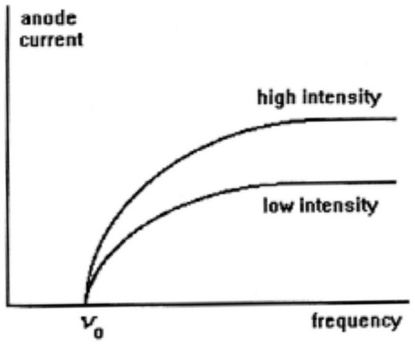
Experiment 4

Photoelectric effect

Albert Einstein predicted the behavior of electrons emitted from metal due to the energy transferred to them from light in 1906. He received the Nobel Prize for his predictions on the photoelectric effect in 1921. In 1915, Robert Milliken verified Einstein's predictions concerning the photoelectric effect which were in contradiction of the predictions of the classical wave theory. In particular, the energy of the electrons released by the photoelectric effect is proportional to the frequency of the impinging light rather than the intensity of the impinging light. Also, electrons will not be released from metals unless the frequency of the incident light is large enough; classical wave theory for light predicts that the release of electrons should occur for any frequency as long as the light intensity is high enough. (Classical wave theory also predicts a time lag in the release of the electrons, but no time lag has ever been observed.)

We will use Pasco Scientific Photoelectric Effect Apparatus to measure Plank's constant and the work function of the metal composing the cathode of the tube within the apparatus. Make sure you include a schematic diagram of the experiment in your report.

Light travels into the evacuated quartz tube and strikes the cathode to liberate electrons which are collected at the anode. The ideal experiment would measure the number of collected electrons as a function of frequency of the incident light (without any variations in intensity). But we do not have a source of light that is precisely tunable in frequency and invariant in intensity. If such a source were available, you could measure the induced current as a function of frequency of incident light at a constant light intensity. The result is expected to be (according to Einstein) a sharp "turn-on" of current that increases as the frequency increases (because the kinetic of each electron increases as the frequency increases-even though the number of electrons liberated would be constant because the intensity is constant). The expected behavior for this ideal experiment is shown in the figure below for two different intensity settings of the tunable source.



It is possible to make good measurements without the ideal source by making use of the retarding potential between the anode and the cathode. When the potential of the anode is increased to the point that the photoelectrons do not have sufficient energy to reach the anode, a value of the maximum electron kinetic value is found. This potential is called the stopping potential. Suppose we have a light

source which emits various spectral lines, and we can isolate these lines somehow. For each isolated line, we would have an associated frequency, and the stopping potential for the electrons liberated by light at the frequency of each spectral line would give us the kinetic energy of the fastest electrons. One complication occurs however. Some energy is required just to free the electrons without any kinetic energy. This energy is material-dependent and is called the work function. An equation that can be written to represent energy conservation in this process is

$$e V_{stop} = h\nu - \Phi,$$

where Φ represents the work function of the material, ν represents the frequency of the incoming light, V_{stop} is the stopping potential, and e and h are the obvious constants. Note that electron-volt energy units are to be used.

If a mercury vapor lamp is used to illuminate the apparatus, four lines in the spectrum of mercury become important. You can find the wavelength of these four lines from the spectral chart if you begin on the small wavelength side. Notice that ALL of the mercury spectral lines will contribute to the photoelectron emission if no filter is used, but if a filter which cuts off the transmission of light at wavelengths at 436 nm and lower is used, then the lowest wavelength spectral line of mercury is NOT used (or any higher frequency either). The photoelectrons with the largest kinetic energy would then need to be liberated by light from the next mercury spectral line around 546 nm or any line at lower energy. You can see how a set of such cutoff filters, combined with the stopping potential measurements can give a graph of the equation shown above. If you plot the stopping potential versus the frequency of the maximum-energy spectral line, you should get a line with a slope of h/e and a y-intercept of Φ/e. using the mercury light source, you can get 4 points on your V_{stop} vs ν curve.

One complication arises in finding the stopping potential. The anode will often give a positive current due to photoelectrons FROM THE ANODE traveling to the cathode. This occurs because contaminants are deposited on the anode during construction of the tube. The best way to determine the stopping potential is to measure the potential required to JUST bring the anode current to its limiting value (which may or may not be 0 A). In fact, it might be wise to take the four data points by approaching V_{stop} from above a few times, and then from below V_{stop}a few times. You should really do these measurements independently <u>for each partner</u>. It will help you determine a better value for the uncertainty in Plank's Constant at the end.

There are three experiments:

1. See what value you get for Plank's Constant and the work function of the material in the cell with the mercury source. Include uncertainties, etc.
2. Compare current versus voltage response for one spectral line at three different light intensities.
3. Compare current versus voltage response for three spectral lines with the same light intensity.