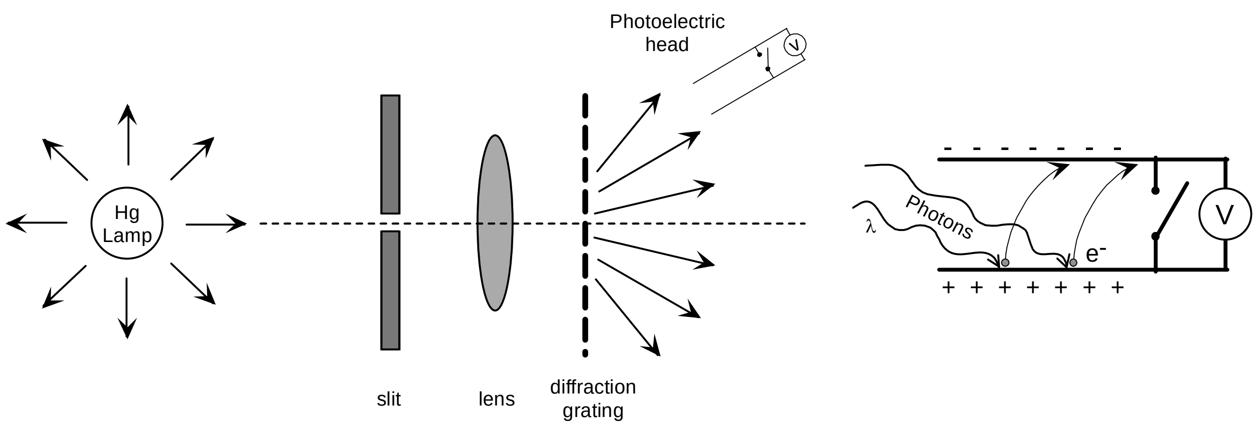
The Photoelectric Effect
Spring 2009

Introduction

In early experiments that attempted to create radio waves, it was noticed that light shining on an electrode sometimes produced a visible spark. Later experimentation found that these sparks were created by the impact of light on an electrode, which caused the ejection of electrons. It was also found that these ejected electrons had kinetic energies that increased *linearly* with the frequency of the light used. These observational results were explained by Einstein assuming that light behaves as a particle. In this experiment you will use the Photoelectric Effect to find Planck's constant from the stopping potential for photoelectrons.

Theory

The apparatus consists of a mercury source behind a slit, a diffraction grating and a lens which images the slit in the wavelength of each mercury line on a phototube. The photons strike a metal plate inside a capacitor, causing electrons to be ejected. These ejected electrons charge the capacitor to roughly their highest energy, so the measured voltage gives us a measure of this energy (also called the *stopping potential,* V_{stop}).



The apparatus

Photoelectric head detail

Each photon has energy $E = hf$, where f is the photon frequency and h is Planck's constant. When a photon strikes a metal surface, a minimum amount of energy, φ, is needed to knock an electron off. The remainder is given up to the kinetic energy of the ejected electron.

$$K_{\max} = hf - \varphi$$

These electrons strike one of the capacitor plates and charge it up. Eventually, the capacitor voltage becomes large enough to stop further charging. This happens when

$$K_{\max} = eV_{\text{stop}}$$

where e is the charge on an electron (1.602×10^{-19} Coulombs). Solving for the stopping potential, we get

$$V_{stop} = \left(\frac{h}{e}\right) f - \left(\frac{\phi}{e}\right)$$

Of the quantities in this equation,

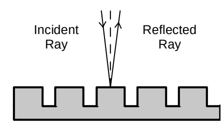
- we can measure V_{stop} ,
- we can find f for each of the given mercury wavelengths ($c = f\lambda$),
- we know $e = 1.602 \times 10^{-19}$ Coulombs,
- we want to find φ, and
- we want to confirm the value of Planck's constant, h.

