Photoelectric Effect

Sreela Das

March 3, 2015

Class: Intermediate Experimental Physics II
Week: 3
Date Performed: February 24, 2015
Partners: Alvin Modin, Lauren Hirai

Objective

To experimentally determine the value of the cutoff potential for different frequencies of light emitted due to the photoelectric effect.

Theory

The electrons in the conduction band of a metal require lower energy ranges to escape from their orbitals. The energy required for an electron in the metal to escape the conduction band is called the work function of the metal. When these electrons are struck by photons with energy greater than the work function, they escape from their orbitals with a kinetic energy equal to the excess energy absorbed from the incident photon. This can be summarized in the following equation:

$$K_{max} + W_f = h\nu$$

Where, W_f is the work function of the metal, h is Planck's constant, ν is the frequency of the incident photon and K_{max} denotes the maximum possible kinetic energy of an escaping electron since all of the energy of a photon might not be absorbed by the electron. The work function can also be represented in terms of a minimum frequency i.e. $W_f = h\nu_0$ which gives us:

$$K_{max} = h(\nu - \nu_0)$$

In this experiment, we used a retarding voltage applied in the direction opposing the motion of the escaping electrons. The photoelectrons would be stopped completely if the work done by the opposing potential was exactly equal to the maximum kinetic energy of the photoelectrons, which means:

$$eV_s = K_{max} = h(\nu - \nu_0)$$

Or:

$$V_s = \frac{h}{e}(\nu - \nu_0)$$

In our setup, we need to account for contact potential –a potential difference created when two metals with different work functions are placed in contact. Since this potential difference acts in the same direction as the stopping potential, the above equation needs to be modified to:

$$V_s = \frac{h}{e}(\nu - \nu_0) - V_c$$

Setup

The phototube, filters and two potentiometers were enclosed in a box that had a window to show which filter was being used, and knobs to control the retarding voltage between the two electrodes. A voltmeter, a galvanometer and a voltage source (two 1.5 V batteries connected in series) were connected to this box as per the circuit diagram provided.

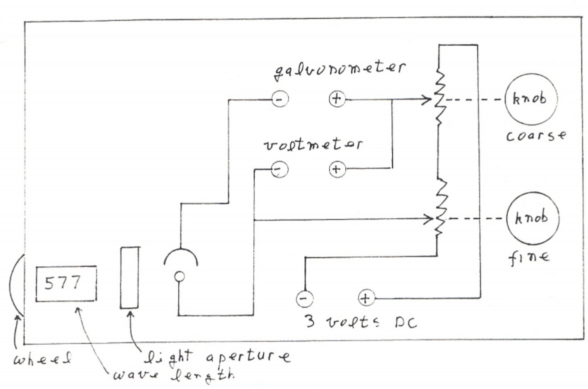

Figure 1: Circuit Diagram

Procedure

1. The circuit was connected as
2. Leaving the circuit open, the cut-off wavelength was set to 435.8 nm and the Galvanometer set to a sensitivity of X1
3. The galvanometer light pointer was switched on and set to zero for the incomplete circuit.
4. The Mercury discharge lamp was turned on and the current was calibrated to a 6.00 cm reading on the galvanometer.
5. The battery was connected and the voltage was incremented in steps of 0.1 V, recording the corresponding galvanometer readings
6. The Voltage was increased until the galvanometer readings stabilized and this voltage was recorded as the stopping potential.
7. This process was repeated for the other two cutoff wavelengths.

Data

NOTE: All Galvanometer readings were measured to ±0.01 cm and Voltmeter readings were assumed accurate up to ±0.002 V. The readings below have been corrected for voltage induced due to ambient light (0.0002 V)

Using the 435.8 nm cut-off wavelength we calibrated the galvanometer to read 6.00 cm when the voltmeter reading for the retarding voltage was 0 V:

Galvanometer reading	5·30	4·10	2·80	1·70	0·80	0·20	−0·25	−0·50	−0·70	−0·85	−0·90	−0·92	−0·98	−1·0	−1·0
Potentiometer reading	0·067	0·167	0·267	0·367	0·467	0·567	0·667	0·767	0·867	0·967	1·067	1·167	1·267	1·367	1·467

Using the 546 nm cut-off wavelength and starting at a galvanometer reading of 2.0 cm corresponding to no retarding voltage:

Galvanometer reading	1·75	1·20	0·70	0·30	0·05	−0·03	−0·08	−0·1	−0·1	−0·1
Potentiometer reading	0·045	0·145	0·245	0·345	0·445	0·545	0·645	0·745	0·845	0·945

