Experiment - The Digital Multimeter

I. Objective

To become familiar with a digital multimeter (DMM) and how it works. At the same time to become familiar with resistors and to learn how to use a power supply.

II. Review of Basic Concepts

Resistor:
> A resistor is schematically shown in Fig. 1. Its characteristic equation is given by Ohm's Law:
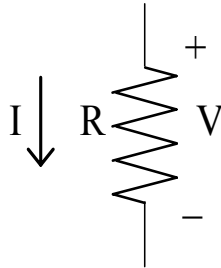
$$V = IR$$

Figure 1

Voltage source:
> The circuit symbol for a voltage source is shown in Fig. 2. Its one characteristic is that the voltage across its terminals is always V volts, no matter what the current going through it is.
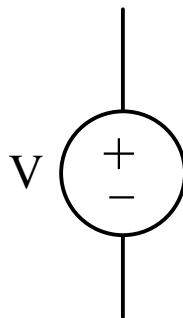

Figure 2

Current source:

The circuit symbol for a current source is shown in Fig. 3. Its one characteristic is that the current through it is always I amps, no matter what the voltage across it is.
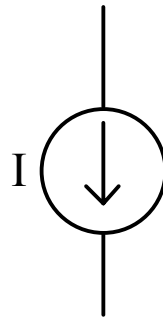
$$I$$

Figure 3

Series connection (see Fig. 4):

This is when the devices are connected in such a way that both devices have the same current flowing through them.

+ V_1 –

I_1

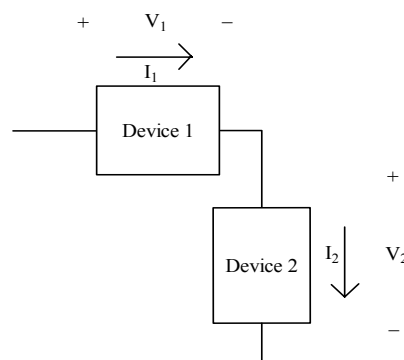Device 1

+

Device 2 I_2 V_2

–

Figure 4

$$I_1 = I_2$$

Parallel connection (see Fig. 5):

This is when the devices are connected in such a way that they have the same voltage across them.
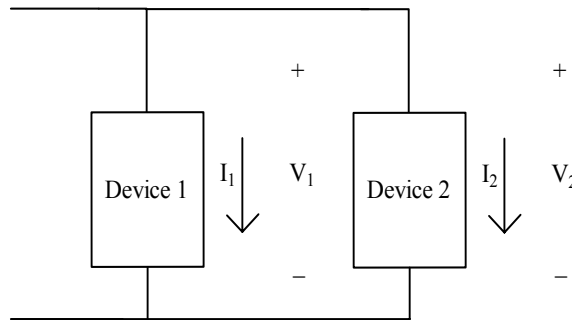

Figure 5

$$V_1 = V_2$$

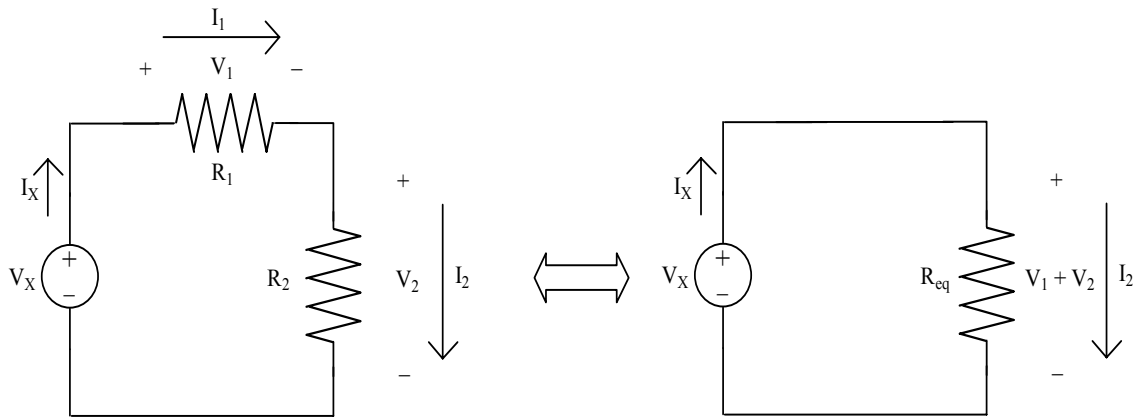Resistors connected in series (see Fig.6):

