# **Resistors and Current Flow**

## **1 Equipment**

In order to investigate resistors and currents you will need the following equipment

- decade resistor box
- known and unknown (coded) resistors
- DC voltage supply
- digital multimeter
- connecting wires
- a ruler
- a Zener diode

### 2 Introduction

In this lab you will be working with resistors, verifying the standard addition formulas and learning how to determine the value of an unknown resistor. You will need to know the laws for adding resistances in series:

$$R_{tot} = R_1 + R_2$$

and in parallel:

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Note that these are different from those for capacitors. (The series formula for one is the parallel form for the other.)

#### **3 Procedure**

**Task 1** In this section we will investigate how well our resistors obey Ohm's laws for serial resistors. First, you need to establish a reference voltage on the dc voltage supply. Although the voltage supply has its own built in voltmeter, the meter is not always

accurate. Set the voltage supply to 10V, and measure the actual voltage output with your digital multimeter. (You may wish to do a more complete calibration measuring the voltage at several different settings so that you can figure the error in the meter itself).

Turn off the power supply, and hook up a known resistor  $(R_K)$  in series with the decade resistor box as shown in the figure below. Attach the digital voltmeter as shown, so that you can measure the voltage drop across the known resistor. Before taking any measurements, calculate below the voltage drop across the known resistor as a function of the value of  $R_b$ , the resistance of decade resistor box:



Vary the settings of the decade resistor  $R_b$  and measure the voltage  $R_k$ . Each knob controls a different decade (factor of ten) of resistance for  $R_b$ , with the final resistance equaling the sum of the settings on all the dials. Vary the total resistance from a factor of four less than  $R_k$  to four times  $R_k$ . Record your values by graphing them on the grid below.



Plot the value of the voltage you expected to get as a function of  $R_b$ . How do the two compare?

**Task 2** An ideal voltage source is one that supplies as large a current as you need to maintain the specified voltage. However, if the voltage source is connected to a low resistance circuit, it may not be able to supply enough current. (Imagine trying to fill up a leaky sieve with water.) We can describe when a voltage source begins to deviate from the ideal by measuring its *internal resistance*. You can view a "real" voltage source as an "ideal" voltage source connected up with a small internal resistance, as indicated in the figure below.



What is the voltage drop across the external ("load") resistor as a function of  $R_i$ ? When do you expect to see a large departure from "ideal" behavior?

Set the decade resistor box for 99Q, and then connect the voltage supply across the resistor leads. Now connect the digital voltmeter across the resistor box. Turn on the voltage

supply and set the voltage for about 10V. Slowly decrease the resistor  $R_b$  until you see the voltage start to change. Now start to record the voltage you observe as a function of  $R_b$  on the graph below. Never set the external resistor to zero.

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Now increase  $R_b$  to a few thousand ohms, and record the voltage. At this value of  $R_b$  you can treat the internal resistance of the voltage supply as negligible. This will give you the value of the ideal external voltage.

V<sub>ext</sub> = \_\_\_\_\_

Choose three or four of your data points, and using the above information, solve for  $R_{int}$  for each one. Compare the value of  $R_{int}$  you get for those points where  $R_b$  is larger than the calculated  $R_{int}$ . Are they comparable?

Task 3 Connect the decade resistor box in parallel with the known resistor, as shown below.



Measure the voltage output of the source. Now reconfigure your digital multimeter to measure DC current (amps). You may have to switch one of the leads to a different jack. Insert the ammeter into the circuit so as to measure the current through the resistor  $R_b$ . Measure the current as a function of  $R_b$ . Record your data in the first four columns below:

V	R <sub>k</sub>	R <sub>b</sub>	I <sub>exp</sub>	I <sub>theo</sub>

Derive a formula below for the expected current as a function of  $R_b$ . Calculated this theoretical current for the points you measured and record your results in the table above. How do your theoretical calculations compare with those you measured?

**Task 4:** Wheatstone bridge: One common method used to measure resistances in experiments is called a *Wheatstone bridge*. Consider the circuit below. Suppose you know the values of  $R_1$  and  $R_2$ ; under what condition will the voltage at *A* be equal to the voltage at B? Work out the voltages at the points *A* and *B* and set them equal. (Hint: You do *not* have to require that  $R_3=R_1$  and  $R_4=R_2$ )



You can use this principle to determine the resistance of  $R_2$  assuming  $R_1$  is known. Connect the circuit up below, where  $R_b$  is the junction box and  $R_k$  is your known resistor. The right hand branch is the long coil resistor. The digital multimeter should be configured as a voltmeter, and one end connected to the region between  $R_k$  and  $R_b$ . Set  $R_b$  to be equal to  $R_k$ .



The idea is this: you can slide the contact of the voltmeter up and down the coil. You can adjust its position until it reads zero volts. Then the upper half of the coil is the resistor  $R_3$  and the lower half acts as  $R_4$ . The ratio of the resistances  $R_3/R_4$  is in proportion to ratio of the length of the coiled wire above the contact to the length of the coiled wire below the contact.

The difficulty is making a good contact with the coiled wire. The slider mounted above the cylinder may work well, however some of them are oxidized and make erratic electrical contacts with the coil. If that is the case, you are better off just sliding the probe of the voltmeter back and forth on the coil, rather than using the slider.

Vary  $R_b$  and slide the point of contact back and forth until you get a zero voltage difference. Measure the ratio of the length of the coil above the point contact to the point below the point contact. Verify the relationship between this ratio and your prediction from above.

R <sub>k</sub>	R <sub>b</sub>	L <sub>1</sub>	L <sub>2</sub>	$L_1/L_2$ (measured)	$L_1/L_2$ (predicted)

Why use a Wheatstone bridge at all? First, note that you needed only make a single measurement to determine the resistance you didn't need to make a current and a voltage measurement to determine  $R_b$ . Second, the method can be easily adopted to all ranges of resistances, by simply varying  $R_k$ . Third, it is a *null measurement:* in order to determine the resistance you had to measure a zero voltage. This is usually quite easy to do, while measuring the precise size of a voltage is harder. Instead, you now need only measure a length accurately, which is in general much easier. The error in your measurement is equal to how much you can alter the lengths and still get a null measurement.

You can use this method to measure an unknown resistance. Obtain a coded resistor from your lab instructor. Record below the code on the label of the resistor. Use the Wheatstone bridge technique to determine its resistance to at least two decimal places, and record your calculated value below. Estimate your error as mentioned above.

R<sub>u</sub> = \_\_\_\_\_

Code:\_\_\_\_\_

**Task 5**: Zener diodes: Not all circuit elements are ohmic: sometimes the relationship between the current and the voltage is *not* linear. One such device is a Zener diode. A diode is a circuit element that conducts current easily in one direction, and has a large resistance in the other direction.

Connect the Zener diode to the voltage source as shown below. If the meter in your voltage source is fairly accurate, use it to measure the voltage and configure your digital multimeter as an ammeter. If the meter in your voltage source is poor, use two multimeters

as shown one set up as an ammeter and one as a voltmeter.



Measure the current as a function of voltage from -10V to 10V, and plot it on the graph below. (You will have to switch the diode in the circuit to get a negative voltage).



From the above graph, determine how the differential resistance, dV/dI would look, and sketch it below as a function of voltage.



## **4** Questions

1. Describe how you might use a Wheatstone bridge configuration with capacitors to measure an unknown capacitance.

2. Why must a voltmeter have a large resistance? Why must an ammeter have a small resistance?