Chapter 7

DC Electricity

In this laboratory session we shall examine the relationships among the motion of electrons (current in Amperes or A), the effect which causes them to move (electric potential difference in Volts or V), and the effects which hinder their motion (resistance in ohms or Ω). Since we cannot use any of our five senses to detect the presence of electrical effects we need one or more detectors to tell us that a current or potential difference exists.

Objectives

1. To learn how to make circuit connections and how to use electrical equipment.
2. To study the principles of operation of a voltage divider, a potentiometer and a bridge.

Apparatus Digital multimeter, DC Power Supply, resistors, potentiometers, thermistors, switches, connecting wires, Vernier temperature probe, LabQuest Mini interface.

This lab consists of two parts: part A - Ohm's Law and resistors in series and in parallel, part B - Voltage divider and bridge circuit.

7.1 Ohm's law. Resistors in series and in parallel

Conservation of charge, mobility of charge, and conservation of energy are the fundamental aspects of this section.

7.1.1 Introduction

An electric current consists of moving electric charges. Batteries and power supplies are devices which maintain a fixed electric potential difference between their two "terminals". When a power supply is connected to a circuit it facilitates the constant flow of charges (like a pump facilitates the flow of water). This kind of current is called a direct current (abbreviated DC). Another type of current which is continually reversing direction is called an alternating current (abbreviated AC). In this lab you will deal only with DC currents. By convention, the current direction is from the higher potential terminal of the power supply (generally denoted by a "+") through the circuit to the lower potential terminal (generally denoted by a "-").

Circuit elements which offer resistance to current are called resistors. According to Ohm's law, current I which flows through resistance R causes an electric potential difference $\Delta V = IR$ across (between the ends of) the resistor.

The instrument used to measure current is called an ammeter. The ammeter should be connected into the circuit such that the current through the ammeter is the same as that through the element of interest (Fig. 7.1). When the same current which flows through the cicuit element also flows through the ammeter this is called having the two elements connected "in series". The internal resistance of the ammeter is very low, so that only a very tiny voltage drop (potential difference) occurs across the ammeter. A voltmeter is an instrument to measure the electric potential difference (also often called the voltage) ΔV between two points in a circuit. The voltmeter must be connected "in parallel" with the given element where "in parallel" means that the voltage drop between the two leads of the voltmeter is the same as that across the given circuit element. The internal resistance of the voltmeter is very large (MΩ's) so that very little current passes through it. A voltmeter reading is usually made simply by touching two points with the voltmeter leads. (Fig. 7.1).

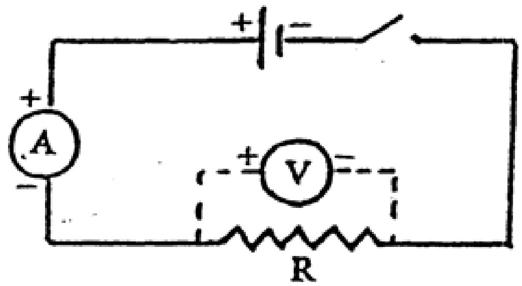


Figure 7.1: Schematic of connecting and ammeter and voltmeter.

Note that the + and - signs on the voltmeter only tell you that what is being measured is $\Delta V = V_+ - V_-$. That is, suppose you are measuring the potential difference between two points in a circuit (call them A and B). If you connect the + side voltmeter probe to point A and the - side probe to point B then the voltmeter measurement ΔV can be positive or negative depending on whether $V_A > V_B$ or $V_A < V_B$.

7.1.2 Experimental

To measure current, potential difference, and resistance you will use a modern instrument called a digital multimeter. A multimeter is a solid state electronic instrument with a digital display. It has a very high internal resistance, 10 MΩ so that practically no current flows through it when connected as a voltmeter. A rotary switch enables one to select the appropriate mode of operation. Fig 7.2 shows the position of the rotary switch and connection of two wires to measure DC voltage, DC current and resistance.

