Lab 5: DC Circuits

Last updated
9/26/06

Concepts

- Introduction to circuit construction
- Kirchhoff's rules

Format

Cookbook

Objectives

The objectives of this lab are:
1) to construct an Ohmmeter (a device that measures resistance) using our knowledge of Ohm's Law, actually construction and calibration.
2) to determine an unknown resistance using our Ohmmeter.
3) to verify Ohm's law.
4) to verify Kirchhoff's Rules by adding the voltage differences around a loop and by adding currents going into and out of a junction.

Introduction

Review of Ohm's Law:

The potential (V) across a resistor is given by Ohm's Law:

$$V = IR$$

Equation 1

where I is the current and R is the resistance.

Kirchhoff's Rules:

Kirchhoff's Rules are a set of two rules which, along with Ohm's Law, allow you to solve for the current, voltage, or resistance of a circuit.

Kirchhoff's Rule #1--The Junction Rule: When wires meet at an intersection, the **algebraic** sum of all the currents going into the intersection must equal zero
the current going in - the current going out =0
Put it in another way:
the current going in = the current going out
This is just another way of saying that charge is conserved.

Kirchhoff's Rule #2--The Voltage Rule: The sum of the voltages gained or lost in a circuit loop must equal zero. Put it in another way:
the potential energy gained = the ptential energy lost in one round trip.
As electrons go across a battery they gain electrical potential energy. As they go across a resistor, they lose that energy. The energy lost should equal the energy

gained, so that when they come back to the same point (i.e. they go in a loop) they should have the same potential energy as before.

Constructing an Ohmmeter:

Having a known voltage source, , and a galvanometer to measure cutrent, we can construct an Ohmmeter to measure resistance according to Ohm's law. The deflection G of the galvanometer's needle is proportional to the current (I) running through it:

$$G = kI$$

Equation 2

where k is just a constant of proportionality depending on the galvanometer. If we construct the series circuit below (the circle is the galvanometer), we can solve for the resistance R_x if we know the voltage (V) and the current (I).

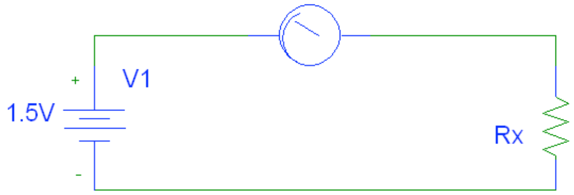

Fig. 1a.

We will be using a standard dry cell for the voltage source, which is nominally 1.5 volts. To make sure that the dry cell is good, you should measure its voltage using a voltmeter. There are two problems of using this circuit as is for measuring resistance:

(1) You don't have a direct reading of the current, you can measure the deflection but you don't know the value of k. This means that we need to calibrate the galvanometer to read current.

Note: Calibration is a standard procedure in instrumentation.

One should put a known amount of current (I) through the galvanometer, measure the deflection (G), then determine the constant of proportionality k, (one can also simply mark the galvanometer scale to read ampere rather than the arbitrary unit, BUT don't mark on the galvanometer! You can cut out a piece of paper and tape on it.

But, how should we generate a known amount of current?

We will use a known resistance, say $R_x = 1{,}800\Omega = 1.8k\Omega$; the expected current is $I = \frac{V}{R} =$ (assuming that the voltage source and the galvanometer have negligible internal resistance).

Please fill in the blank with the known value of voltage source). Read the deflection in the galvanometer and record deflection and the expected current. Hmmm… how accurate is this resistance? Is it exactly $1.8k\Omega$? Probably not. You should use several "known" resistances to get a statistical average calibration. Let's use $2.7k\Omega, 3.9k\Omega, 6.8k\Omega$. (Other values of R_x may be substituted in the event that we run short of resistors, as long as you get four distinct points of the range 10 kΩ) Plot the deflection vs. expected current on a graph. How can you get an statistical average value for k from the graph?

Why don't we use a resistance less than $1.8k\Omega$?
This leads to the second problem of this circuit.
(2) The galvanometer gives full deflection when $R_x = 1.8k\Omega$ => we cannot measure resistance less than $1.8k\Omega$ using this circuit. Furthermore, a lower resistance => higher current => damage the galvanometer!
To remedy both problems, we will connect another resistor (R_k) in series in the circuit, whose purpose is to limit the current, see Fig, 1b below. In fact we use $R_k = 1.8k\Omega$.

