Planck's Constant Experiment

BS192: Undergraduate Science Laboratory (Physics)

Group 7 (Lab No. 2, Experiment No. 3)

A laboratory report by

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I. Aim:

To determine the Planck's constant h by using photocell and demonstrate the inverse square law of radiation.

II. Apparatus:

Vacuum phototube, optical bench of length 40 cm with a halogen tungsten lamp (12V,35W) on it. Regulated power supply, current meter and colour filters with different wavelengths.

III. Theory:

A series of experiments revealed that electrons are emitted from a metal surface when illuminated with light of sufficiently high frequency. This phenomenon was termed as the Photoelectric effect. The main experimental facts regarding phenomenon are as follows:

- Emission process depends on the frequency of incident radiation.
- There exists a critical frequency for each metal such that any light of lower frequency is unable to emit electrons, while light of higher frequency can.
- The number of electrons emitted is strictly proportional to the intensity of the incident light whilst the energy possessed by the emitted electrons is strictly proportional to the frequency of incident light.
- The electrons are emitted instantaneously after the arrival of incident radiation.

Above this frequency the maximum photoelectron energy, KE_{max} , increases linearly with increasing frequency.

$$KE_{max} = h(\nu - \nu_o) = h\nu - h\nu_o$$

where ν_o is the threshold frequency below which no photoemission occurs. The value of h, Planck's constant, (6.626×10^{-34} J·s), is always the same, whereas ν_o varies with the particular metal being ϕ illuminated. The quantity $h\nu_o$ is equal to $e\phi$, where e is the magnitude of electron charge and ϕ is called the work function which is the minimum energy required to remove an electron from the metal surface being illuminated.

$$h\nu = 1/2\ mv^2 + e\Phi$$

The kinetic energy of photoelectrons is measured by retarding potential technique and the potential at which the photocurrent drops to zero is termed as stopping potential.

$$1/2\ mv^2 = eV_s$$

$$V_s = (h/e)\nu - \Phi$$

When we plot stopping potential against the frequency, we get a straight line. The slope yields the value of h and the intercept on y-axis gives the work function.

If L is the luminous intensity of an electric lamp and E is the luminescence at point r from it, then according to inverse square law,

$$E \propto 1/r^2$$

If this light is allowed to fall on the cathode of photoelectric cell, then the photocurrent I will be proportional to E

$$E = L/r^2 = C.I$$

A graph between $1/r^2$ and I is a straight line, which verifies the inverse square law of radiation.

IV. Procedure:

Part I: Determination of Planck's constant.

- While the instrument is off, remove the cover from the phototube and insert red filter (670 mm) into it.
- Adjust the distance between the source and the photocathode to 25 cm.
- Set the voltage direction to negative.

- Increase the de-accelerating voltage in fixed intervals and note down the readings of the photocurrent till it drops to zero value.
- Switch the display mode to voltage and note down the stopping potential where the photocurrent is zero.
- Repeat the above steps for all the remaining filters. Make sure that every time you are changing the filter, light must be switched off. Prepare a table describing central wavelength of the colour filter, the frequency corresponding to it and the stopping voltage.

Part 2: Demonstration of inverse square law of radiation.

- Turn on the setup and insert the red filter (670mm), place the light source 40 cm away from the filter. Maximize the intensity of the lamp.
- Set the voltage direction to positive at +0.1V and turn it on.
- Move the source 2cm closer, and after each move, note down the reading of photocurrent.
- Continue this till the distance between filter and light source is 20cm.

V. Results and Discussion

Part 1:

Observations:

Colour of filter	Wavelength (nm)	Stopping Potential (V)
Red	635	0.31
Orange	570	0.51
Yellow	540	0.64
Green	500	0.75
Blue	460	0.99

In this part of the experiment, we obtained the values of stopping potential for different wavelengths of visible light (various colours). In theory, the graph between the stopping potential and frequency of light should be a straight line.

$$V_s = \frac{h}{e}\nu - \phi$$

V_s = Stopping potential

h = Planck's constant

ν = frequency of light

$e = 1.602 \times 10^{-19} C$ = Charge on an electron

ϕ = Work function

We use the Least Square Fitting method to obtain the equation of a line that best describes our results.

$$y = Ax + B$$

Comparing this with

$$V_s = \frac{h}{e}\nu - \phi$$

We get,

$h = A \times 1.602 \times 10^{-19} Js$ and

$B = \phi$ (the y-intercept of the graph)

To obtain A and B according to the Least Square Fitting method, we use the formulas

$$A = \frac{\sum_{i=1}^{N} x^2 \sum_{i=1}^{N} y - \sum_{i=1}^{N} x \sum_{i=1}^{N} (x \cdot y)}{\Delta}$$

$$B = \frac{N\sum_{i=1}^{N}(x \cdot y) - \sum_{i=1}^{N} x \sum_{i=1}^{N} y}{\Delta}$$

