show to me. **You will have to sketch a total of about 4 diagrams which you will need to include in your report** . Also make sure that I confirm proper connections before you switch on your circuit. And if you are in doubt about something, especially with regard to electrical connections, be sure to ask. I will sign off on your diagrams when I check your circuit.

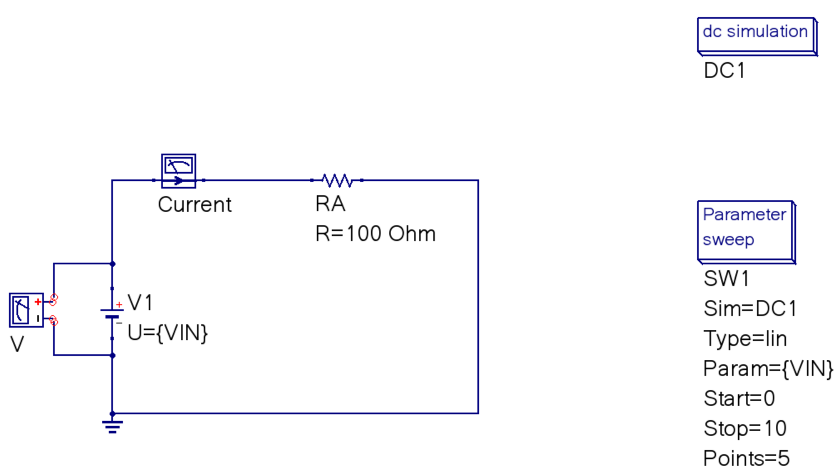
Experiment I: Ohmatic resistances.
Note: do not exceed 5A of current in this lab.

In class, fundamental definition of resistance is given by R=V/I where V is voltage and I is current. Further, if a resistor is Ohmatic, a plot of V vs. I will produce a straight line which is, in fact, Ohm's law. Now, the truth is that rarely does one find a true Ohmatic resistor, and then only for a narrow range of currents. Never-the-less, it is useful to say that resistances are Ohmatic although in exacting applications, problems may arise.

I have provided you with a set of standard resistances. You should connect **resistor A** (100 Ω) into your circuit now. **Vary the voltage from 2 to 10 volts in steps of about 1.5 volts**. Then, measure and record your current at each voltage. Below is the qucs circuit diagram and simulation for a 100 Ω resistor (RA). Note that your lab circuit will not have the ground connection and in your work you should plot the current on the x-axis so that the slope is the resistance. I am including this here because to do parameter sweeps with qucs, you need (usually) to define a ground reference.

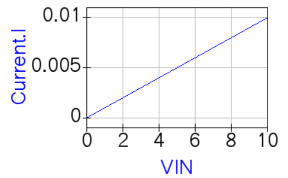


VIN	Current.I
0	0
2.5	0.025
5	0.05
7.5	0.075
10	0.1

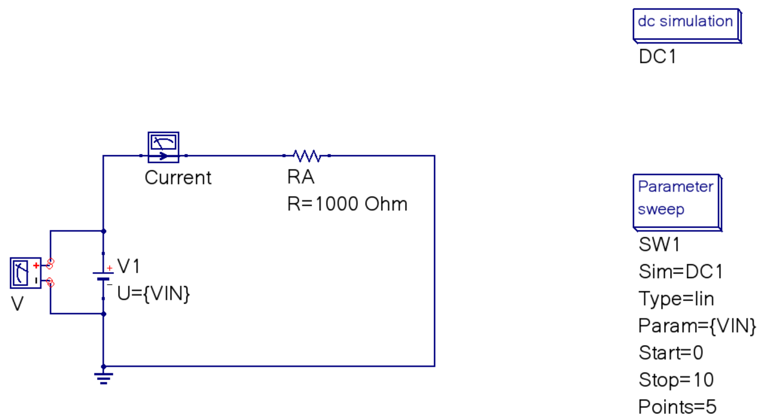


If you run the simulation under qucs, you might want to delete the voltmeter since it is already measured. It also gives a less than important error.