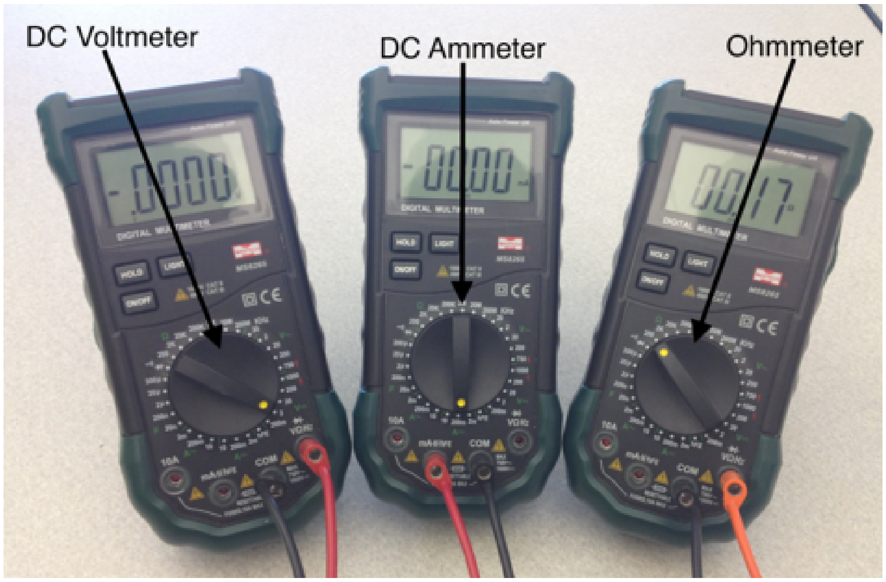


Figure 7.2: Digital multimeter operation.

7.1.3 Prelab Exercise

1. You have two resistors, R_A and R_B, and $R_A = 6$ kΩ. What is the value of R_B so that the resistance of the two in series, R_S, is 4.5 times the resistance of the two in parallel, R_P? That is, what is R_B for $R_P/R_S = 2/9$? Can R_B have more than one value and, if so, what are the two values of R_B that satisfy this condition?

2. You have two resistors, R_1 and R_2, and you know that $R_1 = 10$ kΩ. You set up the voltage divider circuit shown in Fig. 7.9 where the battery voltage, V_0, is 9 V. You measure V_{out} to be 3 V. What is the value of R_2?

7.1.4 Measurement and Calculations

You will be using a solderless breadboard for connecting your circuit and a DC power supply. A DC constant voltage of 5 V will be used. Instructions on how to use and connect the power supply will be provided in the lab. This provides a convenient and clean way of making electrical connections. To understand how the board is wired, refer to Figures 7.3, 7.4, and 7.5.

Lab Safety Rule: NEVER connect or change elements in a circuit if the circuit is connected to a voltage source, either a battery or a DC power supply that is turned on or set to anything above 0 V.

If a component is damaged or missing, please inform the TA so it can be replaced.

1. Connect the circuit shown in Figure 7.6:

   In this circuit two resistors R_1 and R_2 are connected in series.