Figure 6

$$I_x = I_1 = I_2$$

$$V_x = i_x R_1 + i_x R_2$$

$$\frac{V_x}{i_x} = R_{eq} = R_1 + R_2$$

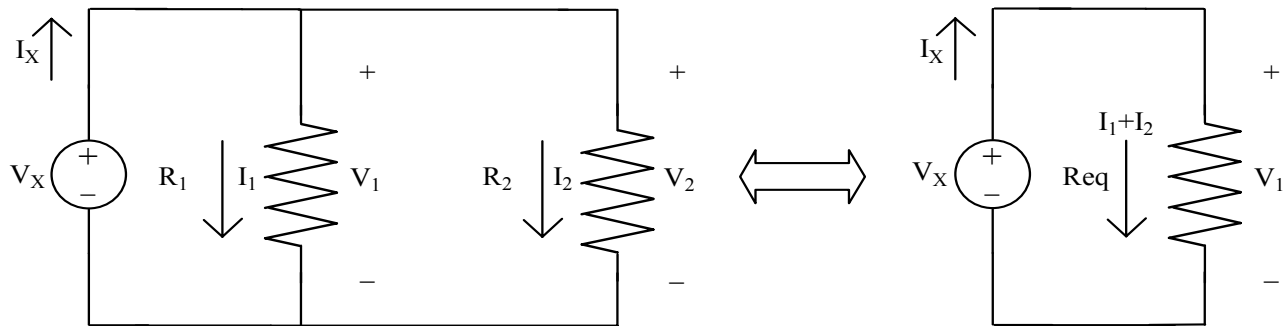Resistors connected in parallel (see Fig.7):

Figure 7

$$i_1 = \frac{V_x}{R_1}, i_2 = \frac{V_x}{R_2}$$

$$i_x = i_1 + i_2$$

$$i_x = \frac{V_x}{R_1} + \frac{V_x}{R_2}$$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{i_x}{V_x} = \frac{1}{R_{eq}}$$

Voltage divider (see Fig. 6):

$$V_x = i_x R_1 + i_x R_2$$

$$V_1 = i_x R_1, V_2 = i_x R_2$$

$$\frac{V_2}{V_x} = \frac{i_x R_2}{i_x (R_1 + R_2)}$$

$$V_2 = V_x \frac{R_2}{R_1 + R_2}$$

$$V_1 = V_x \frac{R_1}{R_1 + R_2}$$

Thevenin equivalent circuit:

Every circuit which consists of voltage sources, current sources and resistors can be represented with a Thevenin equivalent circuit. The form of the equivalent circuit is shown in Fig. 8a and the I-V characteristic is shown in 8b. The open circuit voltage is denoted as V_{oc}; the short circuit current is denoted as I_{sc} and the Thevenin resistance is denoted as R_t.

$$V_{oc} = I_{sc} R_t$$

The values of V_{oc}, I_{sc} and R_t can be determined by measuring the I-V characteristic of a circuit and extracting the parameters from the graph.

