PURPOSES:

- to gain some experience with soldering
- to introduce the concept and jargon of voltage dividers
- to introduce the use of the Thevenin equivalent method of reducing complexities of circuit analysis
- to introduce the concept of the load line

PART I: ASSEMBLING THE DC VOLTAGE DIVIDER

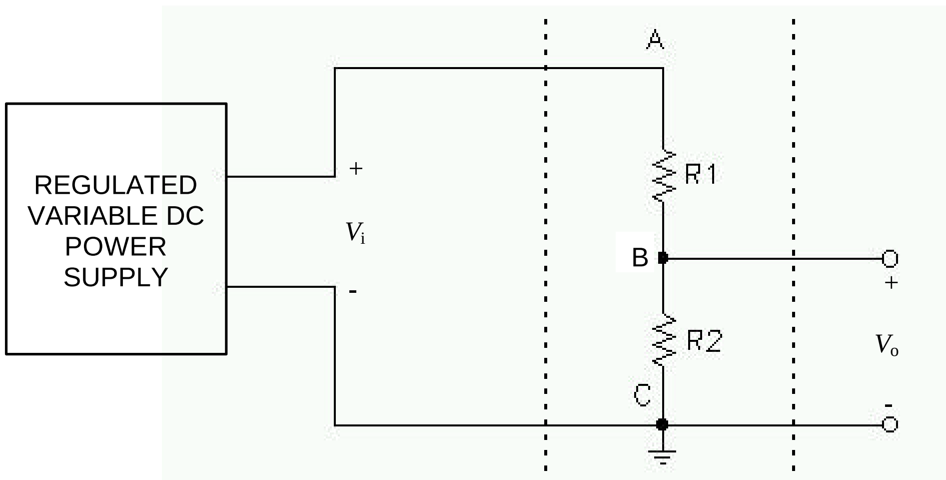
You will need to solder two resistors between terminals on a breadboard. The resistors will share one terminal and will therefore be connected **in series.**

A typical **breadboard** is a rectangular piece of perforated plastic with regularly spaced holes which are usually compatible (in modern times) with the leg spacing on **integrated circuits** (ICs). To establish terminals on the breadboard, you can use **vero pins**. These are small pins that have been **tinned** (i.e., coated with solder) and that you can insert into the holes in the breadboard. You then solder the leads of the components of your circuit to the vero pins. If you are "breadboarding" a circuit you are nearly always assembling the circuit for temporary use, so if you avoid clipping (shortening) the leads of components AND if you avoid any tight wire-wrapping about the vero pins, you can easily recover the components for use another day.

Another kind of breadboard, a **solderless breadboard**, is popular and very convenient to use. It requires no soldering because you simply insert the leads into (latent) terminal strips. We will use these later in this course, but at the beginning you will be invited to learn how to solder.

> ☞ Your instructors will discuss soldering with you and demonstrate soldering technique. Soldering is an art. Even if you consider yourself among the world's experts on soldering, let your instructors help you or determine whether you *are* an expert.

A. THE COMPLETE CIRCUIT FOR THE DC VOLTAGE DIVIDER



A, B, and C denote **terminals** on the breadboard. Connections from the power supply to the voltage divider components should be made with ordinary **clip leads** or **banana-to-banana leads**. (The actual voltage divider circuit is shown enclosed between the two dashed lines.)

B. CONSTRUCTION PROCEDURE

Please do NOT clip the resistor leads. You would do what is commonly called **lead dressing** (use very short leads) if you were building something permanent or if the frequencies involved in the circuit were so high that “stray” (unintended) **parasitic capacitances** might cause troubles.

Use R_1 = 4.7 K and R_2 = 2.2 K . When one of your instructors has approved your soldering of the resistors, make the connections of this "stack" of two resistors to the power supply, but be sure that the power supply is OFF as you make the connections. Your power supply leads should be to COMMON and to the POSITIVE side of the dual supply. (Ask questions about this first encounter you may be having with a multiple-output regulated power supply.)

PART II. USE OF THE VOLTAGE DIVIDER AND DATA ON ITS PERFORMANCE

1. Connect your **digital voltmeter** between nodes A and C so as to measure V_i.

2. Turn on the power supply. As you monitor V_i on the voltmeter, raise the power supply voltage from 0.0 volts to a value close to 12.0 volts. (The value 12.0 is not critical, but the value should not be changed during the experiment.)

