

# ENGR 210/EEAP 240 Lab 5

## Introduction to the Op-Amp

**Purpose:** To become familiar with the operational amplifier (OP AMP), and gain experience using this device in electronic circuits.

### Equipment Required:

- HP 34401A Digital Multimeter
- HP E3631A Power Supply
- 2 - 8.2k ohm Resistors
- 1 - 36k ohm Resistor
- 1 - 10k ohm Potentiometer<sup>1</sup>
- 1 - 741 OP AMP

### Prelab:

Read Sections 4-4 and 4-5 on OP AMPs in the textbook<sup>2</sup>. Review the following handling precautions for semiconductor devices. Use these precautions when handling OP AMPs.

#### Caution

The OP AMP, like any semiconductor device, can be destroyed by over-current, over-voltage or static discharge. Over-current conditions are usually due to a wiring error. Over-voltage occurs when the power supply voltage exceeds the voltage rating for the device. These conditions can be avoided by ensuring that you are using the proper device, and double-checking the circuit layout to catch — and correct — wiring errors. In the laboratory, damage from static discharge is often controlled by the use of grounded anti-static mats on the floor and the work surface. Manufacturers of static-sensitive devices recommend the use of a grounded wrist strap when working on sensitive electronics. You can help avoid damage from static discharge by touching an earth ground before picking up a semiconductor device. Earth grounds are available throughout a modern circuits lab, in the form of any metal case on a grounded instrument. Some power supplies provide a ground lug (green jack) separate from the negative side of the supply. The ground lug provides a good quality connection to earth ground through the third wire (round pin) on the AC power cord. Touching the metal portion of this ground lug (green jack) will discharge any static electricity you have accumulated, and significantly reduce the likelihood of damaging static-sensitive components.

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<sup>1</sup> Actual value is not critical. Basically anything over 1k should be usable.

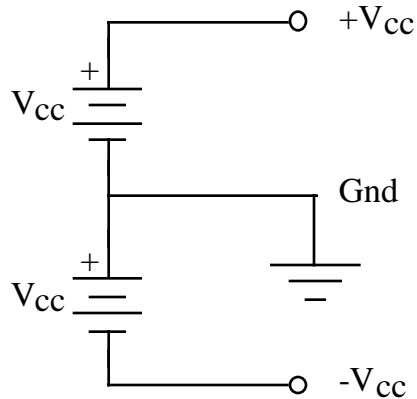
<sup>2</sup> Roland E. Thomas and Albert J. Rosa, *The Analysis and Design of Linear Circuits*, Prentice Hall, (New Jersey, 1994)

## Procedure:

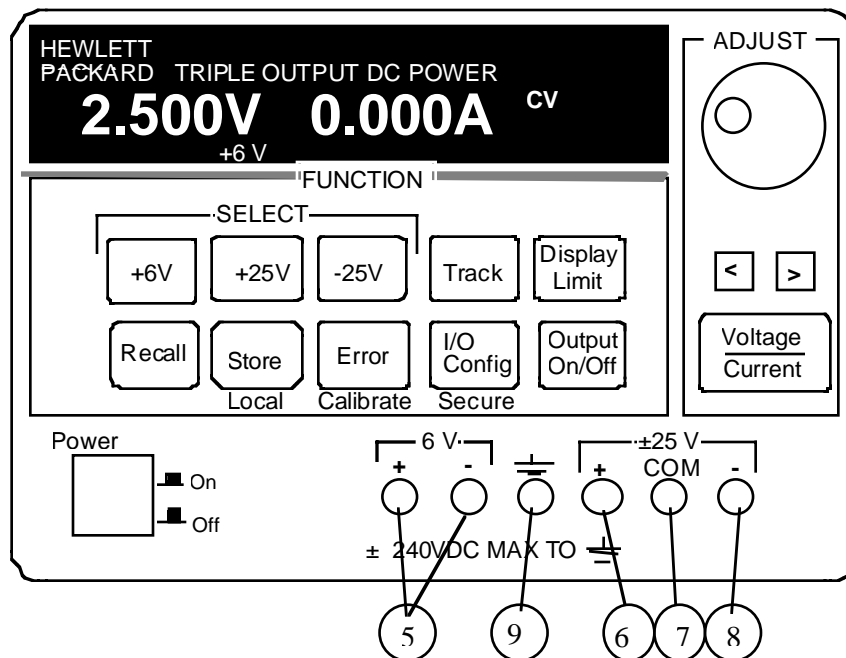
### 1. Prepare the power supplies

#### a. Configure the $\pm V_{CC}$ supplies.

1. The schematic of Figure 1 shows a standard  $\pm V_{CC}$  configuration for an OP AMP power supply. The schematic symbols for a battery are used in Figure 1 to remind us that these supplies need to be a constant DC voltage. They are not signal sources.



