Photoelectric Effect Experiment.

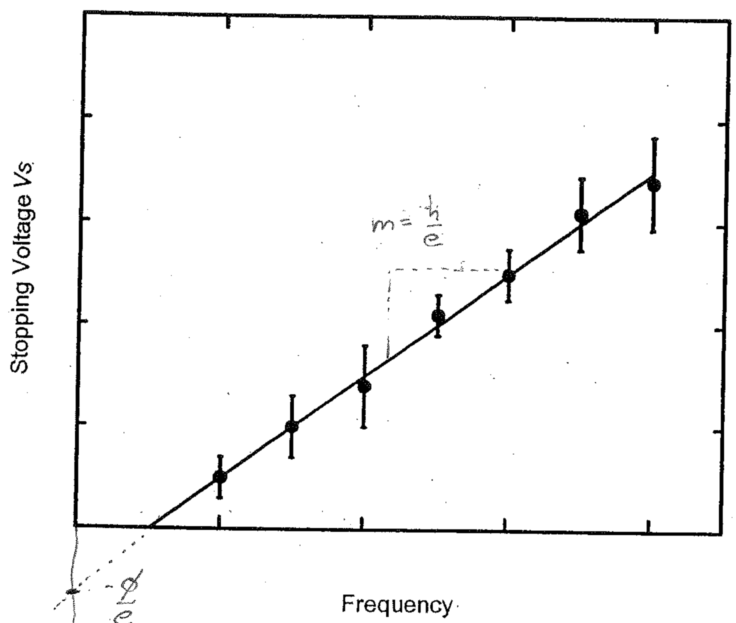
PH 316 Methods of experimental physics

Outline and comments on the analysis of the data from the photoelectric experiment.

(1) The objective of this exercise is to determine the work function, ϕ, of your sample and Planck's constant, h. These quantities will be obtained from the linear least square fit of the set of stopping voltages, V_s, versus the frequency of light, f. The relationship follows from the equation of conservation of energy:

$$hf = KE(\text{kinetic energy of the electron}) + \phi = e\,V_s\,(\text{electron}) + \phi .$$

The set of data from which the above parameters will be determined is schematically depicted below.



$hf = eV_s + \phi$

$eV_s = hf - \phi$

$V_s = \frac{hf}{e} - \frac{\phi}{e}$

$y = mx + b$

where $m = \frac{h}{e}$

$b = -\frac{\phi}{e}$

Figure 1. Stopping voltage as function of the frequency of the incident light.

Design your data collection protocol so that you have at least seven frequency points evenly distributed within the available range of your light source.

(2) The value and standard deviation for the stopping voltage at each frequency point have to be extracted from the computer output specifically from the dependence of measured current on retarding voltage. The dependence of current on retarding voltage is depicted in Fig. 2.

The total current has two components: photocurrent and background current, both contain random noise.

(2a) You can convince yourself that it is only the photocurrent that is dependent on the retarding voltage and frequency, the average value of background current is the same. It is therefore economical to determine the characteristics of background current: average value, variance and standard deviation only once and use this value throughout your data analysis.

(2b) You will of course notice that the "instantaneous" value of the total current is different from run to ~~runs~~ run even under identical conditions. This is the manifestation of noise. To minimize the distorting effect of noise in order to determine the stopping voltage with greater accuracy we will average the current from at least five identical runs. We will adopt the following procedure: first, we will compute the average value of total current, its standard deviation and variance for individual values of retarding voltage at a given frequency of light.

(2c) The value of the stopping voltage at each frequency will be determined from the dependence of photocurrent on the retarding voltage. We will assume that within a narrow range of retarding voltage the dependence of photocurrent on voltage is linear,

$$i_{photo} = a + b^* V_r,$$

$I_{photo} = mV_r + a$, when $I_{photo} = 0$, $mV_r = -a$ ($V_r = V_s$) thus $V_r = \frac{-a}{m}$ or $V_s = \frac{-a}{b}$

where a and b are least square fit parameters and V_r is the retarding voltage. The value of retarding voltage at which i_{photo} equals 0 is the stopping voltage, V_s.

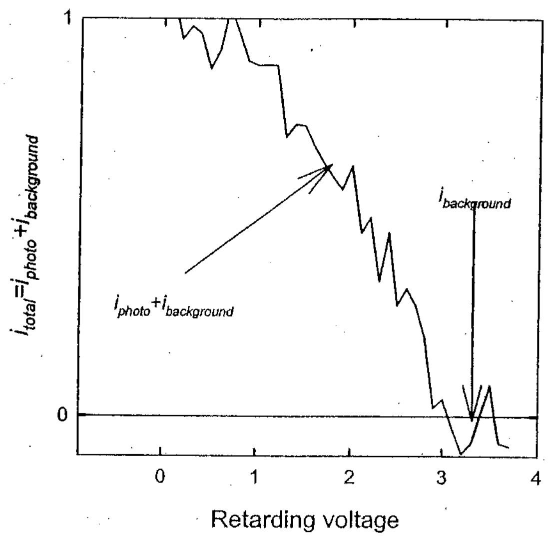


Figure 2. The total current as a function of the retarding voltage.