Using the 577 nm cut-off wavelength and starting at a galvanometer reading of 0.4 cm corresponding to no retarding voltage:

Galvanometer reading	0·35	0·21	0·12	0·09	0·03	0·02	0·01	0·01	0·01
Potentiometer reading	0·045	0·145	0·245	0·345	0·445	0·545	0·645	0·745	0·845

Analysis

To find the cutoff potential, we plotted the galvanometer deflection against the retarding voltage applied. This process was repeated for all three filters. Since galvanometer deflection is proportional to the current, these plots represented a plot of the photocurrent against the retarding voltage.
The potential beyond which the galvanometer deflection remained steady was determined to be the stopping potential – this was the potential at which the drop in galvanometer deflection due to the retarding voltage became negligible.

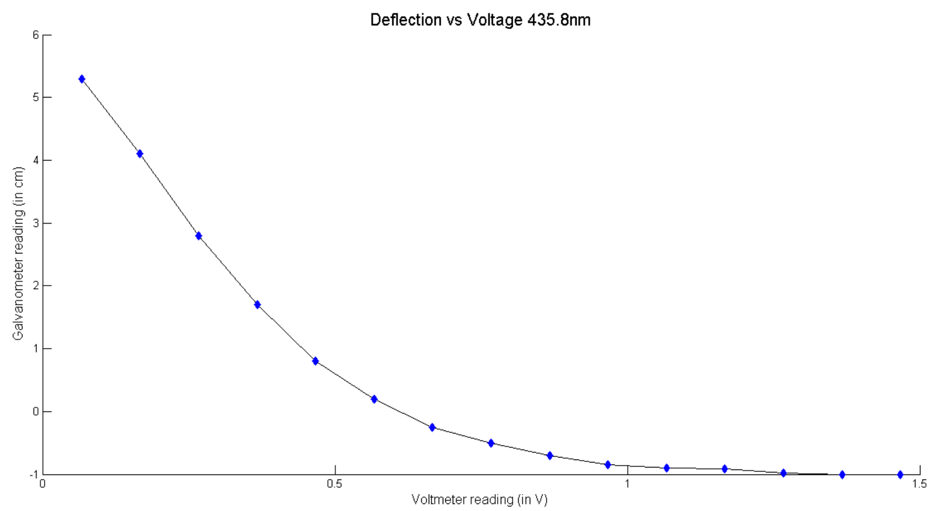

Figure 2: **Plot of Deflection vs Voltage for the** 435.8 nm **filter** Cut-off potential for this filter was found at 1.367 V

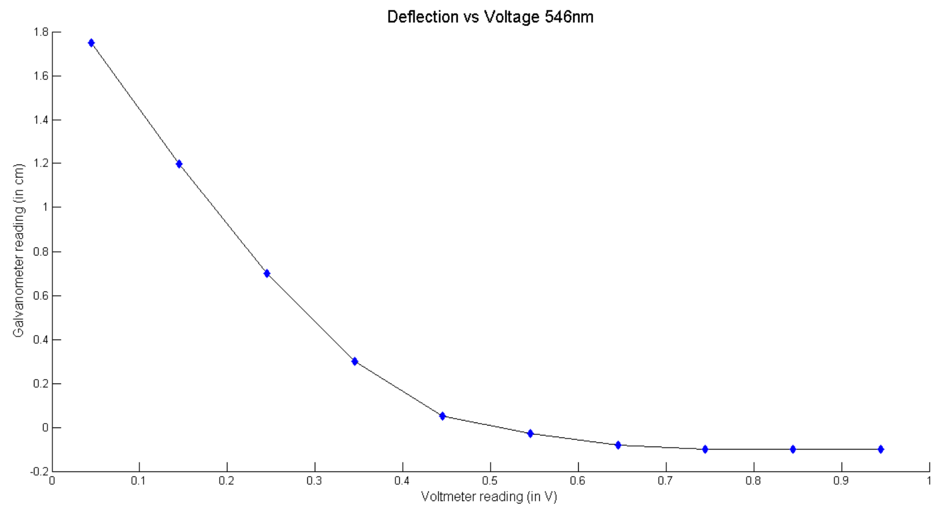

Figure 3: **Plot of Deflection vs Voltage for the** 546 nm **filter** Cut-off potential for this filter was found at 0.745 V