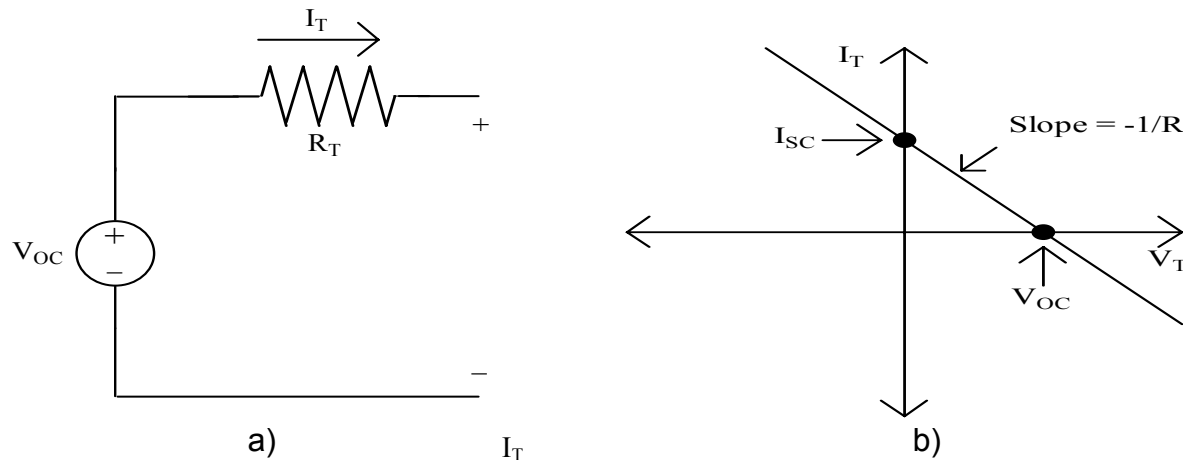a)   b)

Figure 8

III. Operation

The DMM is an instrument which can be used to measure DC (non-time-varying) voltages and currents, AC (time-varying) voltages and currents, and resistance values. The signal is input to the DMM through two leads (wires), and the value measured is displayed.

The DMM uses an A/D (analog-to-digital) converter, which converts DC voltages to a digital code. Therefore, internally the meter can read only DC voltages. Thus to measure current or resistance, the signal must be converted into a voltage value. For current, this is easily done by placing a (very small) precision resistor in the circuit and measuring the voltage across the resistor, which will be linearly proportional to the current (remember Ohm's Law: V=IR). Resistance measurements require more circuitry because a resistor is a passive element, thus a source must be provided in the DMM. In the DMM there is a current source to force a current through the resistor and the voltage is then measured. From this information the resistance value may be determined by Ohm's Law:

$$R = \frac{V}{I}$$

Additional circuitry is necessary to allow variable ranges. For voltage and resistance measurements this consists of various voltage-divider networks which are switched in. For current measurements it consists of different resistors to be switched in. Also, an RMS (root mean square) circuit is used to convert the AC voltages to DC voltages. The DC voltage given is the square root of the average value of the input voltage squared.

$$V_{OUT} = \sqrt{<(V_{IN})^2>}$$

The DC voltage is converted into a digital code by the A/D converter. This digital code is decoded using the range of information and displayed.

Since a voltmeter measures the voltage across itself, it should be connected in parallel (see Fig 9a) with the device to guarantee that the voltage across the device under test (DUT) is the same as the voltage across the voltmeter.

An ammeter measures the current through itself, so it should be connected in series (see Fig 9b) with the DUT in order to ensure that the current through the ammeter is the same as the current through the DUT.

