

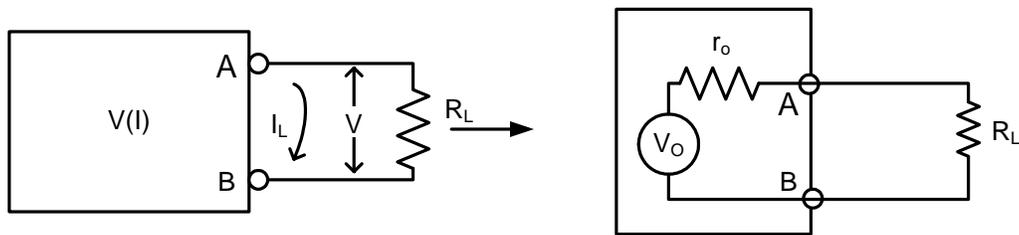
PHYSICS 536
Experiment 1: DC Circuits

A. Introduction

The measurements in this experiment are simple, but the concepts illustrated are fundamental. Proper understanding of these concepts is essential for later work. A summary of the concepts and equations that are needed for this particular experiment is presented herein. Refer to Sections 1,2,3, and 7 in the **General Instructions for Laboratory**, hereafter referred to as **GIL**, for additional background information .

1. Voltage source

Figure 1



A perfect voltage source provides constant voltage regardless of how much current is drawn; this is not the case for real sources. The source voltage, V_L , decreases as the source current, I_L , increases. Using Kirchoff's loop rule, the voltage across the load can be expressed as

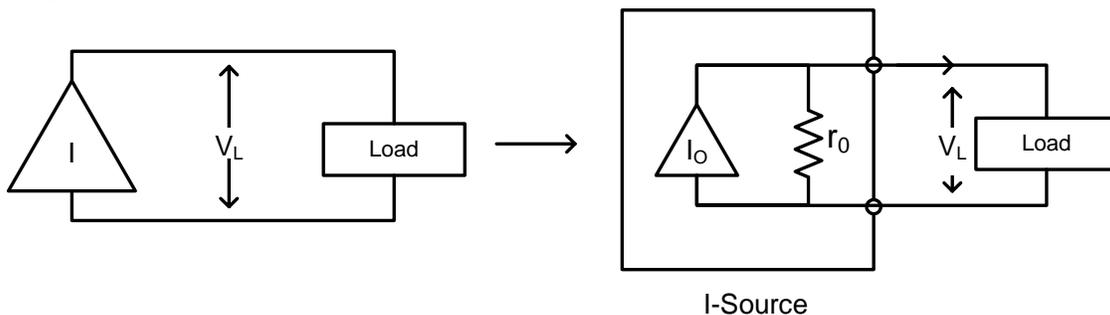
$$V_L = V_0 - I_L r_0. \quad (1.1)$$

V_0 is the voltage of the source when there is no external load, *i.e.* $I_L = 0$, and r_0 is the equivalent resistance of the voltage source. Recalling that $V_L = I_L R_L$, eqn. (1.1) can be rewritten as

$$V_L = V_0 \frac{R_L}{r_0 + R_L} \quad (1.2)$$

2. Current Source

Figure 2



A perfect current source provides constant current, regardless of the voltage, V_L , across it. However, the current, I_L , from a real source is slightly dependant on the voltage, V_L , across the source. Using Kirchoff's branch rule the current through the load can be written as

$$I_L = I_0 - V_L / r_0 \quad (1.3)$$

where I_0 is the source current when V_L is zero.

