

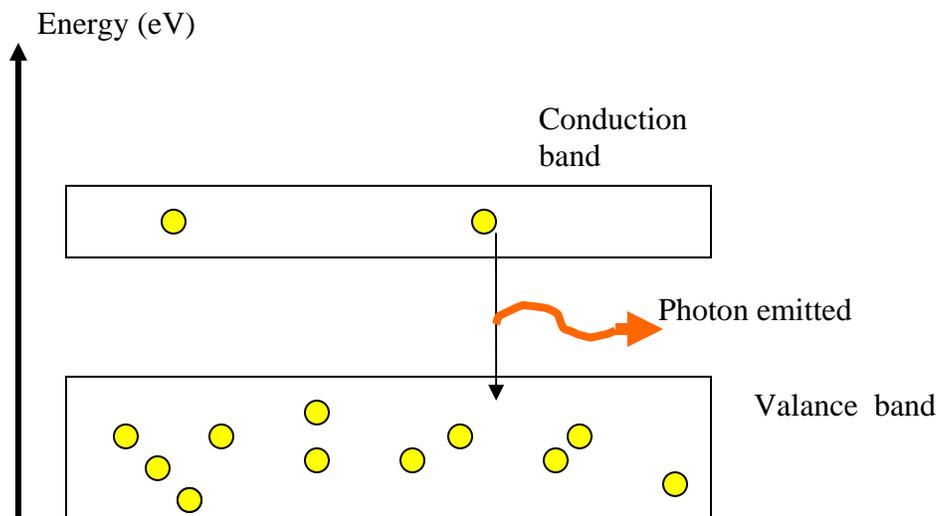
Planck's Constant



In this lab you will experimentally determine the value of Planck's constant by finding both the threshold energy needed to light a variety of LEDs and the peak wavelength of the spectrum emitted by each diode. After performing this experiment, you will understand how the threshold voltage applied to a diode determines the wavelength of the light produced, as well as the relationship between wavelength, energy, and Planck's constant. In addition, you will gain experience using the spectrometer in order to determine the wavelength of light produced by the LEDs.

Theory:

An LED is semiconductor device that takes advantage of the energy difference between the unfilled conduction band, and the filled valence band.



As the semiconductor material is excited, either by thermal excitation, or by an applied electric field, electrons will be promoted from the valence band to the conduction band where they are free to flow if the semi-conductor is part of a complete circuit. Once electrons are conduction band, they are also free to jump down to the valence band, much as an electron in an excited atomic orbit is free to jump down to the ground state.

In this lab, you will provide just enough voltage to a semiconductor called a Light Emitting Diode (LED) to cause electrons to jump to the conduction band. Immediately, some of these electrons will return to the valence band emitting a photon.

The energy to promote the electron from the valence band to the conduction band is eV , where V is the applied voltage, and e is the electron charge. This energy also equals the energy of the photon emitted when an electron jumps back to the conduction band, hf , where h is Planck's constant and f is the frequency of the emitted light.

Since $f = c/\lambda$, the minimum voltage needed to promote an electron from the valence band to the conduction band is related to the wavelength according to the relation:

$$eV = hf = \frac{hc}{\lambda}$$

Thus,

$$V = \left(\frac{hc}{e}\right)\left(\frac{1}{\lambda}\right)$$

In order to account for experimental error, it is possible to plot the minimum voltage needed to light a given LED, as a function of the peak wavelength of light emitted. By plotting V vs. $1/\lambda$, you can calculate h , Planck's constant from the slope of the graph:

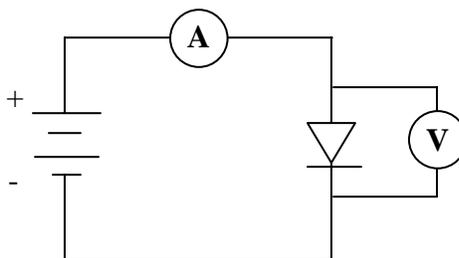
$$h = \frac{e(\text{slope})}{\lambda}$$

Note that thermal motion within the semiconductor will cause the electrons in both the valence band and the conduction band to be in a distribution of energy states. In other words, the light emitted by the LED will not be monochromatic, but will be emitted in a range centered about the peak wavelength. As you will see, the peak wavelength corresponds to the band gap energy for a particular diode. A particular challenge of this experiment is to determine the peak wavelength of diode spectrum and the uncertainty in this value. If you are using a spectrometer to determine the diode wavelength, it is useful to find the angles corresponding to diode color on either side of the central value. Be sure to look at the diode with a diffraction grating to see spectrum for yourself!



Experiment:

1. In this experiment, you will use a vernier spectrometer to measure the wavelength ranges of each diode. In this lab, it is assumed that you are already familiar with the use of a spectrometer. If not, your instructor will guide through the set up. Since you will need considerable accuracy to reduce your uncertainty, carefully align the spectrometer so that collimator, slit, and telescope are aligned with the zeros of the both the upper and lower scales.
2. Set up the circuit as shown in **Figure 1**:

**Figure 1**

3. The longer arm of the LED is connected to the positive side of the power supply. If both arms are the same length, put the diode in place and raise the voltage to one or two volts. If the diode doesn't light (or if the ammeter doesn't move off zero), reverse the LED. Do not raise the voltage beyond 2.5 V
4. Position the optical fiber so it is close to the Diode . With the diode dimly lit (just above the threshold voltage) find the location of peak wavelength and also the range (where the intensity falls to a minimum value on either side of the peak).
5. Once you are certain the LED is oriented the correct way, and the circuit works, lower the voltage to zero. Then, watch both the LED and the ammeter as you slowly turn up the voltage. When the ammeter begins to register current or the diode begins to light up (whichever comes first), record the voltage. Note that you can accurately judge the minimum voltage by watching the diode through the telescope of the spectrometer with the room lights on low. Simply watching the diode with the room lights on will not give accurate results!
6. At a voltage level just above the threshold voltage, use the spectrometer to find the angular range of the peak wavelength. This is done in practice by finding the angular range for the diode color. In other words, if the diode appears green, find the minimum and maximum angle that green appears on the diode spectrum. Record both of these values.
7. Repeat Steps 6-7 with a diode of a different color.
8. Repeat Steps 6 – 7 until you have measured five different diodes.

Analysis:

1. From your data, plot a graph of V vs. $1/\lambda$. Use the average values of the peak wavelengths for each diode.
2. From your plot, determine a value of Planck's Constant, h .
3. Calculate the experimental uncertainty.
4. Do the accepted and experimental values of h agree with each other, within the experimental uncertainty? If not, what modifications to the experiment might you make to bring the values closer together?

Equipment:

- LEDs of various wavelength
- 2 DMMs
- DIGI 35A DC Power Supply
- Bread Board
- Patch Cords and Alligator Clips

Note: a simulation of the theory behind this experiment on the web can be found at:

http://www.scienceshareware.com/led_ov.htm