3. Record the following data:

V_i = __________________ V_o = __________________

4. Remove the power supply from the circuit; then, using a **digital multimeter** in the **ohmmeter mode**, measure the following resistances:

$R_1 + R_2$ =________________ R_1 = ________________ R_2 = _________________

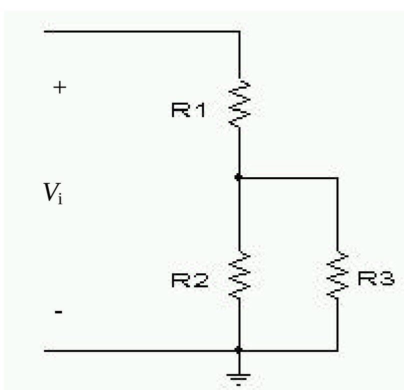
5. The operation of the voltage divider is now to be checked.

   a. In the space below, using Ohm's law, derive a general expression for the value of V_o in terms of V_i , R_1, and R_2.

   b. Comment in quantitative terms on how well your measurements in the preceding Steps 3 and 4 compare with your derived formula.

PART III. THE THEVENIN EQUIVALENT CIRCUIT

Voltage division as we have observed it in Part II is always done for a purpose: to apply to a **load** (e.g., a separate resistor R_3) a voltage reduced from the power supply voltage by a controllable factor. (Refer to the circuit below.)



If the load resistance is extremely high, the load (R_3) will draw very little current and will have an essentially negligible effect on the voltage applied to it by the divider circuit. This fact was tacitly assumed when we had confidence in using the digital voltmeter to measure V_o: the internal resistance of a very good voltmeter is usually extremely high. For the **ideal voltmeter** (a theoretical construct which can be approximated in real life by, for example, an electrometer) the internal resistance is **infinite**.

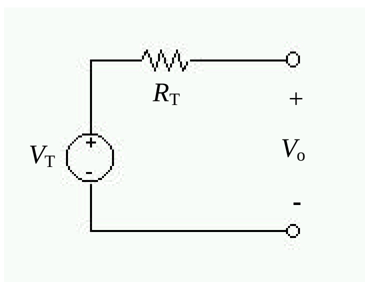
However, you may want to design a voltage divider which will supply voltage and power to an unknown or even time-varying load. What do you do when faced with this problem? This is an occasion when replacing a basic voltage divider by its **Thevenin equivalent** can help. The Thevenin equivalent circuit can:

- provide intuitive insight for design of a voltage divider;
- frequently make formal analysis of the combination of voltage divider and load much easier (as we will see in important "bias configurations" with transistors); and
- make numerical calculations simpler.

A. THE THEVENIN THEOREM

The **Thevenin Theorem** assures you that you can find a simple two-component circuit—consisting of one voltage source and one resistor—which will perform at its output terminals precisely as does a much more complicated circuit with *many* resistors and sources. The **Thevenin equivalent circuit** is shown below.

Circuit of the Thevenin equivalent:



The ideal voltage source denoted by V_T is called the **Thevenin equivalent voltage** and R_T is called the **Thevenin equivalent resistance.**

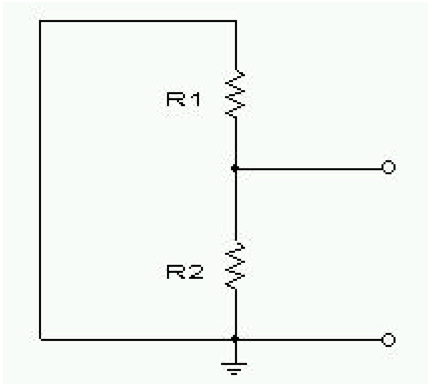
B. PROCEDURE FOR DETERMINING THE THEVENIN EQUIVALENT COMPONENTS

We will now determine the Thevenin equivalent components for the voltage divider you worked with in Parts I and II of this lab. The procedure outlined below is applicable generally to any situation in which you want to find the Thevenin equivalent of a circuit containing only resistors and linear voltage sources.

1. Measure the output voltage V_o of the unloaded voltage divider (you already have this information). The Thevenin voltage is assigned this value. So V_T equals the voltage divider output voltage with no load on the voltage divider. Record this value in the space below.

