A Study of Photoelectric Effect With Light Source of Variable Intensity

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Semester Project for PH212

Outline

1. Our Goal
   - To demonstrate that the stopping potential does not depend on the intensity of the incident light.
   - To study the rate of charging up of the capacitor for various intensities.

Proving intensity independence of stopping potential

Theoretical Justification

- Wave theory of light predicts that the electron energy would be proportional to the intensity of the radiation. Hence, so would be the stopping potential.
- But Einstein showed, by introducing the revolutionary idea that light is composed of discrete particles of energies propostional to the frequency, that indeed the stopping potential should be independent of the intensity of the light used.

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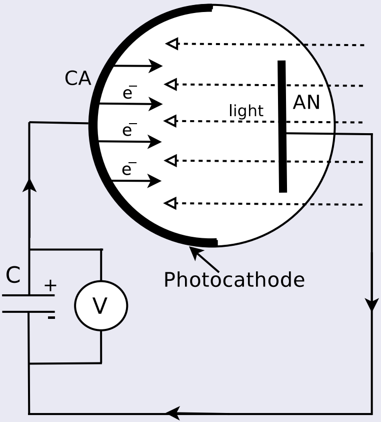
Experimental Setup

Schematic Diagram



- Light rays from a variable intensity source falls on the photocathode.
- Emission of the photoelectrons charges up the capacitor.
- The current stops when the voltage across the capacitor reaches the stopping potential.

Experiment With a 100 Watt Bulb

Description

- Initially, we decided to use a 100 watt light bulb as our light source.
- A voltage controller was used to change the intensity of the light.
- But the results were not quite what was expected ....

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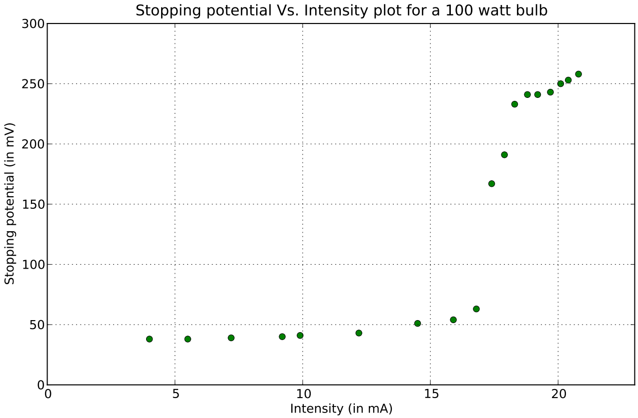
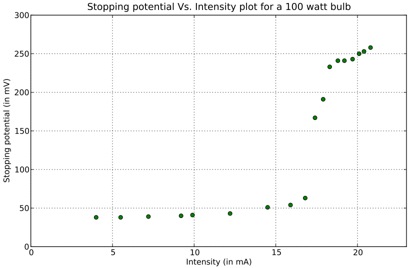
Experimental Results



Experiment With a 100 Watt Bulb
Discussion



- First of all, there is a sharp rise in stopping potential near I=17 mA.
- Apart from that, on an average, stopping potential increases with intensity throughout the whole intensity range!

Experiment With a 100 Watt Bulb
Probable Explanations

- Although the stopping potential is independent of the intensity, *the time taken by the circuit used to reach that potential* is not so.
- As we will prove later, the time required to reach a particular voltage is *inversely proportional* to the intensity.
- So it is quite possible that at low intensities , the rate of approaching the stopping potential was so low that we concluded that the stopping potential had been reached when indeed it had not.

This is a possible explanation of the sharp decline in the measured value of stopping potential.

Experiment With a 100 Watt Bulb

Probable Explanations

But there is another very important issue:

- The light emitted by a light bulb is not monochromatic. It contains a whole range of frequencies.
- While measuring stopping potentials we selected only a narrow frequency range by means of dispersion through a prism.
- But the instrument we used for measuring intensity actually is also a photocachode/miliammeter assembly.
- So we basically used photoelectric current as a measure of intensity.
- But for a polychromatic light source, the photoelectric current would be the sum total of the contribution from all the frequencies, which need not necessarily be proportional to the actual intensity of the radiation of the particular frequency we used while measuring the stopping potential.

