K.Angoni, Physics Dept., Vanier College

203-NYC-05: Waves, Optics & Modern Physics

Experiment #7: Photoelectric Effect

OBJECTIVE: To investigate the photoelectric effect and to measure the Planck's constant.

INTRODUCTION:

When ***light photons*** of sufficient energy (ε_{Ph} = hf) strike a ***metal surface*** with a work function ϕ[*eV*], the maximum value of kinetic energy for an ***ejected electron*** is defined by expression

$$K_{MAX} = hc/\lambda - \phi \qquad (1)$$

$h = 6.626*10^{-34}$ *J*s* is Planck's constant
$c = 2.998*10^{8}$ *m/s* is the speed of light in vacuum.
λ*[m]* is the wavelength of incident light.

One can measure K_{Max} of these "photo-electrons" by applying a stopping potential V_S[*V*] which is **just high enough** to reduce ***to zero the current in the circuit***. The kinetic energy of the most energetic electrons is related to the magnitude of stopping potential by expression:

$$K_{MAX} = e*V_S \qquad (2)$$

$e = 1.602*10^{-19}$ *C* is the magnitude of electric charge on the electron.
V_s is the magnitude(i.e. absolute value) of stopping potential.

By combining and rearranging the two expressions for K_{MAX} one can get:

$$V_S = \frac{hc}{e}\left(\frac{1}{\lambda}\right) - \frac{\phi}{e} \qquad (3)$$

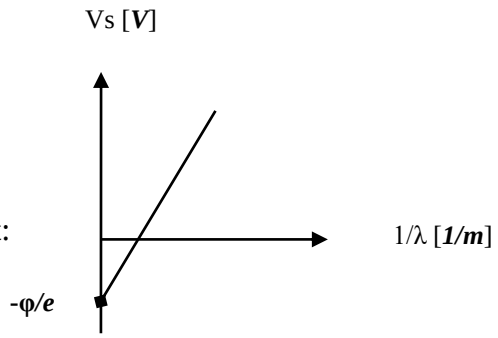

Figure 1 The graph of function (3)

This means that the graph of V_S vs $1/\lambda$ will be a straight line with ***a slope*** of *"**hc/e**" and an **intercept "-ϕ/e".*** So, one may calculate ***h-value*** by the ***slope of this graph*** and the values of *"**c** "* and *"**e**". **The magnitude of work function φ** is equal to the numerical value of constant term at fitting line because **φ [eV] = (φ/e)*e.***

Figure 2. The principal scheme of experiment. The incident light shines the cathode (Cath.) and the emitted photoelectrons are collected to the anode (An.). They pass through circuit and this means a current circulating in the circuit. One can repeal electrons from the anode by applying a negative voltage on it. By changing the magnitude of this voltage one can find the minimum value that stops the current in the circuit (measured by ammeter A).
The basic idea of this experiment is the following:
For a given frequency (or wavelength) of light, the current in the circuit becomes zero, when the magnitude of negative voltage between the anode and cathode "V_{AC}" is equal to the stopping potential, V_S.