You should now connect **resistor B** (1000 Ω) into your circuit now. **Vary the voltage from 2 to 10 volts in steps of about 1.5 volts**. Then, measure and record your current at each voltage. Below is the qucs circuit diagram and simulation for a 1000 Ω resistor (RB). Note that your lab circuit will not have the ground connection and in your work you should plot the current on the x-axis so that the slope is the resistance. I am including this here because to do parameter sweeps with qucs, you need (usually) to define a ground reference.



VIN	Current.I
0	0
2.5	0.0025
5	0.005
7.5	0.0075
10	0.01



If you run the simulation under qucs, you might want to delete the voltmeter since it is already measured. It also gives a less than important error.

You will, in your analysis plot a graph in libreOffice with current on the x-axis and voltage on the y-axis. Be sure to delete my data and replace it with your data. A fit to a linear trend line to your data will automatically happen. **Determine your percent deviation by entering the expected values of your resistance.** The slope of your graph will be the value of the resistance of an Ohmatic resistor. If the data is linear, then your resistor is Ohmatic.

The percent deviation is calculated by:

$$\%\ \text{deviation} = 100\frac{R_{measured} - R_{expected}}{(1/2)[R_{measured} + R_{expected}]}$$

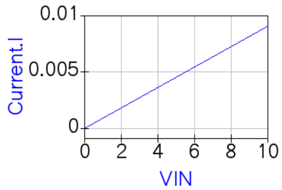
You will find that each of these resistors are Ohmatic and for a good reason: they are called power resistors and they are specially designed to not be affected strongly by IR heating.

Here is a note on units: Resistance is defined by the ratio of applied voltage to the resultant current. The more fundamental SI units are:

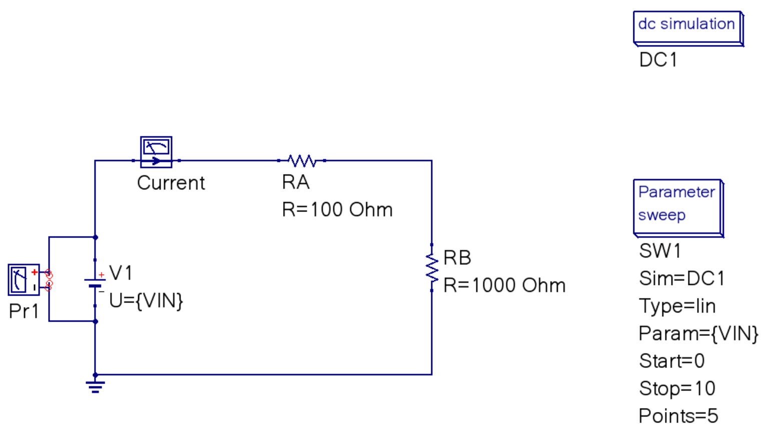
$$V\left[\frac{J}{C}\right] : I\left[\frac{C}{s}\right] : \frac{V}{I}\left[\frac{J/C}{C/s}\right] = \left[\frac{Js}{C^2}\right] = [\Omega] \quad .$$

A series resistance

Connect resistance A and B in series and repeat the same experiment and analysis. You can connect your circuit by refering to the qucs diagram and simulation below. **Vary the voltage from 2 to 10 volts in steps of about 1.5 volts**. Then, measure and record your current at each voltage. Below is the qucs circuit diagram and simulation for the 1000 Ω resistor (RB). Note that your lab circuit will not have the ground connection and in your work you should plot the current on the x-axis so that the slope is the resistance. I am including this here because to do parameter sweeps with qucs, you need (usually) to define a ground reference.



VIN	Current.I
0	0
2.5	0.00227
5	0.00455
7.5	0.00682
10	0.00909



If you run the simulation under qucs, you might want to delete the voltmeter since it is already measured. It also gives a less than important error.

Observate that if you disconnect the cable between RA and RB, no current will flow.