**Figure 1. Power Supply Configuration**



**Figure 2. HP Triple Output DC Power Supply**

Your H-P power supply has two variable outputs. Figure 2 shows a single 6V output (labeled 5) on the left (which you used for your last lab), and a dual output 25 V output (labeled 6,7, and 8) supply (which you will use for this lab) on the right of the front panel. The  $\pm 25$  volt outputs (6,8) have a "common" output (7). As shown in Figure 2, the connection labeled "Gnd"

between the  $V_{CC}$  supplies is a real "earth" ground connected to the metal case of the power supply and to the ground of the power line. This connector is NOT connected to the 6V or the  $\pm 25$  outputs at all and should not be used as the "Gnd" in this lab.

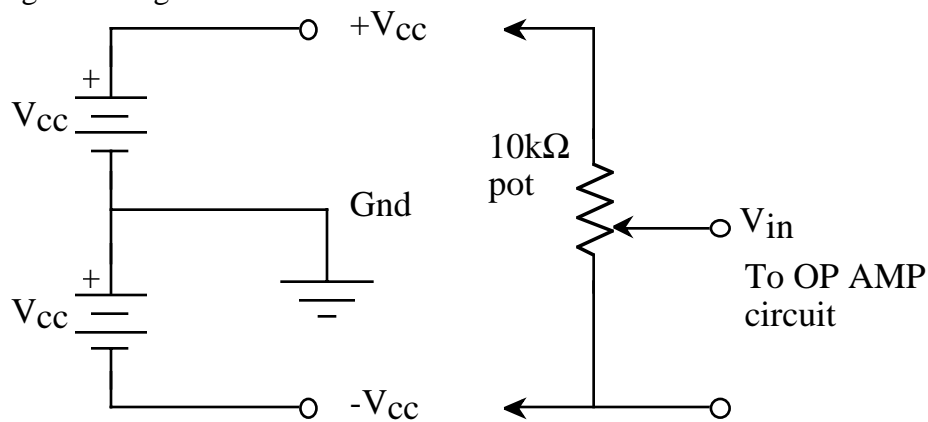
**IMPORTANT**

**The common output (7) in Figure 2 is the connector that actually corresponds to the electrical "Gnd" symbol in Figure 1, Figure 3, Figure 5, Figure 6, Figure 7, and Figure 8. This is the connector to which you should make all connections labeled with the ground symbol in this lab.**

The connector labeled with the ground symbol in Figure 2 is actually a connection to the metal case of the power supply and the ground of the AC line. In general, you should connect the  $\pm 25$  output's common terminal (labeled 7) to the ground of the power supply (labeled 9); otherwise your power supply voltages may "float" and cause measurement problems. Connecting the common terminal to the ground terminal should not be necessary in this lab.

2. Turn on the power supply and adjust the output so the  $+V_{CC}$  and  $-V_{CC}$  are equal — but opposite in sign — at 15 V.

b. Configure the signal source.



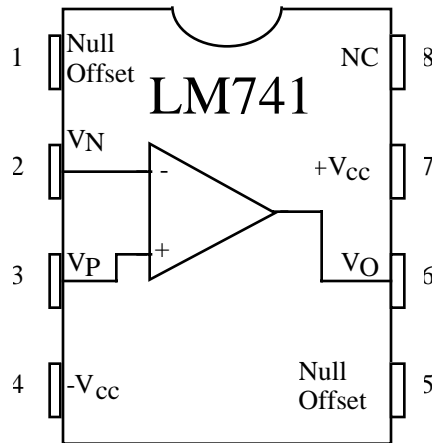
**Figure 3. Signal Connections**

1. Connect the  $\pm V_{CC}$  to the outer terminals of the potentiometer as shown in Figure 3. [Remember that the Gnd in Figure 3 refers to the terminal labeled COM in Figure 2.] The potentiometer will provide a variable-output DC signal source from  $-V_{CC}$  to  $+V_{CC}$ , for input to the OP AMP circuit. Do not attempt to push the connectors for the potentiometer into your protoboard — they are too large for the protoboard and will damage the protoboard. Please use the wires that are soldered on to the potentiometer to make connections to the protoboard.
2. Check the signal source circuit to ensure that it provides the range of voltages desired. The voltmeter should be connected to the center terminal of the potentiometer and the common ground between  $\pm V_{CC}$ . Note that when

adjusting the potentiometer to its maximum rotations the voltmeter should display values that are reasonably close to +15V and -15V.