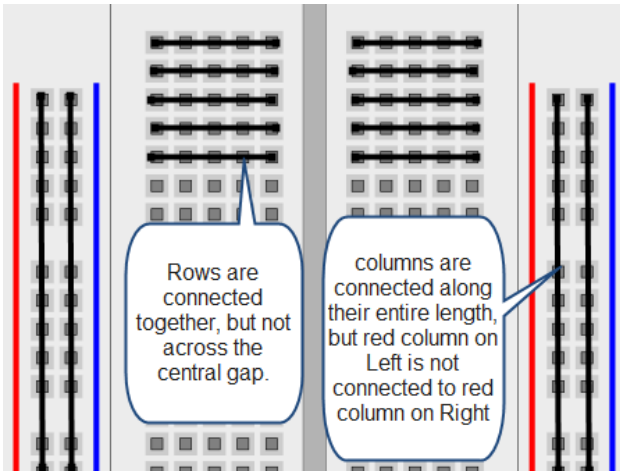


Figure 7.3: Solderless breadboard layout

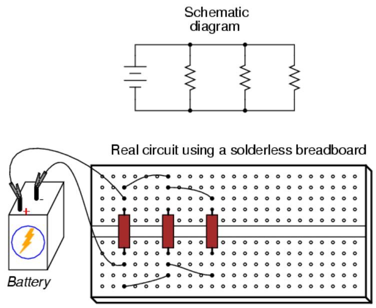


Figure 7.4: Solderless breadboard parallel example

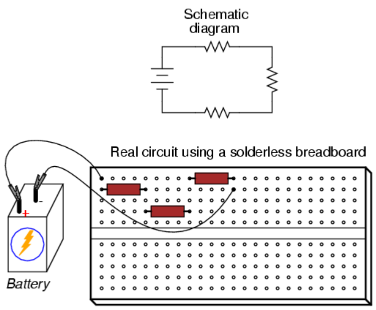


Figure 7.5: Solderless breadboard series example

2. Measure current I at the two different points in the circuit as indicated in Fig.7.6. Is the current the same?

3. Measure the voltage $\Delta V_{\rm ab} \equiv V_{\rm a} - V_{\rm b}$ cross R_1, voltage $\Delta V_{\rm cd}$ across R_2, and $\Delta V_{\rm ad}$ across both resistors. What is $\Delta V_{\rm bc}$? Do you need to use the voltmeter to assert its

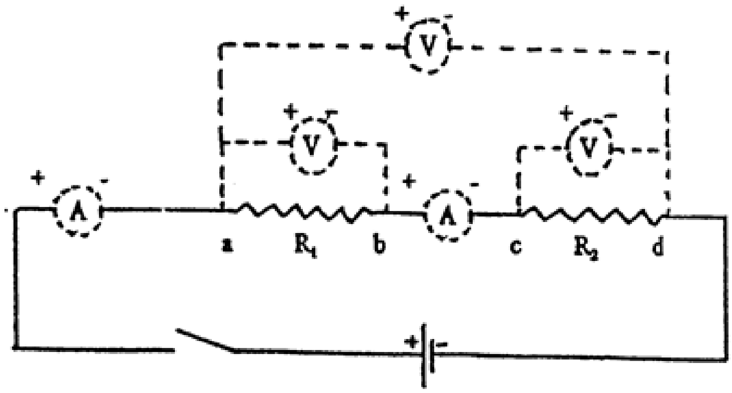


Figure 7.6

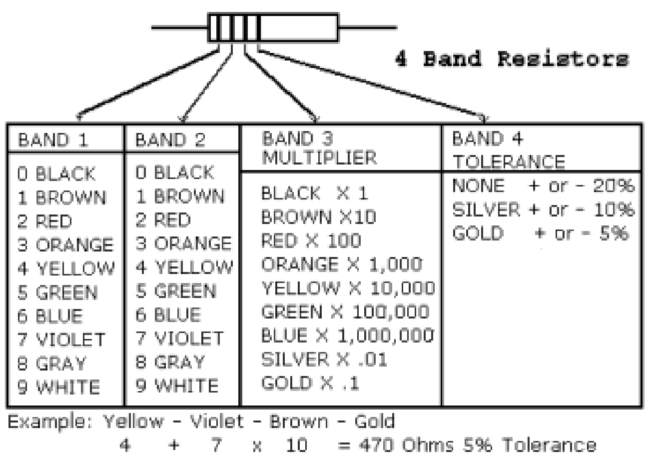
value? To make voltage measurements touch the voltmeter leads to the appropriate points.

4. Check the colour code chart shown in Figure 7.7 to determine the resistances and tolerances of R_1 and R_2 .

5. Use Ohm's law to calculate

$$R_1 = \frac{\Delta V_{\text{ab}}}{I}\ ,\ R_2 = \frac{\Delta V_{\text{cd}}}{I},\ R_s = \frac{\Delta V_{\text{ad}}}{I}$$

Verify that the measured resistances are within the precision limits given by the colour codes. Verify that the equation for the addition of resistors in series, $R_s = R_1 + R_2$, is consistent within the tolerances given.



