Objective
Observe the workings of diodes and transistors. Since this lab is primarily build and observe. Your lab notebook should be a record of those observations.

Equipment and materials from stockroom:
- Wire kit
- EE 1050 kit (if available)

Parts:
These items may be bought from stockroom or may be in the EE 1050 kit.
- 100 Ω (brn,blk,brn), 1 kΩ (brn,blk,red), 22 kΩ (red,red,org), and 100 kΩ (brn,blk,yel) resistors
- 0.22 µF (224) and 100 µF or 47 µF capacitors
- 1N4002 or 1N4004 diode (red glass or black plastic)
- Red, green, and yellow LEDs
- 1N5230 4.7 V zener diode (gray)
- 2N3904 transistor

Note: You will build lots of circuits in this lab—some quite complex. Build them carefully, or you’ll spend too much time troubleshooting. Make your observations and sketches quickly so you can move on. Your sketches don’t have to be perfect, just fast.

Experiment 1, Rectification
Half-wave rectifier: Wire the circuit shown at right, using the “HI” output of the Krone-Hite. The 1N4002 parts are power diodes and they have large leads. These leads can be hard to get into the proto-board holes. If you look closely at the lead ends, you’ll see that many are cut with a wire cutter that leaves a beveled end. If you line the bevel up with the holes that are connected inside the board, they go in a lot easier. Otherwise, wiggle and twist them as you push them in the board.

Hook up the scope, set both scope inputs to “DC”, and turn on the signal generator. Set the signal generator to about 60 or 100 Hz sine wave, amplitude to max, and DC offset off. Observe and sketch the two waveforms that you see (v_s and v_L). Note the half-wave rectification. The load voltage is now “DC”, although it’s not very “pure”.

Experiment 1, Rectification
Place a 47 or 100 µF capacitor in parallel with the load resistors (remember the capacitor polarity—you don’t want to blow the capacitor up). Observe and sketch the filtering effect of the capacitor. The load voltage is better than it was, but it's still not great. The DC voltage still has significant “ripple”. Measure the peak-to-peak voltage of this ripple. Add a second capacitor in parallel with the first. Comment about how the added capacitance effects the ripple.

Notice that the capacitors also distort the input voltage during the short time that they charge. The current during this time is quite high and the distortion is caused by the voltage drop across the 50 Ω output resistance of the signal generator. The same thing happens in power supplies, although the currents are usually higher and the resistances are usually lower. Remove the capacitors.

Change the input to a triangular wave. Observe the waveforms.

**Experiment 2, Other Types of Diodes**

**Zener Diodes**
Replace your diode with the 1N5230 zener diode as shown. Notice that while the diode works exactly like a regular diode in the forward direction, it also lets current flow in the reverse direction when the input is more than 4.7 V negative. The voltage across $R_L$ is proportional to that current. Sketch $v_S$ and $v_L$ you see on the scope.

Change the circuit to that shown at right (notice the resistor is a different value). Now the negative half of the waveform is clipped at about 4.7 V. A zener diode has a specific reverse breakdown voltage and is often used as a voltage reference or regulator. Again, sketch $v_S$ and $v_L$ you see on the scope.

The circuit at right shows a more normal use of a zener diode as a voltage regulator. You DO NOT have to make this circuit. This is called a “shunt” regulator. As long as there is always a reverse current through the zener, the voltage across the zener will be regulated to about 4.7 V.

**Light Emitting Diodes**
Make the circuit on the next page using the DC power supply and one of the LEDs (red, green, or yellow). Notice the resistor 1kΩ again. Calculate the LED current assuming the voltage drop across the LED is about 2 V. This is a pretty good assumption for LEDs. In fact, to design an LED circuit you usually make this 2 V assumption and...
calculate a resistor value which will allow about 10 to 20 mA to flow through the LED. Never just hook an LED up to a voltage source--unless you want to let the smoke out. Measure the actual LED and resistor voltages and calculate the actual current flow in the circuit. Compare this to what you calculated from your assumption. Try the other two LEDs in this circuit and measure the voltage drop across each.