- c. The way in which the power supplies are connected to each other, and to the potentiometer, produces four nodes,  $+V_{CC}$ ,  $-V_{CC}$ ,  $V_{in}$  and ground (GND) or reference. To reduce the risk of connecting the wrong voltage level to your OP AMP, you may want to label each point on the protoboard with its appropriate voltage:  $V_{in}$ ,  $+V_{CC}$ ,  $-V_{CC}$ , GND. You can do this by putting a sheet of paper under the protoboard and labeling the connections on the paper. We recommend that you run the  $+V_{CC}$  along the red connections on one side of the protoboard, and  $-V_{CC}$  along the red connections on the other side of the protoboard. You can run the common (the circuit ground) along the blue connections on either side of the protoboard. Turn the power supply on and verify that the voltage at each of these points matches your labels. Record the actual values for  $+V_{CC}$  and  $-V_{CC}$ , and the maximum positive and negative voltages produced by the signal source circuit, at the node labeled  $V_{in}$  in Figure 3 in Data Table 1.
- d. Turn the power supplies off.

## 2. Connect the OP AMP



**Figure 4. 741 Connections**

- a. Study the chip layout of Figure 4. The standard procedure on DIP (dual in-line package) "chips" is to identify pin 1 with a notch in the end of the chip package. The notch always separates pin 1 from the last pin on the chip. In the case of the 741, the notch is between pins 1 and 8.

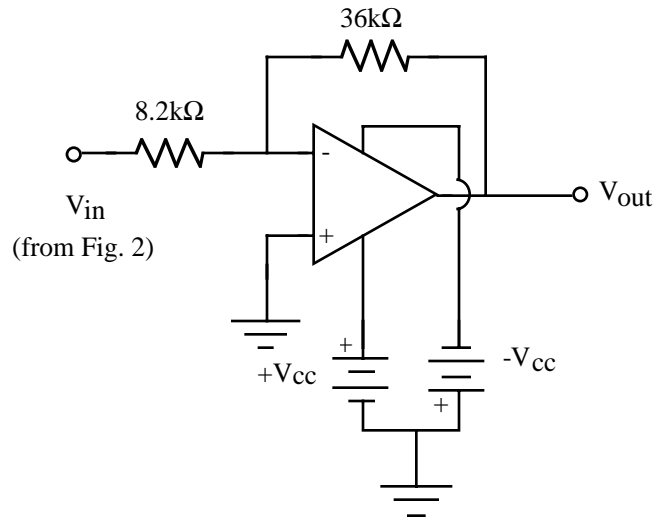
Some integrated circuit packages will have a small round indentation or a "dot" next to pin 1 to identify it. More often pin 1 is simply identified as the pin to the left of the notch (when looking down at the top of the integrated circuit. This notch can be curved as shown in Figure 4 but is often rectangular.

Pin 2 is the inverting input,  $V_N$ . Pin 3 is the non-inverting input,  $V_P$ , and the amplifier output,  $V_O$  is at pin 6. These three pins are the three terminals that normally appear in an OP AMP circuit schematic diagram. Even though the  $\pm V_{CC}$  connections must be completed for the OP AMP to work, they usually are omitted from the circuit schematic to improve clarity.

The null offset pins (1 and 5) provide a way to eliminate any "offset" in the output voltage of the amplifier. The offset voltage (usually denoted by  $V_{os}$ ) is an artifact of the integrated circuit. The offset voltage is additive with  $V_o$  (pin 6 in this case), can be either positive or negative and is normally less than 10 mV. Because the off-set voltage is so small, in most cases we can ignore the contribution  $V_{os}$  makes to  $V_o$  and we leave the null offset pins open.