3. Combining Resistors

The equivalent resistance of a series assemblage of resistors is given by

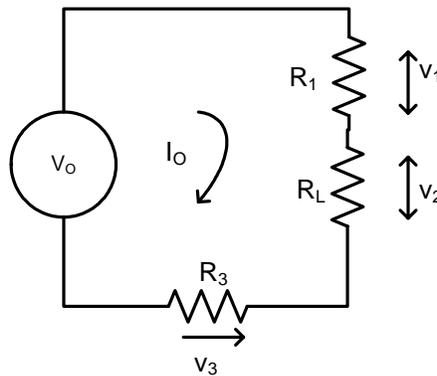
$$R_{eq} = R_1 + R_2 + \dots \quad (1.4)$$

The equivalent resistance of a two resistors in parallel is given by

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \equiv (R_1, R_2). \quad (1.5)$$

4. Voltage Dividers

Figure 3



The voltage, V_L , across several series resistors is distributed proportionally according to the size of each resistor. Referring to Fig. 3, Kirchoff's loop rule states that

$$V_0 = V_1 + V_2 + V_3. \quad (1.6)$$

The current through the loop is given by

$$I_0 = \frac{V_0}{R_1 + R_2 + R_3} \quad (1.7)$$

The voltage across resistor j , V_j , is

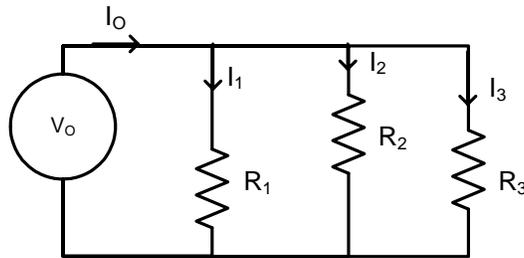
$$V_j = V_0 \frac{R_j}{R_1 + R_2 + R_3}. \quad (1.8)$$

The voltage across the resistor R_1 is

$$V_1 = V_0 \frac{R_1}{R_1 + R_2 + R_3}. \quad (1.9)$$

5. Current Dividers

Figure 5



The current emanating from the voltage source is given by

$$I_0 = \frac{V_o}{(R_1, R_2, R_3)}. \quad (1.10)$$

The current flowing through resistor R_j

$$I_j = \frac{V_o}{R_j} = \frac{I_0 (R_1, R_2, \dots)}{R_j}. \quad (1.11)$$

If, for instance there are only two resistors, the currents are given by

$$I_1 = I_0 \frac{R_2}{R_1 + R_2} \quad \text{and} \quad I_2 = I_0 \frac{R_1}{R_1 + R_2} \quad (1.12)$$

The current flowing through two parallel resistors is inversely proportional to the resistance. Notice that I_1 is proportional to R_2 , not R_1 , and *vice versa*.

6. Thevenin's Theorem

Any linear circuit can be represented by an equivalent voltage source, V_{Th} , and resistance, r_{Th} , in series. V_{Th} is the voltage with no external load. R_{Th} is the combination of resistors obtained with inactive sources: short circuit for voltage source and open circuit for current source.

7. Norton's Theorem

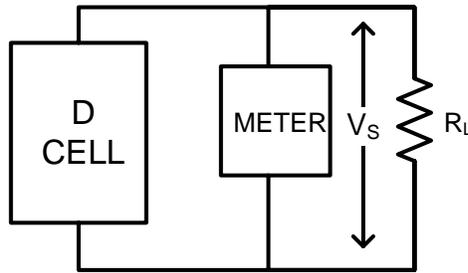
Any linear circuit can be represented by an equivalent current source, I_N , and a resistance, r_N , in parallel. I_N is the current that flows through a short circuit, which replaces the load. r_N is the same for Thevenin's and Norton's theorem.

The specific values needed for the experiment are given on a separate sheet at the back of the lab instructions.

B. Effective Resistance of a Voltage Source

A D-cell will be used to demonstrate the general principle that the voltage from a source decreases when it delivers current to a load. The two posts on the circuit box provide a convenient place to add resistors for the measurement. The white plug-in sockets are not used in this section. Connect the D-cell and the digital meter to the red and black posts on the circuit box.

Figure 6



Load resistors, R_L , will be inserted in the top of the posts to change the current, I_s , supplied by the battery. The load should be connected into terminals only as long as necessary to measure V_s . If too much charge is drawn from the battery, the no load voltage will change.