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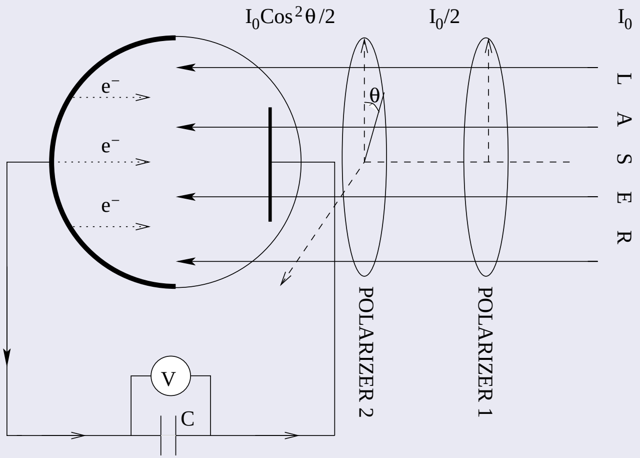
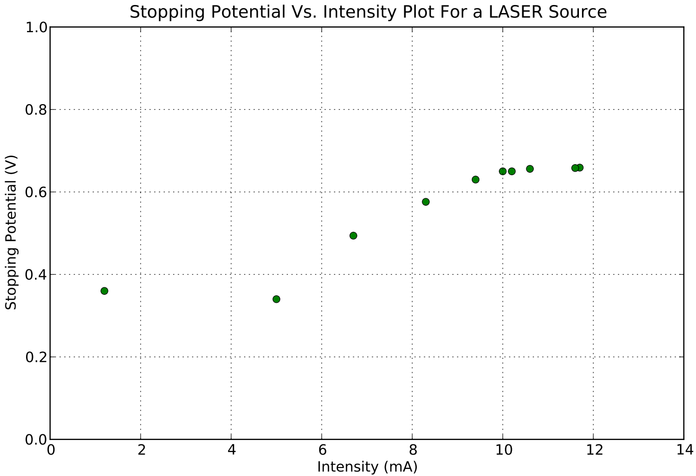
So we decided to use a LASER as our light source

Schematic Diagram of The Experimental Setup



Experiment With A LASER Source

Experimental Results

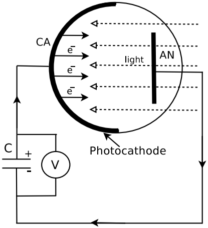


Experiment With A LASER Source
Discussion

- With LASER, the results were closer to the theoretical prediction, but yet the stopping potential was found to increase signigicantly with increase in the intensity of the light source.
- The LASER being monochromatic, a major source of inaccuracy was eliminated this time.
- But the fact still remains that at low intensities, the time taken by the circuit to reach the stopping potential is pretty large.
- Which motivated us to do the second part of the project:

Studying the rate of charging up of the capacitor

Theoretical discussion



The potential across the capacitor : $V = \frac{q}{C}$

But the current in the circuit : $i = \frac{dq}{dt}$

$$\therefore \frac{d}{dt}(CV) = i \qquad (1)$$

Now, in general
i will be a function of both V and I. But

$$i(V, I) = e \times \frac{dn}{dt} \times \textit{the fraction of electrons reaching the anode.}$$

($\frac{dn}{dt}$= the rate of emission of photoelectrons)

Studying the rate of charging up of the capacitor
Theoretical discussion

$$i(V,I) = e \times \frac{dn}{dt} \times \textit{the fraction of electrons reaching the anode.}$$

Now, $\frac{dn}{dt}$ is proportional to the intensity of radiation and independent of V , whereas the fraction of electrons reaching the anode is independent of I.
So we can write:

$$i = I \times f(V)$$

(Where $f(V)$ is some unknown function of V)

Studying the rate of charging up of the capacitor
Theoretical discussion

From Equation(1):

$$\frac{d}{dt}(CV) = I \times f(V) \Rightarrow \frac{C}{I}\int_0^U \frac{dV}{f(V)} = \int_0^T dt$$

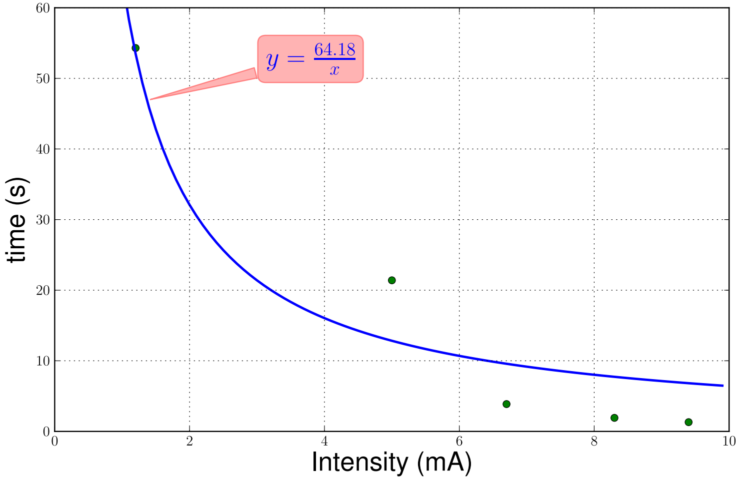
$$\Rightarrow T = \frac{C}{I}[F(U) - F(0)]$$

So, the time (T) needed for the capacitor to reach a certain voltage U obeys the equation:

$$T \propto \frac{1}{I} \tag{2}$$

Studying the rate of charging up of the capacitor

The plot of the time taken for the potential to reach 300 mV against the corresponding intensities



Summary

- In our experiment with light bulb, our data shows considerable increase in stopping potential with increase in intensity.
- Using LASER light, the experimental data comes closer to theoretical values, but still there are some deviations.
- In our opinion, this deviation from theoretical prediction is due to our light source being polychromatic (in case of the light bulb) alongwith the time dependence of the rate of charging up of the capacitor.
- Using LASER, we measured the time taken by the capacitor to charge up to a certain voltage for various intensities. We obtained a somewhat good fit of the data with the theoretical equation.

Acknowledgements

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