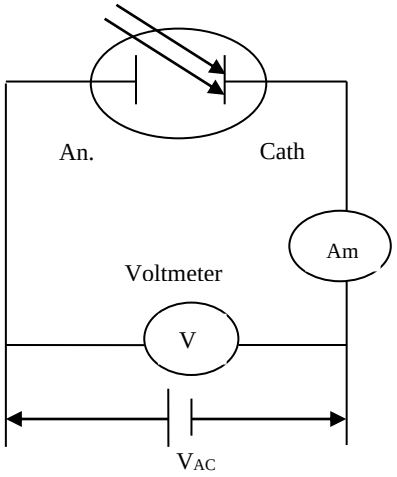

Figure 2 Principal scheme

K.Angoni, Physics Dept., Vanier College

EXPERIMENTAL SET UP

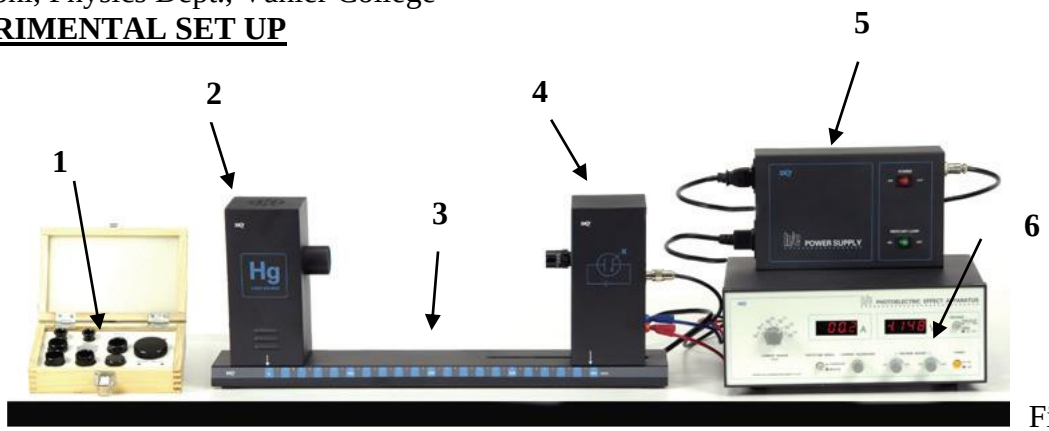

Fig. 1 General view

Included Equipment

1. Optical Filters, Apertures, Caps, and Screws
2. Mercury Light Source Enclosure
3. Base
4. Photodiode Enclosure
5. Power Supply
6. Photoelectric Effect Apparatus

Cables and Cords

Power Cable for Photoelectric Effect Apparatus
BNC Connector Cable for Photodiode Enclosure
Banana-plug Patch Cords, Red and Blue

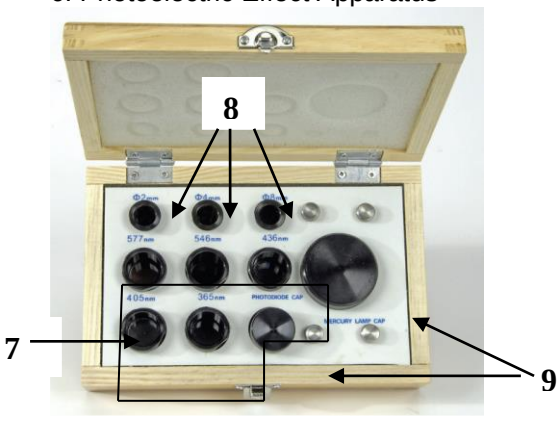

Figure 2

Items in the Optical Filters Box

7. Filters: 365 nm, 405 nm, 436 nm, 546 nm, 577 nm
8. Apertures: 2 mm diameter, 4 mm dia., 8 mm dia.
9. Caps: Photodiode, Mercury Lamp

1) Install the mercury lamp in light source enclosure. ***Att: Do not touch by hand the glass of lamp because oil and moisture from the skin may diminish lamp performance. Use gloves or clean paper towel to handle it***.

2) ***Before connecting any cords*** make sure that ***both switches*** on the ***Power Supply*** are in ***OFF*** position.
Then connect: **a)** the **power cord** from **light source** into "Power Output for mercury ~220V" of ***Power supply***.
b) the DIN-plug-to-DIN plug power cable between the port "Power Supply" on the back of Photoelectric Effect Apparatus and the port "Power Output for Apparatus" on the on the Power supply. Screw the knurled rings on the plug ends of cable onto the threaded section of each port.

Note: The three cords (c, d, e) will be disconnected during calibration. Actually, you do not need to turn off the power from Power Supply when you disconnect and then reconnect these three cords.
c) the BNC-plug-to-BNC-plug cable between the port marked "K' on the photodiode enclosure and the port marked "K" on the back of Photoelectric effect Apparatus. Screw the knurled rings on the plug ends of cable onto the threaded section of each port.
d) the red banana-plug patch cord between the port marked "A" of Photodiode enclosure and the port marked "A" on the back of Photoelectric effect Apparatus.
e) the blue banana-plug patch cord between the ground port (marked with arrow down) on Photodiode enclosure and the ground port (marked with arrow down) on the back of Photoelectric effect Apparatus.
f) the power cord between the port on the side of h/e Power Supply labeled "Power Input ~110V" and an electrical outlet.

h/e Photoelectric Effect Apparatus

The h/e Photoelectric Effect Apparatus has four knobs, three buttons and two digital displays on its front panel, and four ports (labeled A, K, 'down arrow', and POWER SUPPLY) on its back panel. The apparatus measures the photocurrent through the photodiode tube and the voltage across the photodiode tube.

