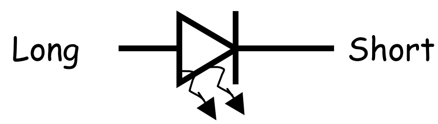
Diodes

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?
2. Repeat these measurements using the 200Ω scale. What do you observe?

LED PLUS OSCILLATOR PLUS OSCILLOSCOPE. Connect an LED to an AC oscillator. This puts an alternating voltage across the LED. Using the oscillator you can control the frequency and amplitude of this driving AC voltage.

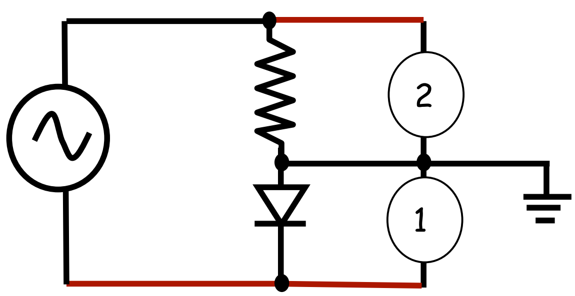
1. Connect the LED to an oscilloscope so that you can observe the time dependence of the voltage across the LED on an oscilloscope. Sketch this circuit in your notes. Pay attention to which lead is attached to ground (black) and which lead is the signal (red). Play around with the amplitude of the driving voltage and observe the LED. Be careful, if you turn up the voltage too much you will kill the LED.
    a. Note the amplitude of voltage necessary to turn on the LED.
    b. Sketch V(t) in your notes for a voltage where the LED is on with a reasonable brightness. Make sure you lable 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. If you flip the LED in the circuit, does the behavior change? If so how. Make another sketch.

3. 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)

MEASURING CURRENT. What's missing is an idea of the current flow in the circuit. We can measure the current flow by connecting the diode in series with a resistor and an oscillating voltage source. The voltage across the resistor is proportional to the current since V=IR. By displaying this voltage on the scope, we can see how the current varies with time. Choose a resistor comparable to the impedance of the oscillator (something around 50-100Ω) and put it in series with the diode. Connect the point at which LED and resistor touch to the ground of the scope. 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).



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?
3. Compare, qualitatively, the resistance of the diode for positive and negative current.
4. What happens if you flip the direction of the LED
5. Now use the XY display mode of your oscilloscope to display the I vs V curve for the diode. Be sure to determine where on the scope the origin (V=0=I) is. Sketch I vs V graph in your notebook (include scales on your graph.)

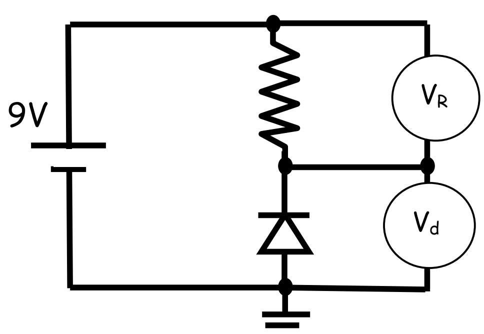
6. What voltage is required to produce significant current? Record this voltage for blue, green, and red LEDs. How do these voltages compare to the energy (in eV) of a typical blue, green, or red photon?

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 these terms are equal 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

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

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

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

Connect the circuit using around a 2000 Ω resistor, and measuring the voltage across the resistor and the diode as you change the light intensity using neutral density filters. 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. Measure the voltage across the diode and the resistor for each ND filter. Plot the voltages as a function of transmission to find where the signal is linear. Repeat with a 1000Ω resistor and a 200Ω resistor. What value of resistance gives you the most linear signal? Why?

STUFF TO DO WITH YOUR NEW TOY:

1. Compare the AC and DC voltages registered by your photodiode sitting in the lab room. Explain why there are both types of signals, and use an oscilloscope to find the frequency of the AC component.
2. Compare the AC and DC voltages registered by your photodiode in a darkroom with a tungsten-filament bulb. Explain why this is different from (1).