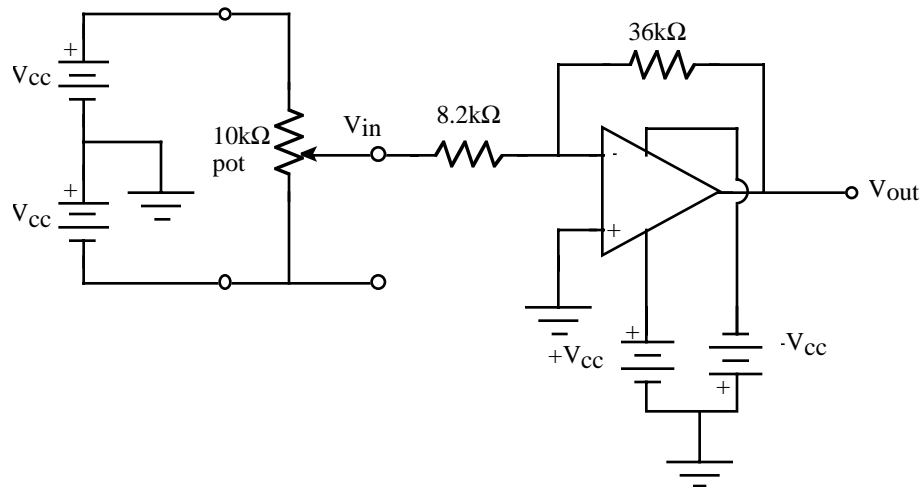
Pin 8, labeled "NC", has no connection to the internal circuitry of the 741, and is not used.

- b. The goal here is to connect the circuit shown in Figure 5. This is an easy task . . . if you've done this before! For this lab we'll walk through how to actually wire up an OP AMP.



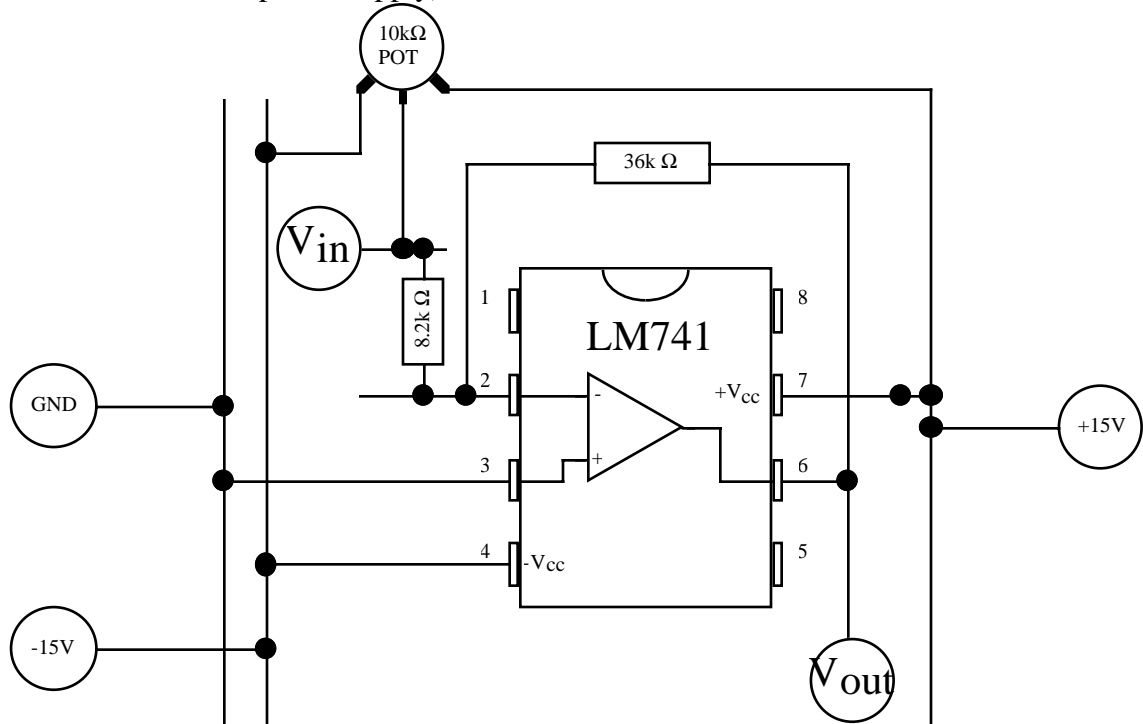
**Figure 5. Actual 741 OP-AMP Circuit**

- c. Figure 6 represents a first step in transferring our circuit schematic of Figure 5 into a real circuit. This figure shows all the elements we will use to implement the circuit of Figure 5. Although Figure 6 shows four battery symbols we really only need one HP power supply which can produce  $+V_{cc}$  and  $-V_{cc}$  to build this circuit.