BAND 1	BAND 2	BAND 3 MULTIPLIER	BAND 4 TOLERANCE
0 BLACK	0 BLACK	BLACK X 1	NONE + or - 20%
1 BROWN	1 BROWN	BROWN X10	SILVER + or - 10%
2 RED	2 RED	RED X 100	GOLD + or - 5%
3 ORANGE	3 ORANGE	ORANGE X 1,000	
4 YELLOW	4 YELLOW	YELLOW X 10,000	
5 GREEN	5 GREEN	GREEN X 100,000	
6 BLUE	6 BLUE	BLUE X 1,000,000	
7 VIOLET	7 VIOLET	SILVER X .01	
8 GRAY	8 GRAY	GOLD X .1	
9 WHITE	9 WHITE		

Example: Yellow - Violet - Brown - Gold
4 + 7 x 10 = 470 Ohms 5% Tolerance

Figure 7.7: Resistor colour code chart

To use the colour code chart you have to match the colour of the band with the digit associated with this band. For example, if the first band is red, the second green, the third red and the fourth silver, then the value of the resistance would be $25 \times 10^2 = 2500\ \Omega = 2.5\ \mathrm{k}\Omega$ and its precision (tolerance) is 10%. (i.e. $0.1 \times 2500 = \pm 250\Omega$).

6. Connect the circuits in which resistors R_1 and R_2 are in parallel as shown in Figure 7.8. Start with the circuit (a), then proceed to (b) and (c). The best way to connect

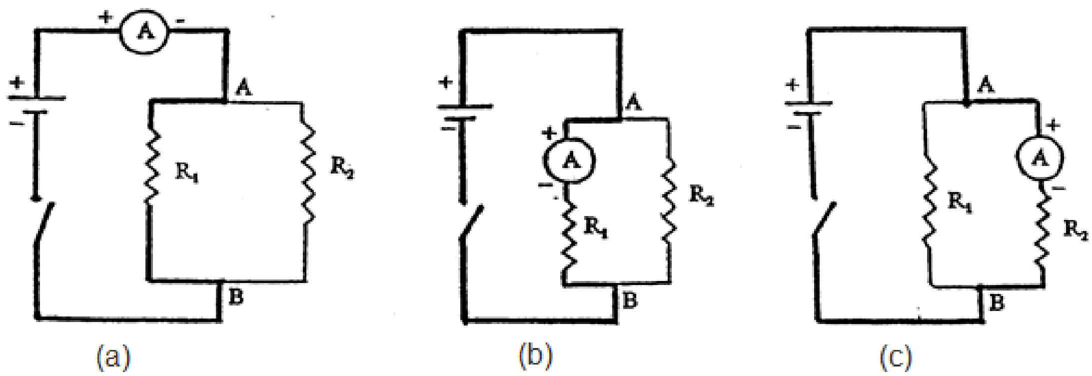


Figure 7.8: Various circuits

these circuits is to first connect the loop drawn with a thick line in each case and then attach the second resistor.

7. Measure currents I (Fig.7.8a), I_1 (Fig.7.8b), I_2 (Fig. 7.8c). How are the currents related?

8. Measure ΔV_{AB} i.e., the voltage across R_1 and R_2 in parallel. (The circuits in Fig. 7.8 are the same with the ammeter removed).

9. Calculate $R_p = \Delta V_{\mathrm{AB}}/I$ – the equivalent resistance of R_1 and R_2 in parallel. Use the value of R_p, and values R_1 and R_2 measured in point 4, to verify that

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \Longrightarrow \qquad R_p = \frac{R_1 R_2}{R_1 + R_2}$$

within given resistor tolerances.

7.1.5 Questions

1. An ideal voltmeter should have an internal resistance approaching infinity, while an ideal ammeter should have an internal resistance equal to zero. Explain why.

2. In the circuit shown in Fig.7.6, you have measured voltages ΔV_{ab} (across R_1) and ΔV_{cd} (across R_2). Is the sum of these two voltages equal to the emf of the battery?

NOTE: For the following two sections, The Voltage Divider and The Bridge Circuit, you will be working in pairs.