An ohmmeter sends out a current and measures the voltage produced across the DUT. Because the ohmmeter is ultimately measuring a voltage, it should be connected in parallel (see Fig 9c) with the DUT. When measuring a resistance, one end of the resistor should be disconnected from the circuit so that all of the current from the DMM's current source is passing through the resistor to be measured. Otherwise one is not measuring the resistance value of the resistor because the current going through the resistor is unknown.
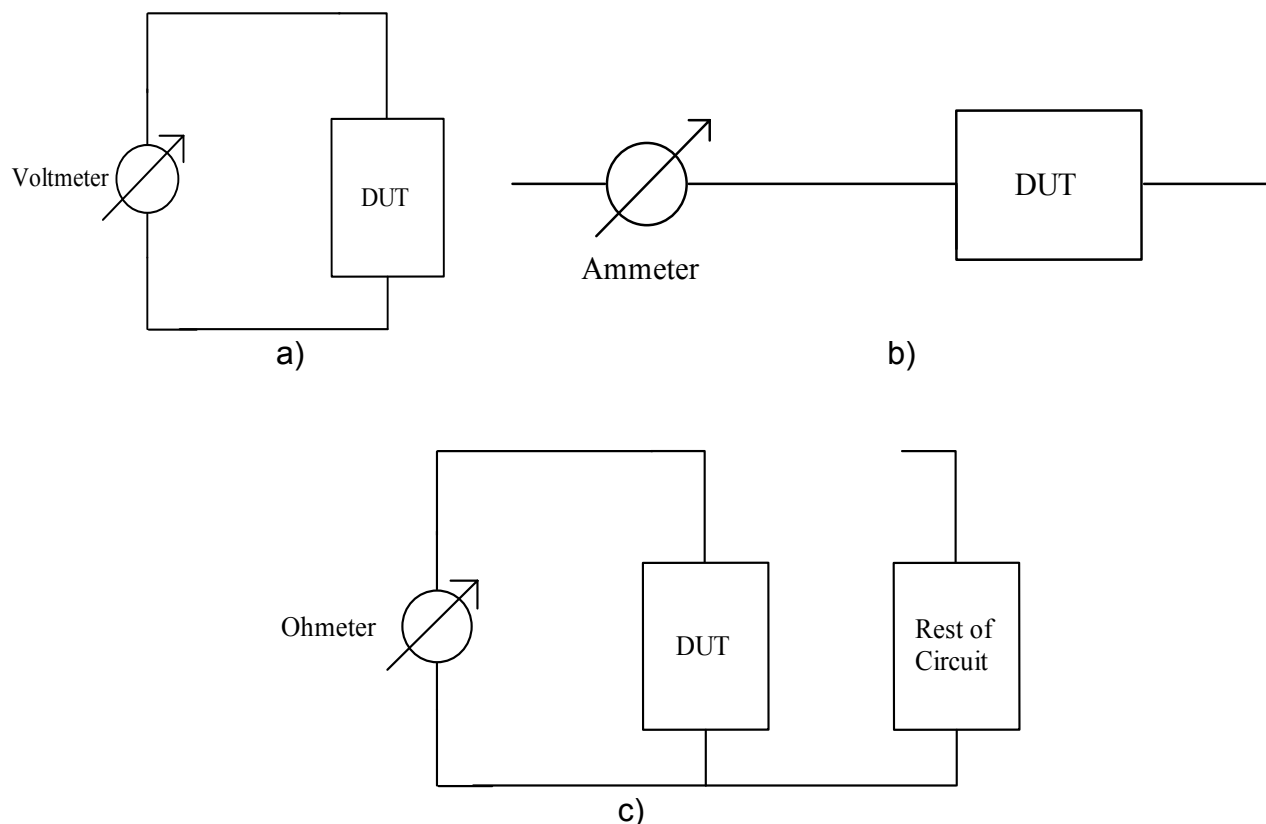
Figure 9

IV. Multimeter Controls

There is a diagram of the front of the multimeter given in Fig. 10.
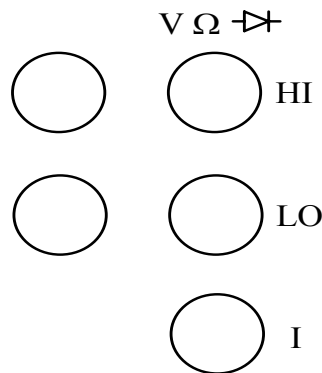
V Ω ⊣▷⊢

Figure 10

To measure voltage:
    1. use the right ports labeled HI and LO (see Fig. 10)
    2. choose either AC or DC voltage by hitting the AC V or the DC V key
    3. connect the DMM in parallel as shown in Fig. 9a
    4. adjust the range of the measurement using the level up and down keys

To measure current:
    1. use the right ports labeled I and LO (see Fig 10)
    2. choose either AC or DC current by hitting shift AC V (AC I) or the shift DCV (DC I) key
    3. connect the DMM in series as shown in Fig. 9b
    4. adjust the range of the measurement using the level up and down keys

To measure resistance
    1. use the right ports labeled HI and LO (see Fig 10)
    2. choose resistance by hitting the Ω 2W key
    3. connect the DMM in parallel with the resistor disconnected as shown in Fig. 9c
    4. adjust the range of the measurement using the level up and down keys