The equation for V_{stop} looks suspiciously like our linear friend, $\boldsymbol{y = mx + b}$. Thus, if we plot the measured V_{stop} versus f we should get a straight line. From the slope we can find Planck's constant and from the intercept we can find the work function, φ, and hence the binding energy of the electrons.

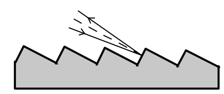
Experiment

Important note: Do not turn off the Hg lamp until you are ready to leave the lab!

1. Turn the photohead on by pressing the power switch on its side.
2. The diffraction grating is 'blazed', which causes the images on one side to be brighter than the other. Using the images on the bright side, align each color over the window of the photohead, press and hold the **Zero** button until V = 0, then release the button to measure the stopping potential. Repeat each measurement several times (pressing the Zero button between each measurement) and average the results. Be sure to use the *green* filter for the green line, and the *yellow* filter for the yellow line (no filter is required for the violet and blue lines). These filters limit higher frequencies of light from entering the photoelectric head.



Reflection Grating


Blazed Grating

3. Calculate the frequency, f, for the mercury lines listed in the table below (spectroscopic tables tend to list the wavelengths). Note that the yellow line is actually a double line. You will only be able to resolve it as a single spectral line, so the wavelength given in the table is the *average* of the actual wavelengths (577.0 *nm* and 579.1 *nm*). Be careful with the units!

Color	**Wavelength (nm)**
Violet #1	365.0
Violet #2	404.7
Blue	435.8
Green	546.1
Yellow	578.1

4. Take several measurements of the stopping potential for each line, then calculate the average, $< V_{stop} >$. It will be difficult to graph in the dark, so plot $<V_{stop}>$ vs. f after collecting your data. You should get a straight line. If a point is not on the line, remeasure V_{stop}. If it still isn't on the line, check to see if you have measured the correct mercury line.
5. It will be too dark in the lab to plot by hand, so use *Excel* to plot $<V_{stop}>$ vs. f. Calculate Planck's constant and the electron binding energy from a linear fit. Since it has been awhile since you used Excel 2007, here are a few hints:
   a. Enter the frequency in the first column, the voltage in the second.
   b. Use the following format to enter numbers using scientific notation: 1.2×10^{14} is entered as **1.2E14**.
   c. After the data is entered, click one cell of data, then choose a scatter plot from the *Insert* tab.

d. Click the *Change Chart Type* button, then choose the *Templates* folder, and finally *SLU Physics*.

e. With the graph selected, click the *Move Chart* button, and choose *New Sheet*.

f. Enter an appropriate title and label the axes.

g. The horizontal axis does not need to start at the origin, so you can change the range of values as follows: Right-click on any number along the horizontal axis, and choose *Format Axis*. In the *Axis Options* section, click the button next to *Fixed* in the *Minimum* row, and set the value to **5E14**, then click the *Close* button.

h. Add a best-fit line by right-clicking on any data point, and choosing *Add Trendline*. Click the button next to *Linear*, and click the box next to *Display Equation on chart*. The click the *Close* button.

i. Note that the value displayed for the slope only has 1 significant figure. Increase the number of digits displayed by right-clicking on the line equation and choosing *Format Trendline Label*. In the *Number* section, choose the *Scientific* category, and change the number of *Decimal places* to **3** (note that this will give you a slope with *4 significant figures!*) Click the *Close* button when finished.

j. Finally, add your names to the header (click the *Office Button*, then *Print*, then *Print Preview*; under *Page Setup*, click the *Header/Footer* tab, then *Custom Header*), and print a copy of the graph for each member of the group.

Discussion

- Report your value of Planck's constant and the binding energy of the electrons in the phototube.
- The published value of Planck's constant is $h = 6.626\text{x}10^{-34}$ *J•s*, and the manufacturer of the photoelectric head gives $\varphi = 2.18\times10^{-19}$ *J*. Discuss the agreement with your calculated values of these quantities.