Experiment 5
Photoelectric Effect

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Synopsis

In this experiment, we attempt to measure Planck's constant and test the validity of the inverse square law.

I. THEORY AND PROCEDURE

A. Theory

It was observed as early as 1905 that most metals under influence of radiation, emit electrons. This phenomenon was termed as photoelectric emission. The detailed study of it has shown:

1. That the emission process depends strongly on frequency of radiation.
2. For each metal there exists a critical frequency such that light of lower frequency is unable to liberate member of electrons is strictly proportional to the intensity of this radiation.
3. The emission of electron occurs within a very short time interval after arrival of the radiation and member of electrons is strictly proportional to the intensity of this radiation.

The experimental facts given above are among the strongest evidence that the electromagnetic field is quantified and the field consists of quanta of energy $E = h\nu$ where ν is the frequency of the radiation and h is the Planck's constant. These quanta are called photons.

Further it is assumed that electrons are bound inside the metal surface with an energy $e\phi$, where ϕ is called work function. It then follows that if the frequency of the light is such that $h\nu > e\phi$ it will be possible to eject photoelectron, while if $h\nu < e\phi$, it would be impossible. In the former case, the excess energy of quantum appears as kinetic energy of the electron, so that

$$h\nu = \frac{1}{2}mv^2 + e\phi \tag{1}$$

which is the famous photoelectrons equation formulated by Einstein in 1905. The energy of emitted photoelectrons can be measured by simple retarding potential techniques as is done in this experiment. Retarding potential at which the photocurrent stopped, we call it stopping potential (V_s) and it's used to measure the kinetic energy of photoelectrons (E_e), we have:

$$E_e = \frac{1}{2}mv^2 = eV_s \qquad \text{or} \qquad V_s = \frac{h}{e}\nu - \phi \tag{2}$$

So when we plot the graph of V_s as a function of ν, the slope has a value of $\frac{h}{e}$ and it intercepts on x-axis at $V_s = 0$ and the ν at the intercept with the slope of the graph gives the work function ϕ.

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B. Procedure

1. Read the user manual of the setup (Refer to Refernce-(1)).
2. Insert the red color filter (635 nm), set light intensity switch at strong light, voltage direction switch at '-', display mode switch at current display.
3. Adjust to de-accelerating voltage to 0 V and set current range selector at X 0.001. Increase the de-accelerating to decrease the photo current to zero. Take down the de-accelerating voltage (V_s) corresponding to zero current of 635 nm wavelength. Get the V_s of other wave lengths, in the same way.
4. For verification of inverse square law, remove filters, fix the intensity of light around a proper value, and take the current values by varing the light source at different distance from the vaccum-tube.

C. Precautions

- Ensure there is no obstruction between the source and the photo-tube (see Appendix A).
- Clean all the filters properly
- Check weather the filters work (see Appendix B).

II. OBSERVATIONS

Filter Wavelength (nm)	**No. of filters**	**Voltage (V)**
635	1	-0.32
585	4	-0.48
540	3	-0.65
500	4	-0.71
460	2	-0.99

TABLE I. Stopping voltage at different filters, with source at $l = 25.0$cm. Data taken on 11-Mar-2025

Least count of Voltage = 0.01V
Least count of Current = 10^{-7} A
Least count of Wavelength = 10^{-8} m

Distance (cm)	**Current (μA)**
16.0	12.2
18.0	10.0
20.0	7.6
24.0	4.9
30.0	3.3
35.0	2.5
40.0	2.2

TABLE II. Current at different distances, fixed intensity. Data taken on 11-Mar-2025

Least count of Voltage = 0.01V
Least count of Current = 10^{-7} A
Least count of Length = 0.0001 m

III. UNCERTAINTIES AND SOURCES OF ERROR

A. Uncertainties from precision of instrument

- Distance Measurements: All length values have an uncertainty of $\Delta l = \pm 0.5$ mm due to instrument resolution.

- Current Measurements: Current values have an uncertainty of $\Delta A = \pm 5 \times 10^{-8}$ A due to instrument resolution.

- Voltage Measurements: Voltage values have an uncertainty of $\Delta V = \pm 0.005$ V due to instrument resolution.

- Filter Uncertainty: To account for the error in non-ideal filters, we take the uncertainity to be ± 5 nm.