**Figure 6. DC OP-AMP Amplifier with Variable DC Input**

- d. Figure 7 translates the schematic of Figure 6 into a mechanical representation (or pseudoschematic) showing the physical lay out of the circuit and the connections on the protoboard. Note that this pseudoschematic has only two power supply connections (labeled +12V and -12V) and the GND (which goes to the COM terminal on the HP power supply).



**Figure 7. Pseudoschematic of Figure 6**

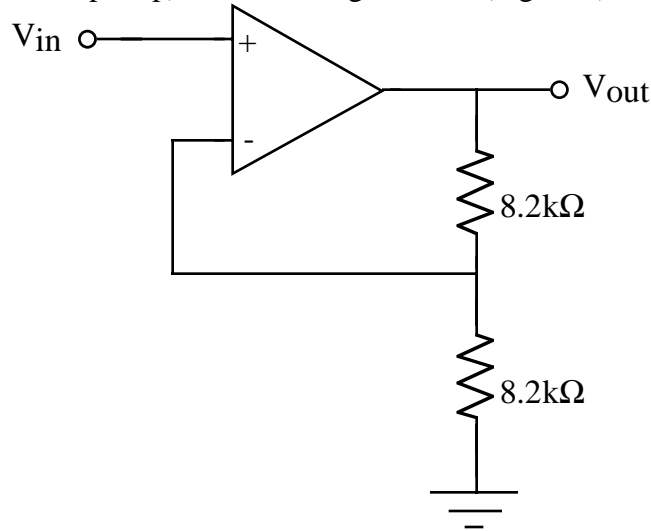
- e. Although we won't go through this level of detail in future lab write-ups, it is useful for you to draw a pseudo-schematic for future labs before actually trying to wire your circuit.

### 3. The inverting amplifier

Using a multimeter, carefully measure the values of the resistors that will be used in the circuit of Figure 5. Record these values in Data Table 2. Use these measured values to compute the calculated circuit gain,  $K$ , then record this value in Data Table 2. With the power supply output off, construct the inverting OP AMP circuit using Figure 7 as a guide. **Please have a TA check the circuit before turning on the power supply.** With the power supply turned on, adjust (Figure 5) the  $10\text{k}\Omega$  ohm potentiometer to achieve a  $V_{in}$  of 1 V. Measure  $V_{in}$  and  $V_{out}$  and verify that the actual  $V_{out} = KV_{in}$ . If  $V_{out}$  is correct, your amplifier circuit is probably working correctly, and you may proceed. If the measured  $V_{out}$  is different than calculated  $KV_{in}$  by more than 10%, you probably have an error in the circuit. Troubleshoot the circuit until it is operating properly.

- a. Turn on the power supply output and for a  $V_{in}$  of about -10 V, carefully measure  $V_{in}$  and  $V_{out}$ . Record  $V_{in}$  and  $V_{out}$  in Data Table 3. Increment  $V_{in}$  by 1 volt, and repeat the measurements. Again record  $V_{in}$  and  $V_{out}$  in Data Table 3. Collect data in this manner 19 more times, incrementing  $V_{in}$  by 1 V after each measurement until  $V_{in} = +10$  V. Record your values for  $V_{in}$  and  $V_{out}$  in Data Table 3. For each line of data in Data Table 3, compute and record calculated  $KV_{in}$  and the error between calculated  $KV_{in}$  and measured  $V_{out}$ .

- b. At  $V_{in} = 2$  volts, accurately measure and record  $V_{in}$ ,  $V_P$  (pin 3) and  $V_N$  (pin 2) in Data Table 4. Circuit Values. If measured using a sensitive voltage scale, a very small difference between  $V_P$  and  $V_N$  can be measured. Measure and record the voltage difference between  $V_P$  and  $V_N$ .
- c. Turn off the power supply output. Without removing the OP AMP, disassemble everything in the circuit of Figure 7 except the power supply connections (pin 4 and pin 7 on the OpAmp) and the voltage divider (Figure 2).