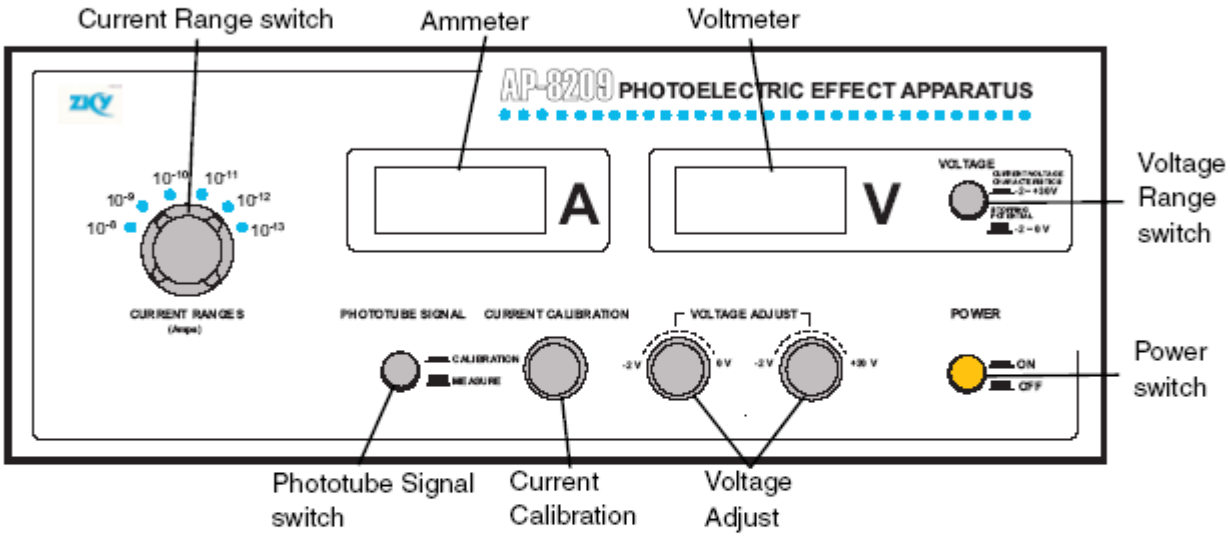

Figure 4: Photoelectric Effect Apparatus

- Current Range switch: Sets the current range for the instrument's current amplifier (10^{-8} to 10^{-13} A).
- Ammeter: Displays the photocurrent through the photodiode tube.
- Voltmeter: Displays potential across the photodiode tube.
- Voltage Range switch: Sets the voltage range as -2 to +30 V for plotting current-voltage characteristics and -2 to 0 V for measuring the stopping potential.
- Power switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the potential across the photodiode tube for both voltage ranges.
- Current Calibration: Sets the current through the instrument to zero.
- Phototube Signal switch: Sets the signal from the photodiode tube to CALIBRATION or MEASURE.

MEASUREMENT PROCEDURE

In this experiment you will measure the stopping potential, i.e. the **minimum value** of electric potential that makes **zero the current in the circuit**. It is clear that the current remains zero for bigger negative values of potential. So, to find the first potential that blocks the photocurrent is very important to measure with high precision small values of current in the circuit. At this step we mention the existence of a "dark photocurrent" which may not allow to measure accurate values for stopping potential. Actually, this effect is avoided by the calibration procedure that fixes to zero the current value in circuit when there is no signal from the photodiode.

***Note:** It is very important to allow the light source and apparatus to warm up for **20 minutes prior** to making any measurements.*

Preparation before measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap from the Optical Filters box. Cover the window of the Photodiode enclosure with the Photodiode Cap from the Optical Filters box.
2. On the h/e Power Supply, turn on POWER and MERCURY LAMP. On the Photoelectric Effect Apparatus push in the POWER button to the ON position.