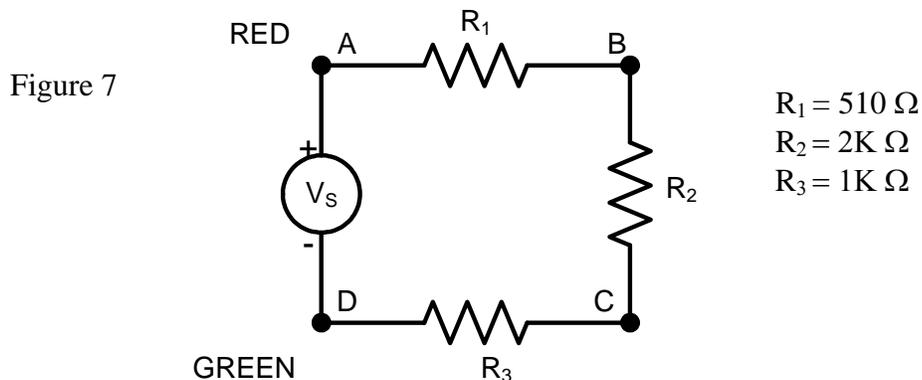
1 – Assuming a battery voltage of 1.5 V, *i.e.* $V_0 = 1.5$ V, and an internal resistance, r_0 , of 0.5Ω , calculate V_s for $I_s = 0, 0.1$, and 1 A. Include the results of these calculations in your lab report. Measure V_0 of a D-cell battery. Set up the circuit as shown in Fig. 6. Measure V_s for $R_L = 10\Omega, 4.7\Omega, 2.2\Omega$, and 1Ω . Recheck V_0 at the end. If the value has changed calculate the mean. Calculate the current through the load using the formula

$$I_s = V_s / R_L \quad (1.13)$$

Plot V_s (vertical) versus I_s and determine r_0 from the slope. This r_0 could be used to calculate V_s for any R_L . Include in your lab report example calculations for $R_L = 10 \Omega$ and $R_L = 1 \Omega$. For both the calculations and measurements enter your data into a spreadsheet program and plot the data. How close are the data to linear? Use the spreadsheet program to fit a line to the data. How good is the fit? Include these results in your lab report.

C. Voltage Divider

Set up the circuit shown in Fig. 7 on the plug-in box. Connect the 12V output of the DC power supply to the red and green terminals. Use resistance values shown below.



This is a nonstandard connection because the circuit common (black) is not included initially.

- 2 - Measure the voltage across each resistor. Use both meters, noting differences in your lab report. The meters read the voltage on the input lead relative to the “common” lead. The common side of the meter may be labeled as “low” or “-”. In this circuit the voltage of A relative to D should be positive and D relative to A should be negative. Try several variations until you understand the polarity conventions of the meters. Do the measurements made in this part of the experiment confirm Kirchoff’s first rule? Repeat the measurements several times, noting all voltages. Do the measurements always agree? Based on these measurements, what is the reproducibility of the voltmeters?

D. Circuit Common

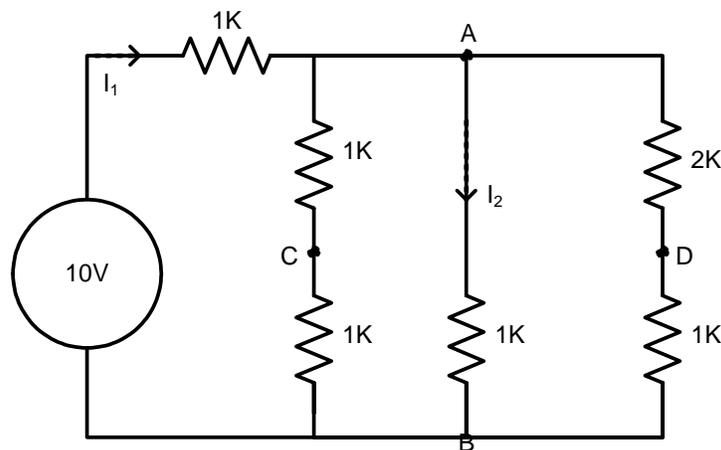
The black post, sockets, and the metal box are connected together so they can be used as a “common” voltage reference. Refer to section 12 in GIL. The circuit in the preceding section is “floating” *i.e.*, not connected to the common. Use the analog meter to measure the voltage between the box and points A, B, C, and D of the circuit. The reading should be zero for all four cases. When the meter is first connected, there is enough conduction to bring the box and the point in the circuit to the same potential. However, when one point in the circuit is connected to the box with a good conductor, the potential of each point is fixed relative to the box.