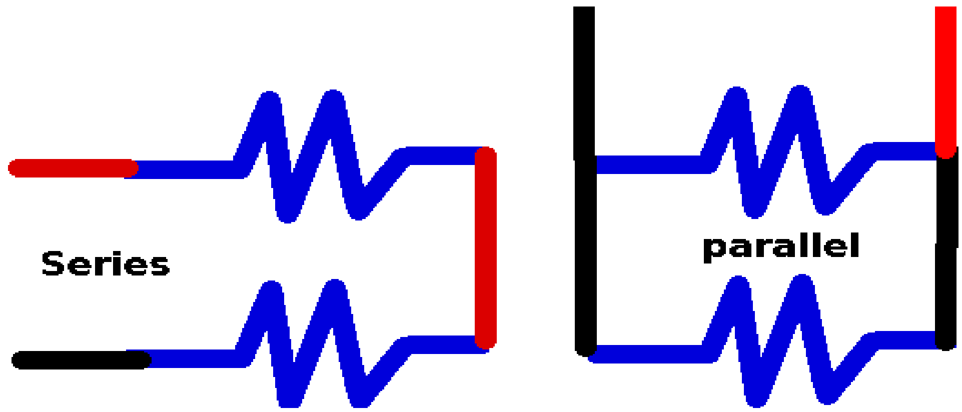
You can trace this through by imagining yourself to be an electron moving through the wire. Series means you go through one resister and then the other. You can now check the accuracy of the addition formula for series resistance by the following: Suppose you measured for the series resistance $R_{measured}$ and here

$$R_{calculated} = R_A + R_B \quad .$$

The percentage deviation in this measurement is given by

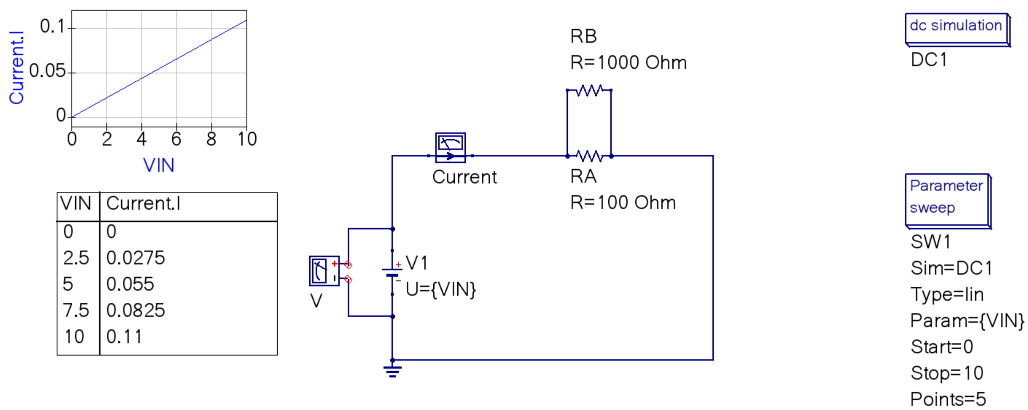
$$\%\ deviation = 100 \frac{R_{measured} - R_{expected}}{(1/2)[R_{measured} + R_{expected}]} \quad .$$

Find your percentage error by entering the correctly calculated series resistance in the spreadsheet helper. Your values should be in good agreement.



A parallel resistance

Now, connect resistance A and B in parallel and repeat the same analysis. You can connect your circuit by refering to the qucs diagram and simulation below. **Vary the voltage from 2 to 10 volts in steps of about 1.5 volts**. Then, measure and record your current at each voltage. Below is the qucs circuit diagram and simulation for the 1000 Ω resistor (RB). Note that your lab circuit will not have the ground connection and in your work you should plot the current on the x-axis so that the slope is the resistance. I am including this here because to do parameter sweeps with qucs, you need (usually) to define a ground reference. **One observation to make is if the cable to R2 is removed, current will still flow.**



VIN	Current.I
0	0
2.5	0.0275
5	0.055
7.5	0.0825
10	0.11

If you run the simulation under qucs, you might want to delete the voltmeter since it is already measured. It also gives a less than important error.