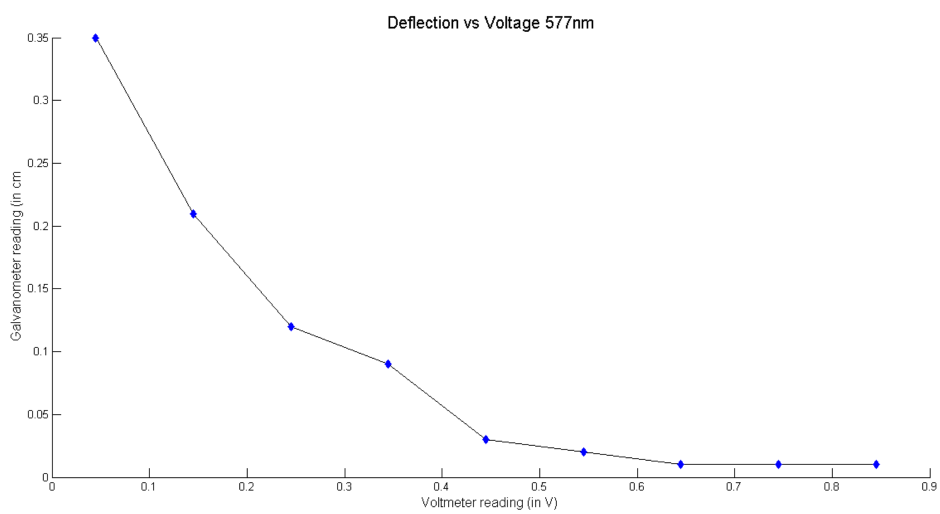

Figure 4: **Plot of Deflection vs Voltage for the** 577 nm **filter** Cut-off potential for this filter was found at 0.645 V

Wavelength (in nm):	435.8	546	577
Stopping Potential (in V):	1.367	0.745	0.745

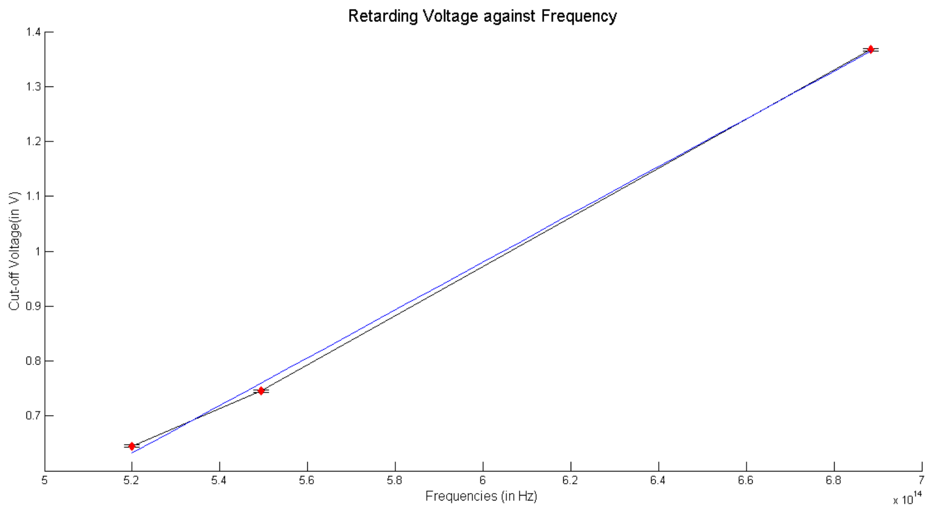

Figure 5: Plot of cutoff potential against frequency: the slope was found to be 0.435×10^{-14}J and a y intercept of $-1.627\,\mathrm{V}$

From the slope and y-intercept of the best-fit line, we were able to calculate an experimental value of Planck's constant using:

$$eV = h\nu \implies h = \frac{eV}{\nu} = 0.435 \times 10^{-14} \times 1.6 \times 10^{-16} = 6.95 \times 10^{-34}\,\mathrm{J\,s}$$

Error Analysis

Uncertainty in the Voltmeter readings was $\pm 0.002\,\mathrm{V}$ and the uncertainty in the galvanometer readings was 0.01 cm. We plotted a line of best fit for the stopping potential against the frequencies with these uncertainties and found a line with an r^2 value of 0.951. From this we know that the uncertainty in the slope for the given data with the given uncertainties is within 5% which is 0.218×10^{-15}J.
Using the following equation for uncertainty propagation:

$$\delta_y = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial y}{\partial x_i}\right)^2 \delta_{x_i}^2} \implies \delta_h = \sqrt{\left(\delta_e \frac{\partial h}{\partial e}\right)^2 + \left(\delta_m \frac{\partial h}{\partial m}\right)^2} = \delta_m \frac{\partial h}{\partial m} = 3.48 \times 10^{-35}$$

Which gives us an uncertainty of 5.27% placing the accepted value of Planck's constant is well within our range of uncertainty.