$I_{photo} = m V_r + b$

$V_r = V_s \rightarrow mV_r = -b$

$V_s = \frac{-b}{m}$

It follows that V_s=-a/b.

Unfortunately, there is some uncertainty in the value of stopping potential. The least square fit parameters are not known accurately because they are obtained from the noisy photocurrent.

The standard deviation of V_s is equal to: $\sigma_{V_s} = \left(\frac{\sigma_a^2}{a^2} + \frac{\sigma_b^2}{b^2} \right)^{1/2} \cdot V_s$ $\quad \left(\frac{\sigma_{V_s}}{V_s}\right)^2 = \left(\frac{\sigma_{intercept}}{Intercept}\right)^2 + \left(\frac{\sigma_{slope}}{Slope}\right)^2$

Include the derivation of this formula in your report.

(3) We saw earlier that the total current i_{total} has two fluctuating components and that the stopping voltage has to be determined from the condition of zero photocurrent.

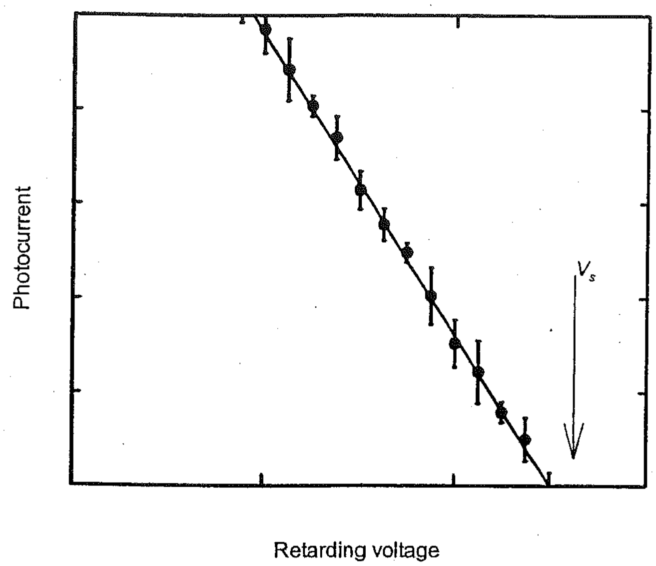


Figure 3. Photocurrent as function of the retarding voltage.

The photocurrent is equal to: $i_{photo} = i_{total} — i_{background}$.

The variance of photocurrent at each value of retarding voltage is equal to:

$$\sigma^2_{photo} = \sigma^2_{total} + \sigma^2_{background}$$

The status of the intermediate analysis representing the average of at least 5 identical runs is shown in Fig. 3. There we show a set of average values and standard deviations of the photocurrent as a function of retarding voltage. A similar plot of your data should contain about 5—10 voltage points and the ratio of highest and lowest current values should be approximately five.
Due to random noise, the standard deviation of photocurrent varies from point to points. For that reason we will use the method of weighted least square fit for the determination of parameters a and b, their variances, and finally V_s and its standard deviations as indicated in section (2c).

Instruction Manual

for

EP-05 Photoelectric Effect

* STUDENTS! we don't have this setup, just for info!

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. Plotting the stopping potential as a function of the reciprocal of the wavelength of the radiation gives a straight line plot, the slope of which can be used to calculate Planck's constant.

λ s 1700Å - 7000Å

set f

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 photodiode tube base, fulfills this requirement nicely. The minimum detectable photocurrent is of the order of 5×10^{-10} A, which is quite good for such a simple apparatus.

material: ϕ 1-6 choose 1

Range

Start: 0v

Inc 1

#: 20-50

The apparatus includes three filters to provide spectral separation. If monochromatic sources are not available, the filters with a fluorescent and a tungsten lamp can be used, although the results are not as good as with a monochromatic source.

OPERATION

These instructions assume that a white fluorescent lamp and a tungsten lamp are used with the supplied filters. The mercury arc spectral lines

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DISCUSSION

The classical physicist would propose 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 up its energy in whole, or not at all. This can be summarized by Einstein's relationship:

$$E=hc/\lambda$$

$$\text{Thus} \quad e(V + \varnothing) = hc/\lambda$$

where

- e = the electronic charge
- V = the stopping potential
- Ø = the work function of the metal of the photosurface
- 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

$$V = (hc/e)\,(1/\lambda)$$

From a plot of V versus $1/\lambda$, the slope of the line can be determined. Since the slope equals hc/e, then

$$h = (\text{Slope} * e)/c$$