**Figure 8. Non-Inverting DC OP-AMP Amplifier**

4. The non-inverting amplifier
  - a. Calculate and record the expected gain for the circuit of Figure 8 in Data Table 5.
  - b. You will use the source circuit of Figure 3 to provide  $V_{in}$  for the non-inverting amplifier of Figure 8. Draw a circuit diagram similar to Figure 6 for the schematic of Figure 8. Record this in Data Table 7. Draw a pseudoschematic similar to Fig. 6 for this circuit and also record this in Data Table 7.
  - c. Connect the circuit of Figure 8, using your pseudoschematic as a guide. Test the circuit by verifying that  $V_{out}$  is approximately equal to  $KV_{in}$  when  $V_{in} = 1V$ . If not, troubleshoot the circuit until it is operating properly.
  - d. Starting at a  $V_{in}$  of  $-10V$ , make 19 measurements of  $V_{in}$  and  $V_{out}$ , incrementing  $V_{in}$  by  $+1V$  after each measurement. Record  $V_{in}$  and  $V_{out}$  in Data Table 6. Fill in the remaining two columns of the table with the needed calculated values.

# DATA AND REPORT SHEET FOR LAB 5

Student Name (Print): \_\_\_\_\_ Student ID: \_\_\_\_\_

Student Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Student Name (Print): \_\_\_\_\_ Student ID: \_\_\_\_\_

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Student Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Lab Group: \_\_\_\_\_

Measurement	Measured Value
+Vcc	
-Vcc	
V <sub>in</sub> (maximum positive)	
V <sub>in</sub> (maximum negative)	

**Data Table 1. DC Voltage Source Measurements**

Parameter	Calculated Value	Measured Value	% Difference
8.2 kΩ resistor			
36 kΩ resistor			
K (voltage gain of amplifier)			

**Data Table 2. Resistor Values**





<b>Parameter</b>	<b>Calculated Value</b>	<b>Measured Value</b>	<b>% Difference</b>
K (voltage gain of amplifier)			

**Data Table 5. Non-Inverting Amplifier**

$V_{in}$	$KV_{in}$ (calculated)	$V_{out}$	% Error

**Data Table 6. Non -Inverting Amplifier Performance**

**Data Table 7. Schematics for Non-Inverting Amplifier**

## WRITE-UP

1. For the inverting amplifier circuit, plot  $V_{out}$ ,  $KV_{in}$ , and error vs.  $V_{in}$  (three plots superimposed onto the same graph). Repeat for the non-inverting amplifier circuit. On each graph, draw a vertical line at the transition between the saturated and active regions of operation for these amplifier circuits. Label the mode of operation for each of these regions. Points will be taken off for not doing this.
2. Measure the slope of the curve in the active region by using Excel to fit a straight line (polynomial of order 1) to your data. How well does the slope agree with the theoretical gain computed from the measured values of the circuit elements?
3. For the active regions for both circuits, discuss the possible sources of any error between  $V_{out}$  and  $KV_{in}$ .

**Since you learned how to do Excel data analysis in Lab 4 we expect Questions 1 and 2 to have Excel plots of the data. The vertical lines and labels can be hand drawn although this can also be done in Excel.**

### Notes:

- (a) **You can superimpose multiple plots on the same graph in Excel. Simply make the appropriate calculations in the spreadsheet and select all the columns to be plotted (the first column must be the independent variable, the input voltage in this case). All the columns will be independently plotted on the same chart. HINT: In the Chart Wizard pick a Chart sub-type (any one but the default) which shows the lines between the data points. This will give you a better looking graph.**
- (b) **Question 2 only uses part of the full set of data you used in Question 1. You can either edit your data file from Question 1 or select only the data for the active region to produce a separate chart containing only points from the active region. You must fit the curve only to points in the active region to get a proper estimate of K.**

Extra Credit (not for the weak of LabVIEW heart). Modify the dual channel VI you used in the last lab to collect data instead of the DMM. In addition, you can replace the potentiometer with an analog signal generated by LabVIEW. However, LabVIEW output is more complicated than analog input — you must first generate the data to be output using **AO Write** (where the data must be a 2D array) and then you must use the **AO Start** to actually output the data. You will need to use the LabVIEW references on reserve in the library for this. Turn all extra credit work in to Dr. Merat.