B. Systematic Errors

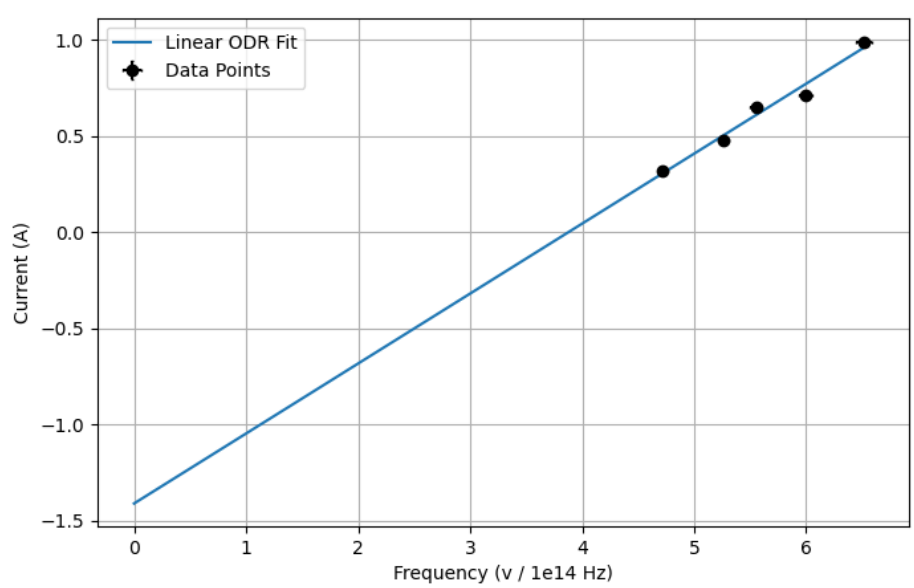
IV. CALCULATION AND ERROR ANALYSIS

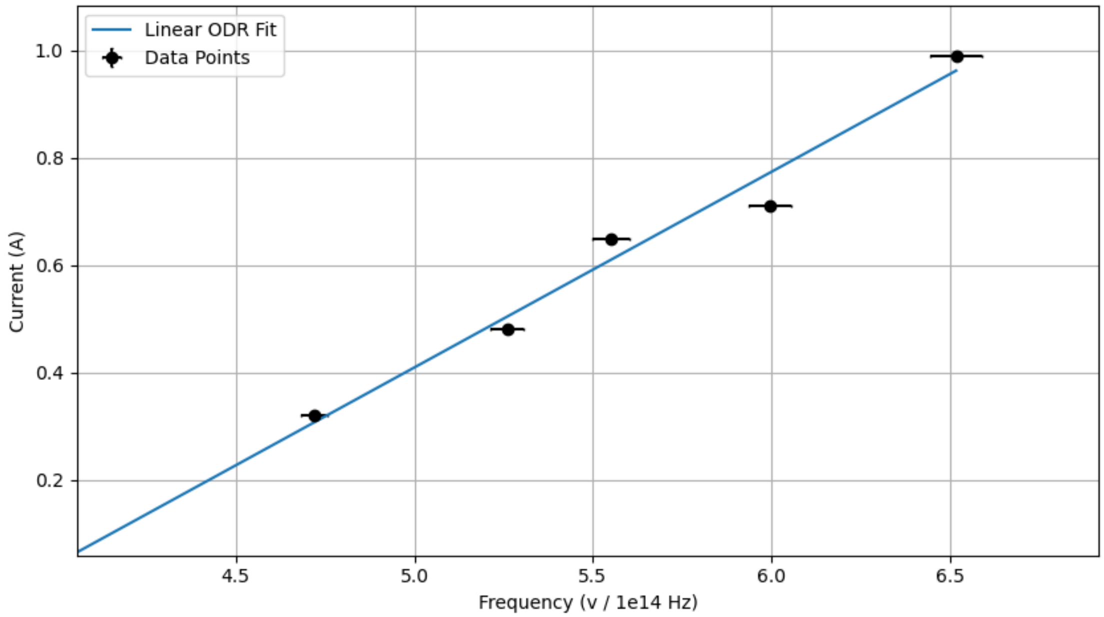
A. Plank's constant

To calculate the Plank's constant we use Equation-2, and plot the graph of V_s vs ν. The slope of the graph will have value of h/e. Now since $c = \lambda\nu$, this gives us $\nu = c/\lambda$ and **ENTER A BOOK REFRENCE HERE**

$$\Delta\nu = c\frac{\Delta\lambda}{\lambda^2}$$

Plotting the graph of ν vs V_s with their respective uncertainty: **ENTER A CODE REFRENCE HERE**