Note: Be very careful that when set up to measure current you don't put the DMM in parallel with the voltage source (see Fig. 11). The wrong way will blow the fuse in the multimeter. This is because of the small resistance of the ammeter (R_a). The resistance seen by the voltage source is approximately R_a, which is very small so the current I_a would be very large, thus exceeding the maximum current that the fuse can handle.
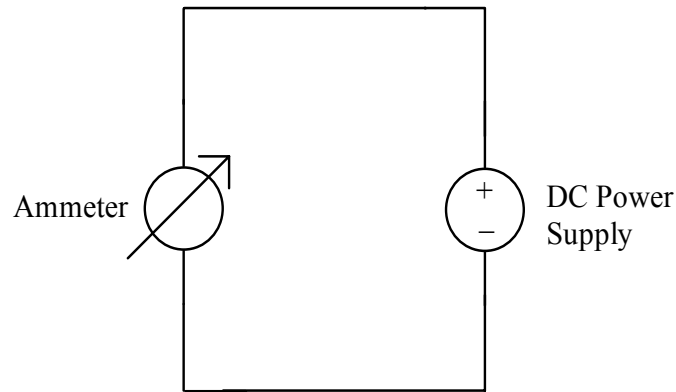
Figure 11

V. DC Voltage Supply Controls

The voltage source that we have actually contains three variable voltage sources, with maximum voltage values of +25V, -25V and 6V (see Fig. 12 for a diagram of the three sources and the power supply connections).

To set a voltage source:

1. Make sure that the supply's output is off. This can be toggled by hitting the output on/off key. The display will say OUTPUT OFF when it is off or it will display the output voltage and current.
2. Select which source you would like to set, the +25V, the –25V or the +6V by hitting the corresponding key on the supply. The supply you have selected will be displayed along the bottom of the display screen.
3. Then hit the display limit key. You will know that you are changing the limit because LMT will be displayed along the bottom of the display.
4. Select to set the voltage or current limit by hitting the voltage/current key. The one that is blinking is the one that you are editing.
5. When done setting the limits, hit the display limit key again to return to displaying the actual output.
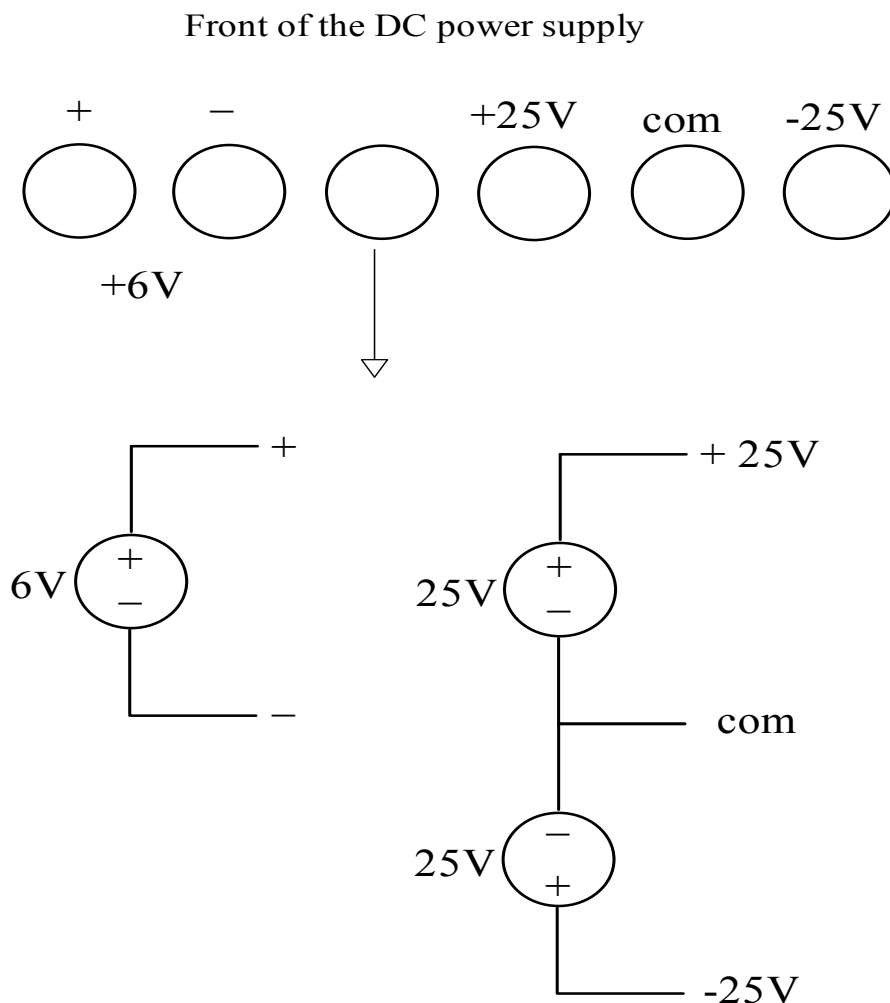6. Turn the output on once you have connected the supply to the circuit.