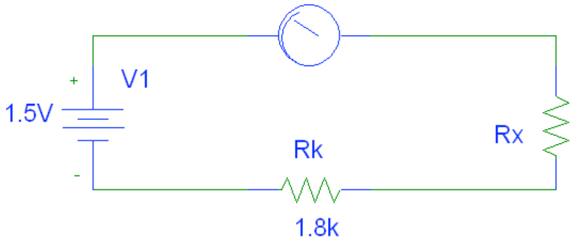

Fig. 1b

Now, even if you are measuring a R_x which has a very low resistance, you don't get the saturated deflection. Let's relate the current (I) through the circuit to the "unknown" resistance, R_x.

Applying Kirchhoff's Rule #2:

$$V = IR_x + IR_k$$

Equation 3

Rearranging this formula for R_x, an unknown resistor, in terms of R_k , a known resistor, and V, a known voltage source, we easily obtain:

$$R_x = \frac{V}{I} - R_k$$

Equation 4

We know R_k (it is given). We know the voltage, V and we can measure the current, I, using a galvanometer. Plugging this in, we have the equation:

$$R_x = \frac{(kV)}{G} - R_k$$

Equation 5

With the calibration done previously to find k, we are all set to go. But we can also do a direct calibration of resistance (R_x) vs. deflection (G). Again use use R_x

$= 2.7k\Omega, 3.9k\Omega, 6.8k\Omega$ as before, measure and plot R_x vs. 1/G, you should get a straight line. What is the value of the slope? What is the value of the "y"-intercept? Use Eq. 5 and see if you measured values agree with the (kV) and R_k? Remember that with this circuit, you can measure a resistance smaller $1.8k\Omega$, connect a $R_x = 1.5k\Omega$ and see if the measured deflection falls on the straight line.

Now that you are confident with your calibrated Ohmeter, ask the TA to give you an unknown resistance. You will measure it and report in your lab report, also estimate the error in the measured resistance (what are sources of error?). When your TA gets your lab report, he will compare your reported value with the "known" value".

Verifying Kirchhoff's Rules:

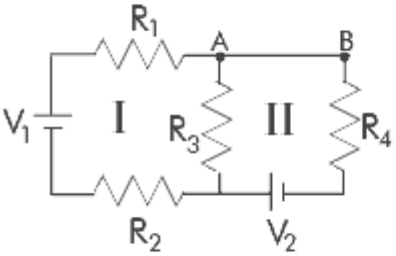

Figure 1: Today's Kirchhoff's Rules Circuit

We want to verify Kirchhoff's two rules. First we will verify the voltage rule by measuring the voltages around the loops. (Remember that you don't know theoretically which way the current will flow at this point). Second we will verify that the current coming into node A equals the current going out of node A.

Procedure:

1) Create the circuit shown in class on the tester board. Use resistors in the 1-10 kΩ range all of the same value. This will ease circuit analysis, but is not strictly necessary.

2) Check your circuit. An improper connection here is easy to make and will throw off all your results. Use the continuity setting (looks like a sound wave) on the multimeter. In this mode, the meter will make a sound when there is a low resistance path between the positive and negative terminals.

3) Find the voltage across all the batteries and the resistors. Remember, the orientation of the probes of your multimeter is important: if you reverse the leads across one of the resistors the loop will not sum to zero.

4) Find the direction and magnitude of the currents going into and out of the node marked A. Again, be careful with the orientation of the leads. Draw the current directions and magnitudes on the circuit in your lab write-up. *** Before you leave, please make sure you turn off the multimeter.

Questions:

1. In part II of the experiment, you should have noticed that one of the resistor voltages you measured was positive instead of negative. Does this mean that an electron is gaining energy when it goes through this resistor? Explain.

2. Why should a voltmeter have a high resistance? Why should an ammeter have a low resistance? (Hint: A meter should be "invisible" to the circuit. It should not change the voltage or current of the element it is reading.) You may want to draw some simple circuits.

3. See if you can analytically solve for the voltage across R_2 without using your experimentally obtained voltages across the other resistors (i.e. just using the resistor values and battery voltages).