**Experiment 3, Transistors**

**Transistor switch**

A transistor is a nifty little device which controls current flow. It has three terminals--the base, the collector, and the emitter. The current flow from the collector to the emitter (through the transistor) is controlled by the current flow from the base to the emitter. You can think of this as the base current controlling the collector current. A small base current can control a much larger collector current. They are related by a simple factor, called beta (β). For a given base current, the transistor will allow β times as much collector current. Big power transistors usually have a β between 20 and 100. For little signal transistors, β is usually between 100 and 300. Because a small current can control a large current a transistor can be used as an amplifier. That is, it can make a larger signal from a smaller one. (A signal is a voltage or current that carries information. In the lab we usually simulate signals with sine waves.)

A transistor can also be used as a current controlled switch. When there’s no base current, it acts like a switch that’s off. When there is a base current, it’s on. When it’s on there are two possibilities. 1. The transistor is in control and limiting the collector current to β times the base current (βI_B). Or, 2. the transistor does the best it can to let βI_B current flow but circuitry outside the transistor won’t let that happen. In that case the transistor turns on completely, like a closed switch and other elements in the circuit limit the collector current to less than β times the base current. In the first case the transistor is said to be operating in the active region because the transistor is in active control of the current. In the second case the transistor in the saturated region and is working like a switch.

Find your 2N3904 transistor. It’s a small black part with three leads. The leads are labeled on the part as E, B, and C, meaning Emitter, Base, and Collector. Expand your LED circuit to the one shown at right. Note the symbol for the transistor, and it’s E, C, and B labels.

The LED should be lit, indicating that the transistor is “on”. Disconnect the 100 kΩ resistor and the transistor turns “off”, reconnect it and the LED lights again. Repeat this several times to convince yourself that the base current controls the collector current. Notice now that the base current flows through a 100 kΩ resistor whereas the collector current flows through only a 1 kΩ resistor. The base current (the controller) is roughly 100th the collector current (the controlled)!
Transistor amplifier
In the final circuit we'll use a transistor to amplify a voltage signal. I won't try to explain the circuit. I just want you to build it and see that it works.

Construct the circuit shown at right. Use the LO output of the Krohn-Hite function generator as $v_s$ and set the frequency to about 5 kHz. DO NOT connect the 100 μF capacitor at this time.

Adjust the input signal ($v_s$) so that the output signal ($v_o$) shows some clipping. Turn the input up all the way—you'll see what I mean. Now turn the input down somewhat so that the output looks good, with no visible distortion or clipping. The output voltage is a combination of the AC output signal and a DC bias voltage. You may have to adjust the vertical position knob on the scope or set the CH2 scope input to AC in order to see the signal on the scope. Measure the input ($v_s$) and output ($v_o$) signal voltages (AC peak-to-peak). Calculate the circuit voltage gain ($gain = v_o/v_s$). It should be about 10. Notice that the output signal is inverted with respect to the input. This is normal for this circuit. Sometimes the gain is reported as a negative number to indicate this inversion (-10).

Add the 100 μF capacitor (47 μF will also do) and repeat the previous step. The gain should be much bigger now (I measured 200) but is not so easy to predict. It is now dependant on variations in the transistor. Also notice that the output has a more distorted appearance (top is more rounded, bottom is sharper). Nevertheless, you must admit that this is a pretty remarkable gain for such a simple circuit. I hope you can see where such a circuit might come in handy.

Conclusion
Page back through this lab and just look at all the circuits that you built today. You've come a long way this semester, and you should pat yourself on the back. I hope that it wasn't too painful.

The transistor that you used in known as an “active device”. Active devices are the basis of electronics and all that electronics can do these days.

As always, check off your notebook and write a conclusion.