- 3 - Connect point C to a black socket with a wire, measure the voltage on points A, B, and D relative to the common. Briefly describe your results in your lab report. The common of the circuit is not connected to the building grounding system, but that has no effect on the preceding measurements. The silver post on the back of the power supply is connected to ground through the third wire on the AC plug. Measure the voltage between this ground and the circuit box. It should be zero.

E. Combining Resistors

Consider the circuit shown in Figure 8. Using equivalent resistances, and Kirchoff’s rules if needed, predict V_{AB} , V_{AC} , I_1 , and I_2 .

Figure 8

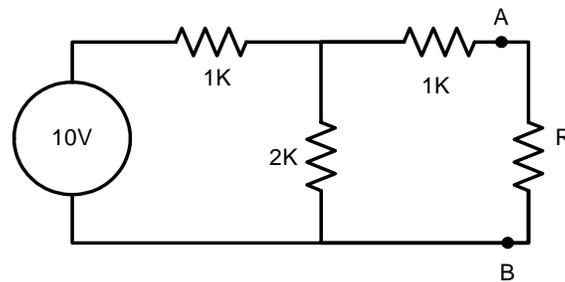


- 4 - Set up the circuit in Fig. 8 on the plug-in chassis and connect it to the power supply. **Do not** insert the meter probes into circuit sockets because the probe tips damage the sockets. Measure V_{AB} , V_{AC} , I_1 , and I_2 . Compare these measurements with your calculations; make a table comparing the two. Refer to section 2 in GIL for reference on the measurement techniques.

F. Thevenin's Theorem

- 5 - Set up the circuit shown in Fig. 9 and measure V_{AB} with $R = 2K \Omega$, $9.1K \Omega$, and without R (open circuit). Comment on the results in light of Thevenin's theorem. Calculate the Thevenin equivalent voltage and resistance, and draw the Thevenin equivalent circuit.

Figure 9

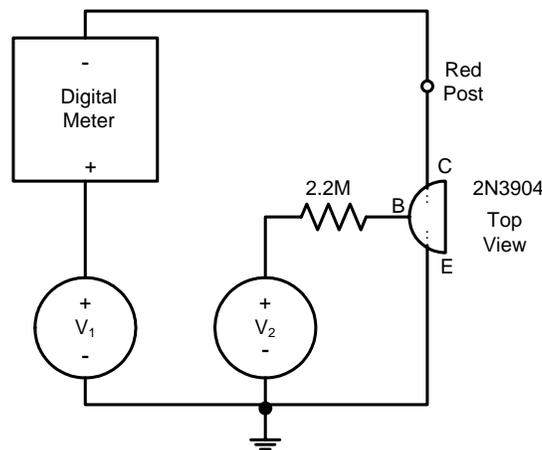


G. Current Source and Norton's Theorem

A transistor is used to illustrate a current source. You do not have to understand transistor operation to make the measurements, but remember the results because they will be helpful when you study transistors later.

Set up the circuit shown in Fig. 10. Both voltage sources from the power supply are used in the positive mode. The multimeter, configured for current measurements, is connected in series between the power supply and the red post on the circuit box. Additional reference information is in GIL sections 2.2, 3.2, and 3.3.

Figure 10



Positive charge is flowing into terminal C of the transistor. Set $V_1 = 5 \text{ V}$. V_2 controls the transistor current source. Adjust V_2 until the current coming from the transistor is approximately 1 ma. This current is denoted as I_c . This current would remain constant for an ideal current source when V_1 is varied.

6 - Record the transistor current for $V_1 = 5, 15,$ and 25 V . Plot this data with I vertical and V horizontal. The current change will be very small, so the I scale should be expanded to show the observed current clearly. Draw a line through the data, empirically determining the slope and intercept. What do these correspond to and what is their significance? Draw a Norton's equivalent circuit for this current source. Draw the Thevenin equivalent circuit.