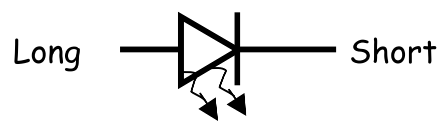
Diodes

Ohm's Law tells us that there is a linear relationship between the current, I, through a device and the voltage, V, across it where V=IR and R is the resistance. But there is a catch. This linear relationship is only true for "ohmic" devices, or, in other words, devices that have a constant resistance. Capacitors, inductors, lightbulbs and diodes are just a few devices that do not have a constant resistance. In this experiment we will learn about the non-Ohmic object called the diode. In class you will learn about the way a diode is fabricated that causes it to behave the way it does. In lab you will study the behavior the diode by looking at the current through the diode and the voltage across the diode.

WEEK I: THE LIGHT-EMITTING DIODE (LED)

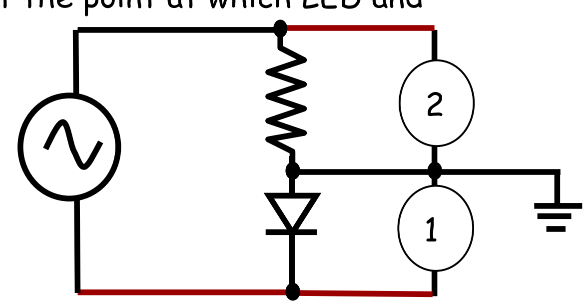
PRELIMINARY. You will notice that each LED has two wires, one is short, and one is long. In all of your sketches and measurements, it will be useful to record which way the diode sits in the circuit. The symbol for the LED is shown below with the length of the leads.



1. Measure the resistance of an LED using an ohmmeter set to the diode symbol. Measure it again with wires reversed. Record your readings. Make sure you include a sketch for each measurement showing the orientation of the LED with respect to the ohmmeter. What can you conclude about the resistance of the diode?

LED PLUS OSCILLATOR PLUS OSCILLOSCOPE.

Using an Audio oscillator you can control the frequency and amplitude of an AC voltage driving an LED. To do this, connect an LED in series with a resistor and an AC oscillator by following the circuit diagram below. This puts an alternating voltage across the LED and resistor. Choose a resistor comparable to the impedance of the oscillator (something around 600 Ω). To make measurements you will connect the oscilloscope as follows: Connect the point at which LED and resistor touch to the ground of the scope (black). Connect the point on the other side of the diode with the "horizontal" channel (CH 1) of your scope, connect the point on the other side of the resistor with the "vertical" (CH 2). Sketch this circuit in your notes.



Diodes

1. Measuring Voltage: Channel 1 of the oscilloscope is connected across the LED so it is measuring the voltage on the LED.

   a. Starting at 0V, slowly increase the amplitude of the driving voltage using the Audio oscillator and observe the LED. Be careful, if you turn up the voltage too much you will kill the LED.
   b. Note the amplitude of voltage necessary to turn on the LED by using the measure feature on the oscilloscope.
   c. Sketch V(t) in your notes for a voltage where the LED has just turned on. Make sure you label the axes with the appropriate units and scales. Note where the voltage is zero on the sketch! (You can find this by grounding the channel).
   d. Sketch V(t) in your notes for a voltage where the LED has a reasonable brightness. Make sure you label the axes with the appropriate units and scales. Note where the voltage is zero on the sketch! (You can find this by grounding the channel).

2. Try flipping the direction of the LED in the circuit, does the behavior change? If so, describe how. Make another sketch.

3. Play with the frequency of the audio oscillator. At what frequency of oscillation do you lose your ability to notice the flicker of the diode turning off and on? (This is a physiology/psychology question, but it's still an interesting experimental question)

4. What voltage is required to produce significant current for your diode? Record this voltage for blue, green, and red LEDs. How do these voltages compare to the energy (in eV) of a typical blue, green, or red photon?

MEASURING CURRENT. What's missing from the above is an idea of the current flow in the circuit. We can measure the current flow using the resistor. The voltage across the resistor is proportional to the current through it → V=IR. Since the diode is in series with the resistor, the currents through the diode is the same as that through the resistor. By displaying this voltage on the scope, we can see how the current varies with time.