7.2 The Voltage Divider

The voltage divider circuit is shown below. It consists of two resistors, R_1 and R_2 connected in series to a power supply. The voltage divider allows one to obtain any fraction of the

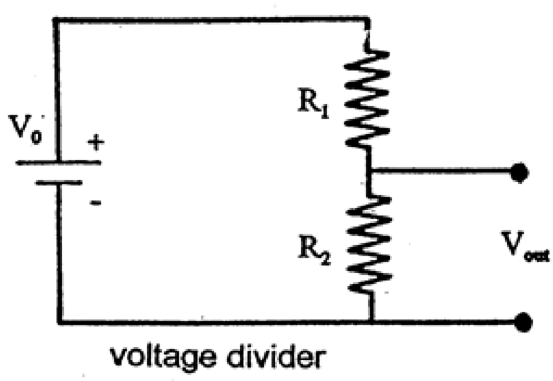


Figure 7.9: Voltage divider circuit.

input voltage V_0 as the output voltage V_{out} . The output voltage can be calculated as follows.

$$V_{\text{out}} = IR_2$$

To find I:

$$V_0 = I(R_1 + R_2)$$

$$I = \frac{V_0}{R_1 + R_2}$$

Thus

$$V_{\text{out}} = V_0 \left(\frac{R_2}{R_1 + R_2} \right)$$

What are the limits of V_{out}?

You will be given three resistors, R_1, R_2, and R_3, in order to construct the circuit shown in Fig.7.10. The values of R_1 and R_2 will be given. Note that the parallel combination of R_2 and R_3 is in series with R_1.

7.2.1 Measurement and Calculations

1. Measure the ΔV across the combination of all the resistors (which would be V_0 in the voltage divider) and the ΔV across the parallel combination of R_2 and R_3.
2. Use the voltage divider analysis given above to extract the value of R_3.
3. Measure the resistance of R_3 directly with the ohmeter. Do you get the same value for R_3 (within uncertainties) as you got using the voltage divider analysis?

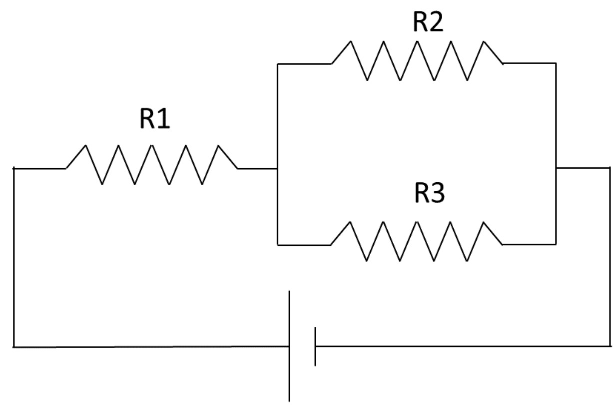


Figure 7.10: The circuit with the "mystery" resistor R_3.

7.3 The Bridge Circuit

A voltage divider in which R_1 and R_2 can be varied continuously is called a potentiometer shown in Fig. 7.11. The sliding contact (point A) can be moved between the two ends of the resistor.

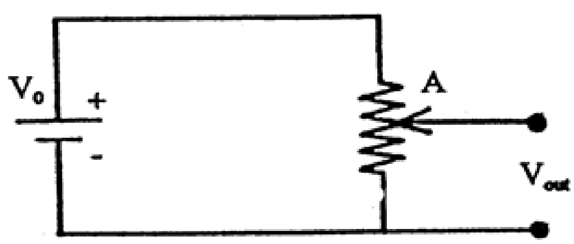


Figure 7.11: Potentiometer.

A bridge circuit is a combination of two voltage dividers "bridged" by a voltmeter. The bridge circuit is shown below, 7.12. A sensitive voltmeter compares the voltage V_1 set by the voltage divider with the voltage V_2 set by the potentiometer. The bridge is said to be 'balanced' when the voltmeter reads zero. In most applications, the bridge is used to detect small changes in resistances R_1 or R_2 . In this experiment, the role of the resistor R_2 is played by a thermistor, whose resistance depends strongly on the temperature. As the temperature of the thermistor changes, the bridge becomes unbalanced (i.e., $\Delta V_{\text{bridge}} = V_1$ - $V_2 \neq 0$. The voltage V_1 is proportional to the temperature and can serve as a very sensitive thermometer. The electrical signal produced by the bridge with the thermistor can be, for example, digitized and analyzed by the computer and automate many devices. In this

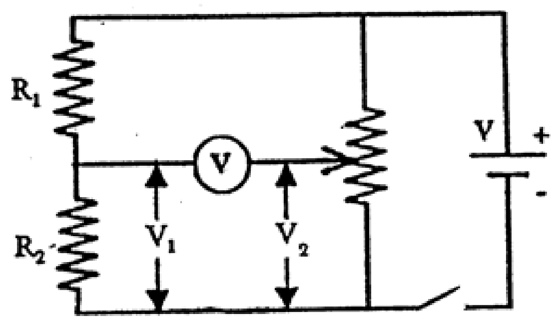


Figure 7.12: Bridge circuit.

experiment you will calibrate the voltage reading as a function of temperature and then use this calibrated bridge-thermistor arrangement to measure the unknown temperature.