Front of the DC power supply

Figure 12

VI. Hands On

a. Resistance

Read Appendix 1 to review the color coding of resistors.

Turn the meter on and set it up to measure resistance in the manner explained above. Measure the resistance of a 1kΩ resistor. Initially have the meter set on auto ranging (i.e. the word MAN is not lit up on the bottom of the display). The value will not be exactly what is marked on the resistor because they are built to a specific tolerance. Then adjust the range as described above (adjusting the range will set the meter to manual scaling). Get another resistor and measure its resistance. Hook the two resistors in series, predict what the measured value should be, measure it. If it disagrees by more than 10%, try again. If the measurement is still too far off, get help. Connect the two resistors in parallel, predict the resistance value, and measure it.

Again confirm that the measured value is reasonable considering the resistor tolerances.

A potentiometer (pot) is a variable resistor. It has a constant resistance between pins 1 & 3 (see Fig. 13) and the knob controls the resistance between pins 1 & 2 and 2 & 3.
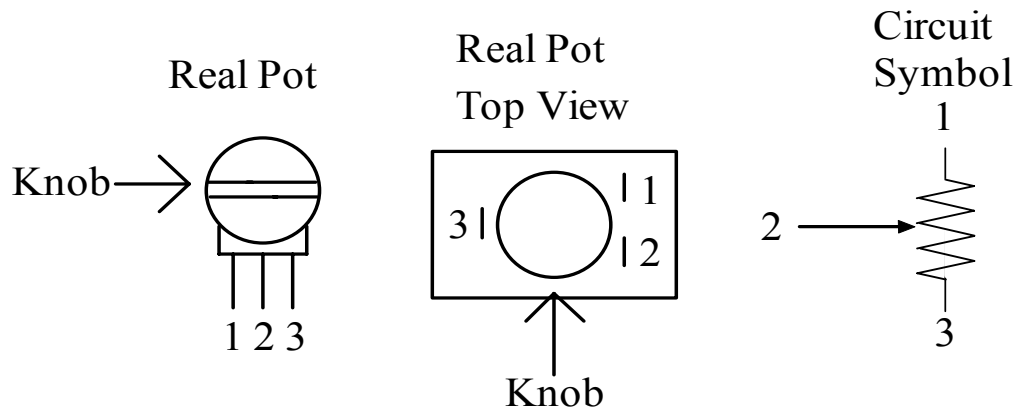

Figure 13

Measuring the resistance of the potentiometer (only connect one leg at a time).
1. With the dial of the pot facing you and the legs pointing down, what is the resistance between the two outside legs?
2. Does this correspond to the value on the pot?
3. When you connect one outside leg and the middle leg to the DMM, does the resistance increase or decrease when you turn the knob clockwise?
4. What happens when you connect the DMM to the other outside leg?

b. DC Voltages

Change the function select to measure DC voltage by pushing the DC V button. Turn on the power supply. Set the current limit to 0.2A, and the voltage limit to 5.0V (note: The display when the output is on is the voltage across the terminals and the current drawn from the supply not the limits.). Measure the voltage across the supply with the DMM. This should indicate how accurate the power supply's meter is. Now try varying the voltage and observe the results.

C. DC Current

Reread the part of the operation of the DMM that deals with current measurements. Measure the current with the DMM (see Fig. 9b). Does this agree with your calculated value? If the measurement is way off, check if the function selected is DC; the leads are connected to Right side LO and I; and if the DMM is connected in series (see Fig. 9b).