Where,

$$\Delta = N\sum_{i=1}^{N} x^2 - \left(\sum_{i=1}^{N} x\right)^2$$

$$N \;=\; number\ of\ readings \;=\; 5$$

x (ν)	x^2 (ν²)	y (V_s)	xy	$(y - A - Bx)^2$
4.47761×10^{14}	2.0049×10^{29}	0.31	1.38806×10^{14}	8.46712×10^{-5}
5.08475×10^{14}	2.58546×10^{29}	0.51	2.59322×10^{14}	0.000378521
5.30973×10^{14}	2.81933×10^{29}	0.64	3.39823×10^{14}	0.000666137
5.76923×10^{14}	3.3284×10^{29}	0.75	4.32692×10^{14}	0.001387172
6.25×10^{14}	3.90625×10^{29}	0.99	6.1875×10^{14}	0.000470415

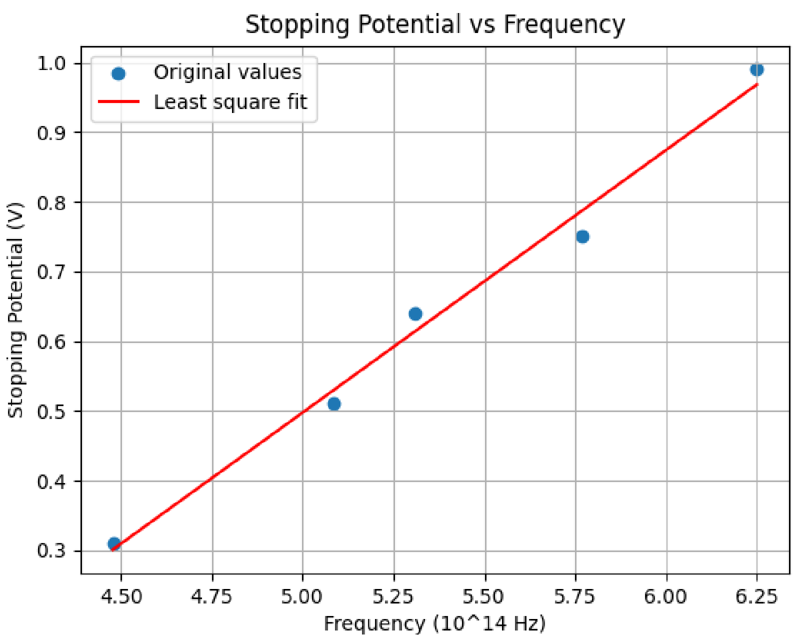
Plugging these values into the above formulas, we get

$$A \;=\; -1.38554941$$
$$B \;=\; 3.76618 \times 10^{-15}$$
$$\Delta \;=\; 9.07401 \times 10^{28}$$

From this, we get the work function of the metal used in the experiment

$$\phi = \; B = 3.76618 \times 10^{-15} eV$$

$$h = A \times 1.602 \times 10^{-19} Js$$
$$= \; 6.02588 \; \times 10^{-34}\, Js$$



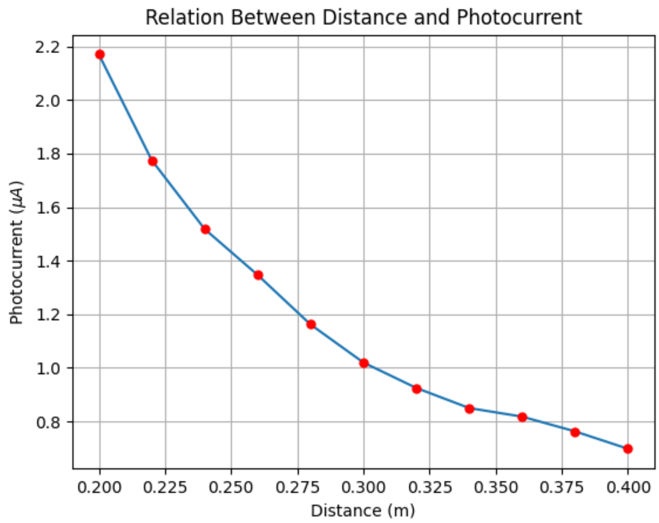
Part 2

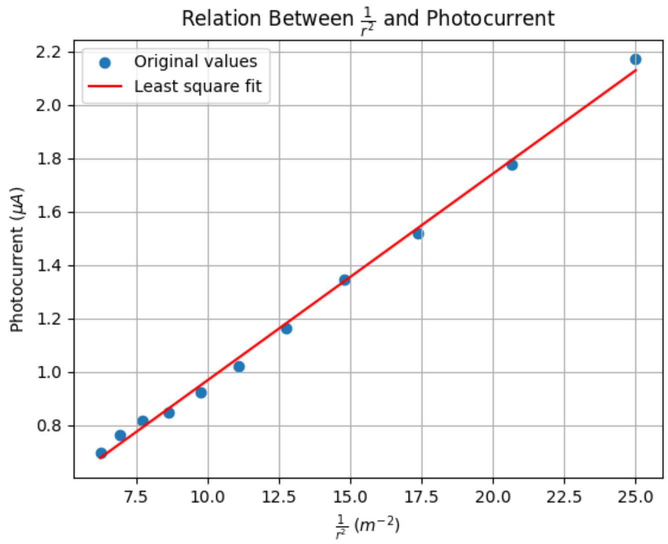
Observations:

$r\ =\ Distance\ (m)$	$\frac{1}{r^2}\ (\ m^{-2})$	$Photocurrent\ (\mu A)$
0.4	6.25	0.698
0.38	6.925208	0.763
0.36	7.716049	0.818
0.34	8.650519	0.85
0.32	9.765625	0.925
0.3	11.11111	1.02
0.28	12.7551	1.162
0.26	14.7929	1.347
0.24	17.36111	1.518
0.22	20.66116	1.775
0.2	25	2.17

In the second part of this experiment, we observed the variation in the value of photocurrent as the distance between the source (fixed intensity and frequency) and the screen varied.

The relation between the distance between the source and the screen and the photocurrent obtained is an inverse square relation, i.e. the photocurrent is inversely proportional to the square of the distance $\left(I \propto \frac{1}{r^2}\right)$. This can be interpreted from the following graphs. The first graph is a direct graph between the photocurrent and the distance. The second graph is between the photocurrent and the inverse of the square of the distance, which is approximately a straight line.





VI. Error Analysis

Part 1 (Error in Linear Regression):

The errors introduced due to the approximation of the line can be calculated as follows

Error in stopping potential:

$$\sigma_y = \sqrt{\frac{1}{\mathrm{N}-2}\cdot\Sigma(y-A-Bx)^2}$$

Error in work function:

$$\sigma_A = \sigma_y\sqrt{\frac{\Sigma x^2}{\Delta}}$$

Error in slope $\left(\frac{h}{e}\right)$

$$\sigma_B = \sigma_y\sqrt{\frac{N}{\Delta}}$$

Using these formulas for error calculations, the errors for the work function and Planck's constant respectively are:

$$\sigma_\phi = \sigma_A = 0.03155375\ eV$$

$$\sigma_h = \sigma_B \times e = 3.74763 \cdot 10^{-35}\ J\ s$$

Hence,

$$\phi = 1.38554941 \pm 0.03155375\ eV$$

$$h = 6.02588 \times 10^{-34} \pm 3.74763 \cdot 10^{-35}\ J \cdot s$$

Calculation of precision error:

$$Error\ \%\ in\ \phi = \frac{\Delta\phi}{\phi}\times 100\%$$

$$= 2.27\%$$

$$Error\ \%\ in\ h = \frac{\Delta h}{h}\times 100\%$$

$$= 6.22\%$$

Calculation of accuracy error (with respect to actual value):

$$Error = \frac{|h_{actual} - h_{calculated}|}{h_{actual}} \times 100\%$$

$$= 9.06\%$$

Possible Sources of Error

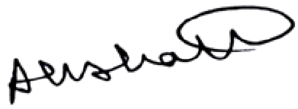
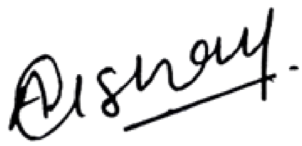
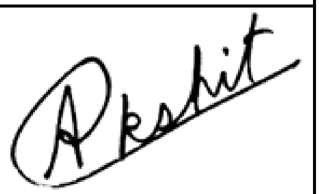
In both parts of the experiment, the obtained results are slightly deviated from the desired results. The likely sources of these errors are:

- The loose hinge might have caused the lamp's light angle to shift when changing the filters.
- The filters being used may be allowing wavelengths other than the desired wavelengths to pass through them.
- The instruments used to measure the stopping potential/photocurrent may be inaccurate.
- The photocurrent fluctuates a lot on changing the stopping potential, because of which we had to take the average value of the observations. Waiting for the result to completely stabilize could result in more accurate values
- Data was only collected for 5 wavelengths. Having more data points would give a much better approximation of the line, and hence a much more accurate value of Planck's constant.
- There may be some human error (for example parallax error in Part 2) involved in setting up the experiment and taking the measurements.

VII. Conclusion

We conducted this experiment to obtain the value of Planck’s constant and the work function of the metal being used as the electrode of the setup. We were able to verify that as the wavelength decreases (frequency increases), the stopping potential also increases. We were also able to show that the energy of the emitted photoelectrons (and hence of photons) is independent of the intensity of the light. We could have observed voltages other than the stopping potential for more data points, which could have resulted in a smaller percentage of error than what we got. For the second experiment, we were able to show the inverse square relation between photocurrent and the distance between source and metal.

VIII. Author Contributions:

Name	**Roll number**	**Contribution**	**Signature**
Aksh Kishor Solanki	24110023	Creation of pre-report	
Akshat Vishal Wandalkar	24110024	Error analysis and possible sources of erors	
Akshay	24110025	Proofreading of reports and elimination of errors, drawing diagrams	
Akshit Chhabra	24110026	Results and discussion in the lap report, operation of equipment	
Akul Gupta	24110027	Documenting data during the experiment, sketching of graphs