Diodes

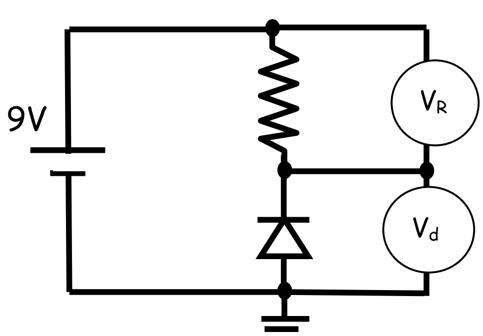
1. Sketch V(t) (Chn1) and I(t) (chn2) in your notes on the same graph so you can see how they overlap. Be sure to include scales and labels on your sketch.
2. What is the resistance (R=V/I) and power dissipation (P=VI) in the diode when it is on at full brightness? Be careful here. The diode is only on for half of the cycle. Be sure to figure out which half. Compare, qualitatively, the resistance of the diode for positive and negative current.
3. Now use the XY display mode of your oscilloscope to display the I vs V curve for the diode. Invert the y-axis. Be sure to put the zero setting for x and y in the center of the scope so that the origin (V=0=I) is at the center. Sketch I vs V graph in your notebook (include scales on your graph.)
4. What happens to your I vs V curve on the oscilloscope as you vary the amplitude of the voltage on the oscillator?
5. Replace the diode with a resistor and adjust the scales on the oscilloscope so that you can see the entire curve. What does the shape of this curve look like? What is the slope? Can you calculate the resistance of the resistor using this information?

WEEK II: PHOTODIODES

Photodiodes are one of the most widely used transducers for measuring the intensity of laser light. You will design and build a circuit which produces a signal from a photodiode which is linear in intensity, you will test the linearity, and then you will use this circuit to perform an unrelated experiment.

LIBRARY WORK. Find out what you can about the physics of photodiodes (BEFORE lab). How do they work?

CIRCUITRY. We can think of the photodiode as a device with a resistance which depends on light intensity, where the resistance is inversely proportional to the intensity. How can we design a circuit to get a signal that is proportional to intensity? Consider the circuit drawn below



where we have a battery in series with a resistor, R, and a reverse biased diode. If we model the resistance of the photodiode, r, as r=A/x, where x is the intensity of the incident light and A is a constant, we can derive an equation for the voltage across the diode and we can derive an equation for the voltage across the resistor. We know that since the elements are connected in series that the current through the diode must equal the current through the resistor. The current through the resistor is given by $I_R=V_R/R$. The current through the diode is given by $I_d=V_d/r$. Since the two are in series, the currents through them are equal and we have $V_R/R= V_d/r$. We also know that $V_R + V_d= V_{battery}=V_{in}$. Using these two ideas you can show that

$$\frac{V_d}{V_{battery}} = \frac{r}{r+R} = \frac{A/x}{A/x+R} = \frac{A}{A+Rx}$$

$$\frac{V_R}{V_{battery}} = \frac{R}{r+R} = \frac{R}{A/x+R} = \frac{Rx}{A+R}x$$

You will check whether the voltage across either r or R is nearly linear in x and find the limits on linearity.

1. Wire the circuit shown on the previous page using around a 2000 Ω resistor.
2. Set up the light source so that it is around 30 cm from the neutral density filter wheel. Put the Photodiode behind the filter wheel as close as you can to the wheel.
3. The transmission of a neutral density filter is given by $T=10^{-D}$, where D is the optical density of the filter. For example, the transmission of a filter of density, D=1.00 is 0.10.
4. Set the light source to its lowest setting. Measure the voltage across the diode and the resistor simultaneously for each ND filter.
5. Plot the voltages divided by the battery voltage as a function of transmission.
6. Repeat with a 10,000Ω resistor and a 200Ω resistor.
7. What value of resistance gives you the most linear signal? Why? To answer this question, I want you to look at the equations above and think about how either of them can give you a linear result.
8. Pick the resistor that gives you the most linear result resistor and repeat your measurements using the highest light intensity setting on the lamp.
9. Plot your voltages divided by the battery voltage on a graph with the data from the low intensity setting using the same resistor.
10. Interpret the result in light of the equations above.