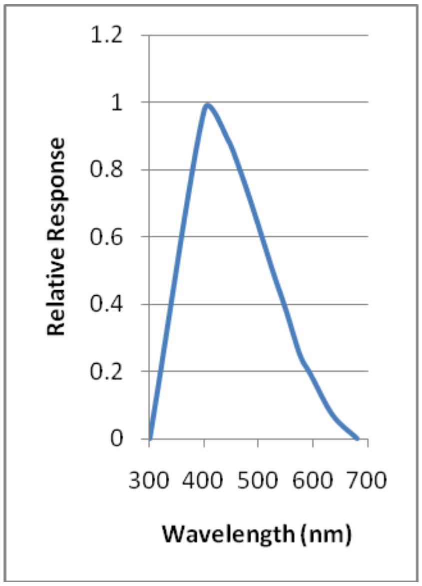
Photoelectric Effect

OBJECTIVE
To use the photoelectric effect to obtain data for stopping voltage and wavelength so that Planck's constant can be experimentally determined.

INTRODUCTION

This important experiment, which provided the first convincing experimental verification of the quantum theory, was suggested by Einstein in 1905. The actual phenomenon of photo emission of electrons from metals was observed by Hertz in 1887 and proved to be impossible to explain using the wave theory of light. Einstein postulated that not only is light emitted and absorbed in discrete but tiny bundles, as proposed by Planck, but it is propagated that way as well; flying through space like a hail of shot at the velocity of light. This conjecture nicely explained the photoelectric effect experiment. In this experiment, the velocity of the electrons leaving the surface of a metal when irradiated by monochromatic light depends upon the wavelength and not upon the intensity of the radiation. When Einstein made his suggestion, there was not sufficient quantitative evidence to confirm or deny his equations. Very precise measurements were subsequently made with the result that the theory was completely verified.

With the Daedalon EP-05 Photoelectric Effect with Amplifier, you will be able to repeat the essential part of the experiment that served to establish the quantum theory of radiation. In the experiment, the photocathode is irradiated by a source of monochromatic radiation and a potential is applied to the tube so that it opposes the energy of the emitted photoelectrons. The voltage required to just stop the current flow is proportional to the energy of the photoelectrons. By plotting the stopping potential as a function of the reciprocal of the wavelength of the radiation gives a straight line plot, the slope can be used to determine Planck's constant.



The Spectral response of the phototube within the EP-05 is shown to the left. From this graph it indicates that the response of the detector lessen as the wavelength increases from 400nm to 700 nm. This however only indicates the number of electrons being release from the surface of the phototube decreases with the wavelength but will have little effect on the stopping voltage for each wavelength which will be measured. This will become more apparent once you start conducting the experiment, it is brought up here to alleviate any concerns that may arise when performing the experiment and the needle indicate does no deflect as much for the higher wavelengths of light. A good source for the theory of the photo-effect can be found at http://en.wikipedia.org/wiki/Photoelectric_effect
For accurate results, the measurement of very small photocurrent is required. In order to do this without introducing extraneous voltages, the amplifier should be placed close to the photodiode. Building the amplifier in the same case, only a few centimeters from the photo-diode tube base, fulfills this requirement nicely. The minimum detectable photocurrent is of the order of $5x10^{-10}$A, which is quite good for such a simple apparatus.

The classical physicist would purpose that as the incident light energy decreases, the energy transferred from the incoming light to the electrons on the surface of the metal would allow progressively fewer electrons to escape until the flux went to zero. Einstein, however, correctly predicted that the energy carried by the incoming radiation is quantized; that is, it has a basic energy level or some multiple of it. Each photon either gives ups it energy in whole or not at all. This can be summarized by Einstein's relationship:

$$E = \frac{hc}{\lambda}$$

Thus $e(V+\varnothing) = hc/\lambda$

Where

- e = the electron charge
- V = the stopping potential
- $\varnothing$ = the work function of the metal of the photo surface
- λ = the wavelength of the light
- h = Planck's constant
- c = the velocity of light

This experiment measures the point where the stopping potential just equals the work function of the metal so that

$$V = \left(hc/e\right)\left(1/\lambda\right) \qquad [1]$$

Then from a plot of V vs. $1/\lambda$, Planck's constant then can be determined using the value obtained from the slope of the line.

As part of the experiment an optical spectrometer will be used to determine the wavelength passed through the filters that are to used. The basic principles of the spectrometer are given in the following section.

Equipment

The equipment to successfully conduct this experiment consists of, a white light LED flashlight, a wooden block, set of wavelength filters, a multimeter and the Daedalon EP-05 Photoelectric Effect with Amplifier apparatus.

The wavelength filters are in a rotating assembly with six positions, position
1: 470nm, 2: 540nm, 3: 570nm, 4: 600nm and 5: 640nm. Each filter are a narrow band filter with a bandwidth of ± 10nm. The Wavetek multimeter on the 2 V scale has an uncertainty of ± 20mV.

Procedure

 First turn on the Photoelectric effect unit to allow it to reach an optimal operating temperature (about 10 minutes).

Task 1 Measuring the stopping voltage for each wavelength band:

 Ideally, it is best to obtain a number of data points for each wavelength thus improving the statistical value for each stopping voltage. A general description for the procedure will be given here but the means of how you obtain the data is left to your own ingenuity.
 You want as little ambient light entering the EP-05 as possible and the apparatus should first be calibrated, (zeroed) with what ambient light is entering the aperture of the device.
 You also want the filters to be near the apparatus with the mirrored like surface towards the light source. The filtered light from the flash light must be directed to fall upon the aperture of the EP-05 apparatus so that the phototube inside is illuminated by the filtered light. It may be necessary to make adjustments to obtain the maximum needle deflection.
 With the volt meter connected to the EP-05 adjust the voltage knob to increase the stopping voltage until the meter on the EP-05 reaches the zeroed position obtained earlier. Hint: Once the needle is close to the zeroed position, block the beam of light entering into the apparatus. Note where the zero position is then unblock the beam and adjust.
You are striving to reach the voltage that just gets it to be zero, which should be indicated by the lack of needle movement between when the light source is block and unblocked.

Task 2: Analysis of the data finding Planck's Constant.

 Graph Stopping voltage vs. $1/\lambda$. Don't forget error bars.
You should have a best and worst fit line so that you may obtain your best estimate of the slope and its uncertainty.
 The linear line of the plotted data represents equation [1]. Be leery of Excel's trend line determination tendency to round small numbers, rather than using m^{-1} try using nm^{-1} for the x-axis.
 Also you can obtain a least squares value for the slope (refer to appendix 1 used in the statistics lab).
 From its slope the value for Planck's constant can be determined after a bit of algebra manipulation.