3. Allow the light source and the apparatus to warm up for 20minutes.
4. On the apparatus, set the VOLTAGE range switch to –2 to 0V. Turn the CURRENT range switch to 10^{-13}.
5. To set the current amplifier to zero, first *disconnect* the 'A', 'K', and 'down arrow' (GROUND) cables from the back panel of the apparatus.
6. Press the PHOTOTUBE SIGNAL button in to CALIBRATION.
7. Adjust the CURRENT CALIBRATION knob until the current is zero.
8. Press the PHOTOTUBE SIGNAL button to MEASURE.
9. *Reconnect* the 'A', 'K', and 'down arrow' (GROUND) cables to the back of the apparatus.

Measurement

1. Uncover the window of the Photodiode enclosure. Place the **4 mm diameter aperture** and the 365 nm filter onto the window of the enclosure. (See the sidebar note.)
2. Uncover the window of the Mercury Light Source. A spectral line of 365 nm wavelength will shine on the cathode in the phototube.
3. Adjust the VOLTAGE ADJUST knob until the current on the ammeter is zero.
4. Record the *magnitude* of the stopping potential for the 365 nm wavelength in Table 1.
5. Cover the window of the Mercury Light Source.
6. Replace the 365 nm filter with the 405 nm filter.
7. Uncover the window of the Light Source. A spectral line of 405 nm wavelength will shine on the cathode in the phototube.
8. Adjust the VOLTAGE knob until the current on the ammeter is zero.
9. Record the *magnitude* of the stopping potential for λ= 405 nm in Table.
10. Cover the window of the Mercury Light Source.
11. Repeat the measurement procedure for the other filters. Record the *magnitude* of the stopping potential for each wavelength in Table 1.
12. To verify that the stopping potential does not depend on light intensity, repeat the measurements using the apertures with diameters 2 and 8mm. Include the data in table.

> ***Note:*** *Always have a filter on the window of the Photodiode enclosure, and put the cap on the Mercury Light source whenever you change the filter or aperture. Never let the light from the Mercury Light source shine directly into the Photodiode enclosure.*

Data, Calculations, Graph and Analysis

1. For each color, calculate the average value of V_S and its mean deviation; record them in the table
2. Use Excel to plot a graph of Stopping Potential (Vs) versus $1/\lambda (\times 10^{-6}\ m^{-1})$.
3. Draw and find the slope of the best-fit line through the data points on the graph V=V(1/λ) Draw the steepest line consistent with the points and the least steep and find their slopes. These are the maximum and minimum slopes consistent with the data.

Table: Stopping Potential of Spectral Lines

Item	1	2	3	4	5
Wavelength λ[nm]	365.0	404.7	435.8	546.1	577.0
$1/\lambda * 10^6 [m^{-1}]$	2.740	2.471	2.295	1.831	1.733
Ap. 4mm Stopping Potential [V]					
Ap. 8mm Stopping Potential [V]					
Ap. 2mm Stopping Potential [V]					
Average stopping Potential [V]					
Uncertainty ΔVs [V]					

4. Record the calculated slopes and use them to estimate the value of Planck's constant, *h*. From the best slope, calculate Planck's constant, h. From the other two slopes, calculate the max and min values of Planck's constant. If all quantities are in standard units, the units for Planck's constant will be joule-seconds (J.s).**Does the officially accepted value for h fall inside the uncertainty interval?**

Note: The graph slope is equal to the ratio of ***hc/e***. So, the Planck's constant " *h"* is the product of the electron charge to the slope divided by the speed of light in vacuum.

5. Using the expression of the best fitting line and its intercept with Oy axis find the best estimation for **work function of cathode metal.** The intercept is equal to the work function in units called "electron volts". Using the extreme values limiting lines in the graph, calculate the maximum and minimum values for the work function (intercepts of these lines). **What is the value of the work function and its uncertainty? Comparing the found result with tabulated data for work function of different materials, identify the most probable metal(s) on cathode.**

NOTE: Your grade will depend on the accuracy and precision of your results for parts 4 and 5!