7.3.1 Measurement and Calculations

1. Use the potentiometer to build the circuit shown in Fig. 7.13. By changing the position of the sliding contact verify that the voltmeter reading changes between zero and the voltage of the power supply.

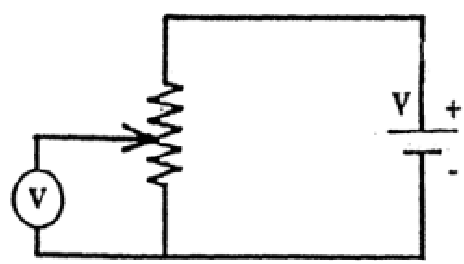


Figure 7.13: Voltage divider circuit.

2. Set up the multimeter as an ohmmeter (see figure below) and measure the resistance of a thermistor at room temperature. Next, hold the thermistor tightly in your hand and note any change in its resistance. Is the change measurable?

3. Build the bridge circuit with the thermistor in place of R_2 as shown below. Set the voltmeter to the 2V DCV range.

4. Balance the bridge by adjusting the control knob of the variable resistor (balanced means the voltmeter reads close to zero).

5. To calibrate your circuit's output, we need to measure voltages for known temperatures. Use the Vernier Temperature probe to measure the temperature for the four cases listed below. Record the voltage for each temperature.

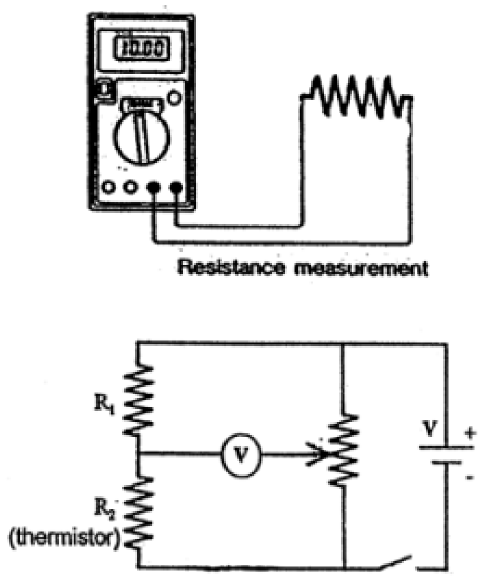


Figure 7.14: Bridge circuit with thermistor.

- Room temperature
- Ice water
- Hot water
- Mixture of hot and cold water

6. Plot these four points on graph paper provided (voltage vs. temperature) and be sure to include error bars. Sketch in a line of best fit. Is a straight line or a curved line a better choice?

7. Using your now calibrated thermistor circuit, determine the temperature when you hold the thermistor between the tips of your fingers, and also when held in your closed hand. Comment on what would you would have expected for these values.

8. The Logger Pro digital thermometer on your table which you have been using to measure the temperature on the computer also contains a simple bridge circuit containing a thermistor. Since thermistors and their associated electronics can be made very small, suggest some applications of thermistors in everyday devices.

7.3.2 Questions

1. What is the smallest temperature change that can be reliably detected using your bridge-thermistor circuit? (Hint: from your calibration curve, the ΔV for a voltage reading you obtained would give you what ΔT on your graph?). How does the accuracy of your digital thermometer compare to a standard mercury thermometer?

END OF LAB

Was this lab useful, instructive, and did it work well? If not, send an email to thatlabsucked@gmail.com and tell us your issues. In the subject line, be sure to reference the your course, the experiment, and session. example subject: *PHYS1010 Linear Motion monday 2:30*. We won't promise a response, but we will promise to read and consider all feedback.