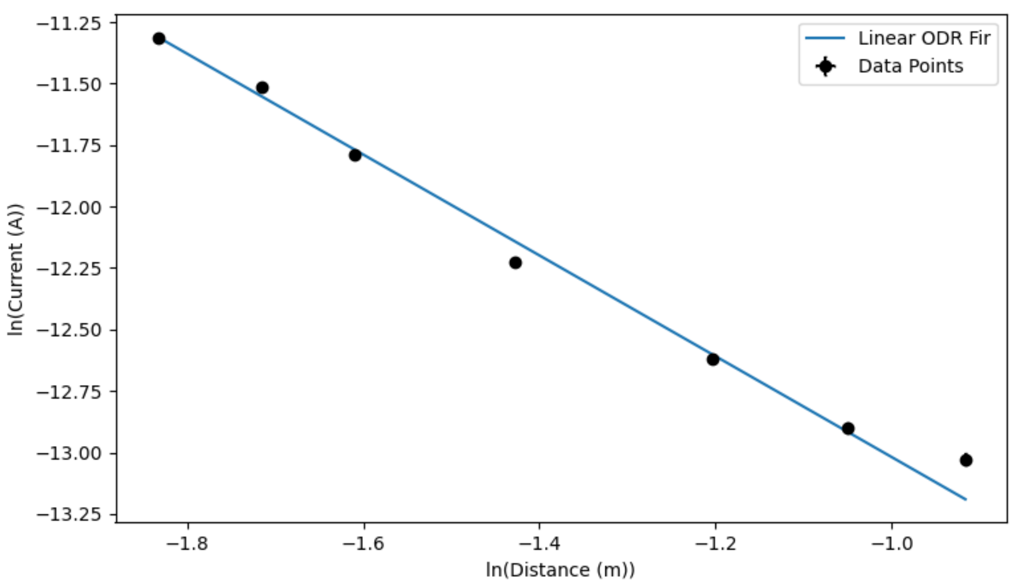




Optimized Parameters: [0.36404357 -1.41054501]

Parameter Errors: [0.03307623 0.17843993]

B. Inverse Square Law



Optimized Parameters: [-2.04953181 -15.06801565] Parameter Errors: [0.08743895 0.14215498]

V. RESULT

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The reference resistance was determined to be: $R_0 = 2.90 \pm 7.7\%$. (This error accounts for uncertainty in temperature measurements)

The Stefan-Boltzmann fit for the tungsten filament showed:

$$P = (4.00 \pm 0.066) \times 10^{-14}\ \mathrm{T}^4$$

The log-log analysis revealed a power-law relationship:

$$\log P = (3.98 \pm 0.06) \log T + (-30.71 \pm 0.48)$$

> The measured slope of $m = 3.98 \pm 0.06$ agrees with Stefan's law prediction of $P \propto T^4$, as the theoretical value of 4 lies within the experimental uncertainty range.

As observed in previous trials, the equipment malfunctioned multiple times (see Appendix A).

To account for filtering issues, multiple filters were used (see Appendix B).

Anomalies in voltage readings, especially with the blue filter, were noted (see Appendix C).

Appendix A: Equipment Faulty on Multiple Occasions

This experiment was performed multiple times, but the obtained values were highly inconsistent. Later, it was discovered that the instrument contained styrofoam inside, which needed to be removed.

Appendix B: Filters Not Working

The filters used in the experiment were not proper optical filters and, as a result, did not effectively filter light. Therefore, multiple filters were used for a given wavelength.

Appendix C: Blue Filter Error

The values obtained with the addition of the blue filter appear incorrect. Without any filter, the voltage should not exceed $0.88V$, but the blue filter resulted in a reading of $0.99V$.

... as discussed in (**?**). (**?**) Referencing the photoelectric effect (4). The code for the experiment can be found in the repository (2). The apparatus used is described in (3), and the detailed manual is available in (1).

REFERENCES

[1]FSU HEP Group. Photoelectric Effect Experiment Manual. `http://www.hep.fsu.edu/~wahl/phy4822/expinfo/photel/SVSPhotel.pdf`, 2025. [Online; accessed 17 March 2025].

[2]LAUGHINGCATMEME. PH2233 - Code Repository. https://github.com/LAUGHINGCATMEME/PH2233, 2025. [Online; accessed 17 March 2025].
[3]Ses Instruments. Planck's Constant Experiment (PC-101). https://www.sesinstruments.in/planck-s-constant-experiment-pc-101-5141096.html, 2025. [Online; accessed 17 March 2025].
[4]Wikipedia contributors. Photoelectric effect. https://en.wikipedia.org/wiki/Photoelectric_effect, 2025. [Online; accessed 17 March 2025].