Now check the accuracy of the addition formula for parallel resistance. Be sure to report the percentage error. For your expected value, use that actual resistance R_A and R_B from your previous work.

I have a warning: students I have taught have often shown themselves to have problems working with the parallel resistance addition formula. How the resistance add:

$$\frac{1}{R_{eq}}=\frac{1}{R_A}+\frac{1}{R_B}$$

Again, enter the correctly calculated equivalent resistance into the spreadsheet helper to obtain your % deviation. Your values should be in good agreement.

Non-Ohmatic resistances

As you now know, rarely are resistances Ohmatic. Indeed, if you had taken very precise data on the resistances above, you would have seen a departure from linearity. Just because a resistor is not Ohmatic, however, does not mean that it can not be used. Indeed; quite the contrary! You are pretty much limited to a space of only non-Ohmatic resistors. Let's look at a non-Ohmatic resistor.

The light bulb

Note: do not exceed about 5 Volts across the light bulbs. They easily burn out and will if you go higher than 5 Volts. However, you will not see non-linear behaviour until the lightbulb glows. So you may go above 5 volts but do not go so high that the bulb gets very bright (and burns out).

Light bulbs are good examples of non-Ohmatic resistances. The rating on light bulbs (in W) is given at the normal operating temperature. But, the resistance can vary significantly before the bulb reaches its operating temperature. **Connect one of your light bulbs in the circuit (as you did, for example, for the 100 Ohm resistor) and repeat the analysis above except you might want 10 minimum data points here (start above zero).** This time, however, you will not be able to fit a linear trend-line to the I-V curve. In the light bulb helper, I have fit ln(V) vs ln(I). The resulting fit will be then:

$$V = e^{\text{intercept}}(\text{current})^{\text{slope}}$$

where the intercept and slope come from your graph. There is, however no further analysis required. **In order to obtain nice data here, increase the voltage applied until you can see the light bulb begin to glow (dimly). That will be your first data point. Increase your voltage in small steps up to about 7 volts and take a total of 10 data points.**

The various parameters of this I-V fit tell us what the resistance will be at a specified voltage. You will note that the light bulb starts out with a low resistance which increases. This is a characteristic of metals: the resistance increases as temperature increases. Bulb manufactures know this and sell more bulbs than they should because of this Here is how it works. When you first switch on a light bulb, there is little resistance in the circuit. This means that the current is quite high through the circuit. But a high current through the circuit is exactly what is needed to cause the filament to burn out. Thus, the likelihood of failure in a light bulb is as soon as it is switched on. My light bulbs have almost always burned out when I cut them on. When do your light bulbs burn out? It is also interesting to note that glasses, by contrast to metals, show a decrease in resistance as temperature increases.

Your write up for this lab consists of plots showing the slope for each of the Ohmatic resistances, along with the normal required elements of your lab report. Below each plot, you should type a sentence (or two) which discusses what the resistance is, if the material is Ohmatic and why.

Your sample calculation today consists of the addition formulas for series and parallel resistors showing CLEARLY the algebraic steps together with the correct units. Your calculations will be verified.

Summary of required measurements

(1) Resistor A : 5 points from an IV curve
(2) Resistor B : 5 points from an IV curve
(3) Resistor A in series with Resistor B: 5 points from an IV curve
(4) Resistor A in parallel with Resistor B: 5 points from an IV curve
(5) Single Light Bulb: about 10 points from an IV curve

Notes about the analysis

You should use your measured value of RA and RB in the spreadsheet for the expected value of the series or parallel combination. This means you will need to do a calculation by hand correctly to determine these expected values. Thus you will have to add these correctly for the particular circuit at hand.

Possible hypothesis today include that Ohm's law is observed to be valid for some materials but not all of them. Another hypothese concerns how resistors in parallel or series add.