Connect a 1kΩ resistor across the power supply with the voltage limit set to 5V and the current limit set to 0.2A. Predict and measure the current through the resistor. (Note: Remember what was said about connecting the DMM in parallel when it is being used as an ammeter. If you accidentally do this you will blow the fuse in the DMM and it won't work as an ammeter anymore.)

Get a 51 Ω power resistor from the TA; this is about 2 inches long and 0.5 inches wide- not one of the small resistors. Set the voltage to 10V and the current limit to 0.1A. Connect the 51Ω power resistor across the supply. What should the current through the resistor be? Measure it, and measure the voltage across the resistor. Why is V≠10V? Change the current limit to 0.4A and measure the current. Can you explain why the first measurement wasn't as calculated? It is possible to look at the voltage supply and tell whether the output is controlled by the current limit or the voltage limit. There is a CV (controlled by voltage) in the lower right corner of the display if the voltage limit controls the output and a CC (controlled by current) if the current limit is the controlling factor in the output. What is the purpose of the current limit? What is the minimum resistance you would use with a current limit of 0.1A to have V=10V still?

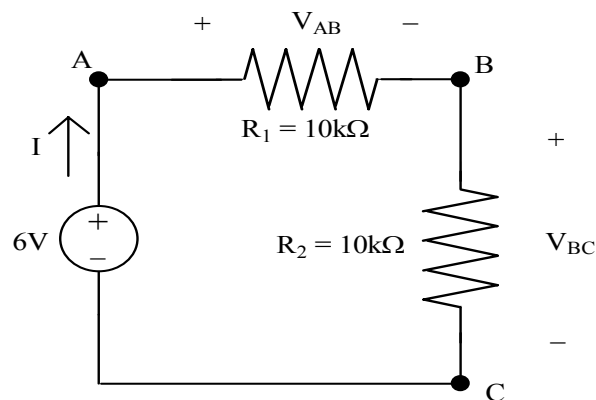### d. Measuring a Real Circuit

Build the following circuit (see Fig.14).

Figure 14

1.   Measure V_{AB}.
2.   Measure V_{BC}.
3.   Measure I.

e. Circuits with Potentiometers

Replace R2 in the previous circuit with a pot (see Fig 15).
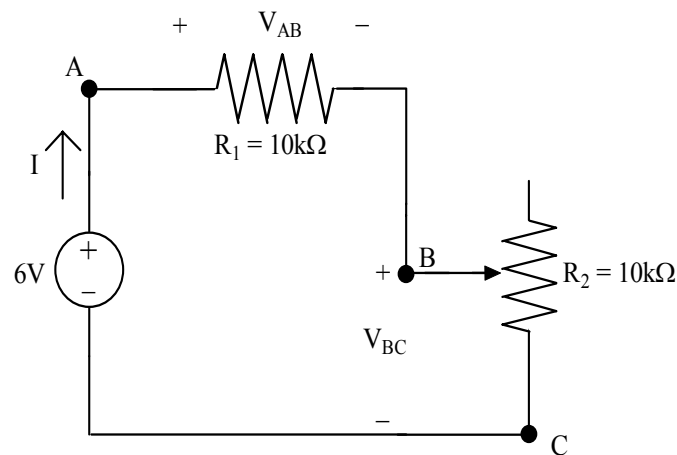
Figure 15

1.   Measure I, V_{AB} and V_{BC} for three values of the pot.
2.   What happens as the resistance of the pot is increased?

f. Current-Voltage (I-V) characteristics

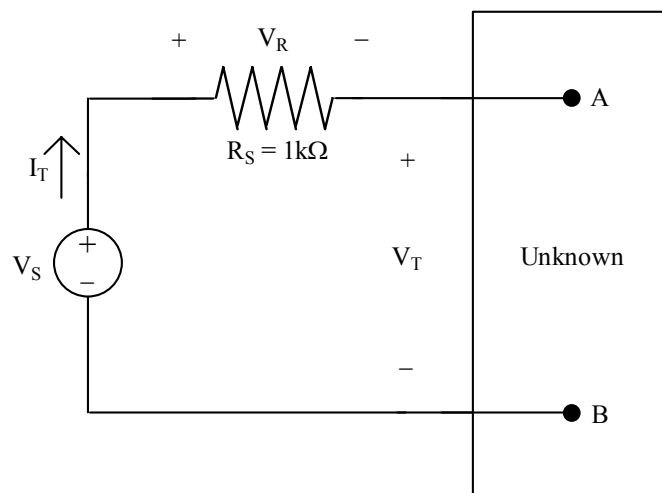Construct the following test circuit: (see Fig. 16)

Figure 16

Get a resistor from the TA and connect it as the unknown. Set V_s to a voltage of your choice. Measure the values of I_T and V_T, and plot this information on an I_T vs. V_T graph.