   V_T = ______________________

2. To determine the Thevenin resistance R_T , you imagine doing something which will seem completely artificial. But, in fact, if you remember that an ideal voltage source has no internal resistance, you will discover that there is nothing really artificial about this procedure. The procedure is as follows: the regulated power supply in the original basic voltage divider is imagined to be SHORTED OUT, and then you calculate the resistance between the two output terminals of the original voltage divider. This is the resistance of the parallel connection of R_1 and R_2, as depicted in the figure below.



$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

Record the Thevenin resistance of your unloaded voltage divider below.

R_T = ______________________

C. TEST OF THE EQUIVALENCE OF THE THEVENIN EQUIVALENT AND THE ORIGINAL VOLTAGE DIVIDER

As a result of your efforts in Steps 1 and 2 above, you have determined the Thevenin equivalent components, which are supposed to give you the same **terminal characteristics** as your original voltage divider. This means that the actual voltage divider, or whatever other circuit you have developed the Thevenin equivalent for, should not be distinguishable from the equivalent for any load. We will now test the equivalence by actually constructing the Thevenin equivalent of the original basic voltage you built in Part I.

1. Since it is very unlikely that you can find a single resistor that will closely approximate your calculated value of R_T , we will use a variable resistor and adjust it as closely as we can to the required value of R_T . (Actually, a 1.5K fixed resistor of sufficient accuracy will do just fine. Ask your instructors about this. Do you agree with this choice?) The regulated power supply will easily be adjusted to give a good approximation for V_T.

2. Keeping your original basic voltage divider on the breadboard, now construct its Thevenin equivalent by using a variable resistor provided by your instructors. You now have two circuits which are supposed to have essentially identical terminal characteristics.

3. Using each of the load resistances shown in Table 1 measure the output voltage V_o and **calculate** (don't *measure*) the output current I_o for your original voltage divider and for the Thevenin equivalent. Record your data in Excel on the computers in the lab as well as on Table I in this lab handout. Can you expect this system to handle a "dead short"? Try it only briefly in case the current drawn causes overheating of any resistors.

TABLE 1: Quantitative Test Of The Thevenin Theorem

LOAD (R_3)	**ORIGINAL VOLTAGE DIVIDER**		**THEVENIN EQUIVALENT**	
	V_o	I_o	V_o	I_o
"infinity"				
2.2 k				
1.0 k				
0.47 k (470 ohms)				
0.0 ohms				

4. Now use Excel to make a scatter plot of the load current I_o versus the load voltage V_o for the two sets of data (i.e., the data for the original voltage divider and the data for the Thevenin equivalent). Plot these two data sets on the **same set of axes** and **do not connect the points with lines.** Print out your plot and hand it in with your lab.

5. Discuss your results above: how nearly equivalent do the original voltage divider and its Thevenin equivalent seem to be? You need to recognize that for a given load resistor the two sets of output voltage and current values should be very nearly the same.

PART IV. THE LOAD LINE

The **load line** of a circuit regarded as a source (i.e., a circuit to which you connect a **load**) provides all the information you can ever need about the voltage and current that the source will supply to any load that you connect to it. That is, the load line completely characterizes the source. Load lines are called *lines* because they are linear if the components that make up the source are linear. (Note that the load can be nonlinear...the method of analysis by load lines still applies.) In this context, the "source" is *everything except the* load. In the case of the voltage divider circuit you built in Part I, the source is the regulated DC power supply *and* the (unloaded) voltage divider circuit.

1. Now that you have demonstrated to yourself that your original voltage divider and its Thevenin equivalent are indeed equivalent, we can use the Thevenin equivalent to find the load line, with the assurance that the load line will be the same for the original voltage divider. So in the space below, derive the **load line equation** for your Thevenin equivalent circuit.

2. Using the computers in the lab, plot the load line on the same set of axes as the I_o-vs-V_o data points you plotted in Part III c. Print out this plot and hand it in with the rest of your lab.

QUESTIONS:

(1) Do you discern any relation between the magnitude of the slope of the load line and the Thevenin equivalent resistor? If so, what is the relation?

(2) What is the expected value of output voltage from the Thevenin equivalent when the output current is 0.00 amperes?

(3) Discuss below how well your I_o-vs-V_o data points (both for the original voltage divider and the Thevenin equivalent) agree with the load line you derived.