Continue adding data points to the I_T vs. V_T graph by setting Vs to other values. If the resistor is really a "linear" device, then you do not need to include many data points on your plot. After adding the data points, draw a best-fit line. Your I_T vs. V_T graph is the I-V characteristic of your resistor.

g. Black Boxes (Extra Credit)

For the next two parts, make sure the power supply's current limit is set to 50mA.

Get black box #1 from the TA and connect it to the Figure 16 circuit as the unknown. Measure the I-V characteristic for the black box. Draw a possible circuit for the black box. What do you actually find in the box? You might want to review your knowledge of combining resistor in series and parallel before understanding what you find in the box.

Get black box #2 from the TA and connect it to the figure 16 circuit as the unknown. Measure the I-V characteristic for the box. Draw a possible circuit for the black box. What do you actually find in the black box?

Now connect black box #2 to a voltmeter (see Fig. 17). Measure the black box's open circuit voltage VOC. Negligible current flows in and out of the black box's terminals because a voltmeter has an extremely large input resistance.
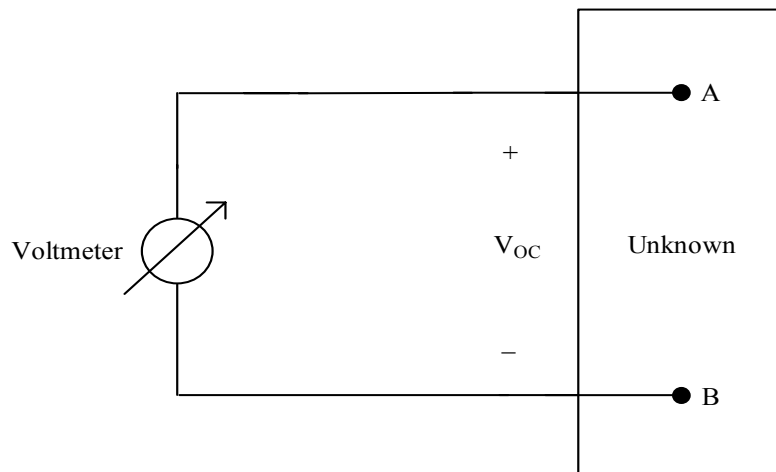

Figure 17

Now connect black box #2 to the DMM set up to measure current (see Fig. 18). Recall that because the ammeter has negligible resistance, the ammeter can be regarded as a short circuit. Measure the short circuit current ISC.

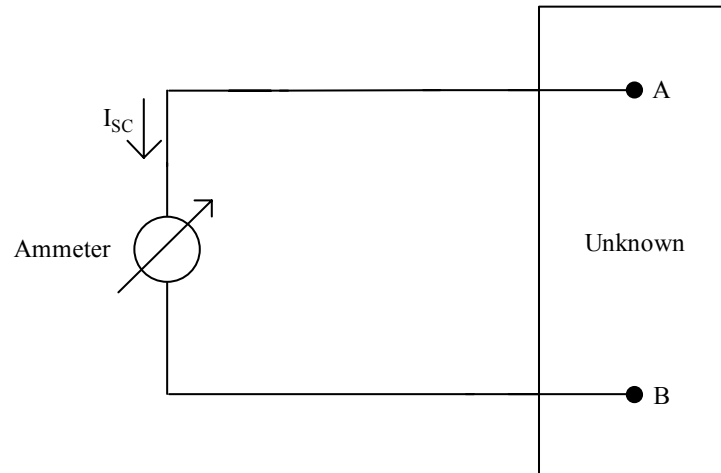Figure 18