# A Study of Photoelectric Effect With Light Source of Variable Intensity

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PH212 Project

**Abstract**

One of the most influential experimental discoveries made in early 20th century indicating that the laws of classical physics were inadequate for describing nature were the fact that during the emission of photoelectrons from a metal surface, the stopping potential does not depend on the intensity of the incident light. This phenomenon, unsolvable from Maxwell's description of light, was explained by Einstein in 1905 using the quantized model of light which eventually led to the formation of quantum theory.

In this project, we tried to verify this fact and obtained unexpected results. Those results inspired us to measure the time taken for the capacitor in our circuit to charge up for each intensity, which enabled us to explain the results we got.

## 1 Verification of Intensity Independence of Stopping Potential

### 1.1 Theory

According to Maxwell, light is a type of electromagnetic wave. Wave theory of light predicts that the electron energy would be proportional to the intensity of the radiation, since both are proportional to the sqare of the amplitude of the electromagnetic wave. Hence, in a photoelectric effect phenomena, so would be the stopping potential.

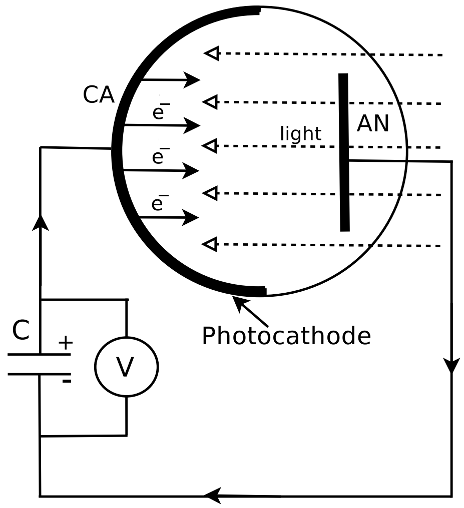
But this was at stark contrast to the experimental evidence. In 1902, Philipp Eduard Anton von Lenard proved that the stopping potential depends on the *frequency* of the radiation rather than the intensity.

In 1905, 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. This feat later earned him the Nobel prize.

### 1.2 Experiment with a light bulb

#### 1.2.1 Experimental setup:

At first, we used a light bulb as our light source. For varying the intensity, we used a voltage controller. Our experimental setup is illustrated schematically in the figure below:




The radiation from our variable intensity light source falls on the photocathode CA. Some of the electrons emitted reached the metal plate AN. As a result, the capacitor in the circuit would get charged.

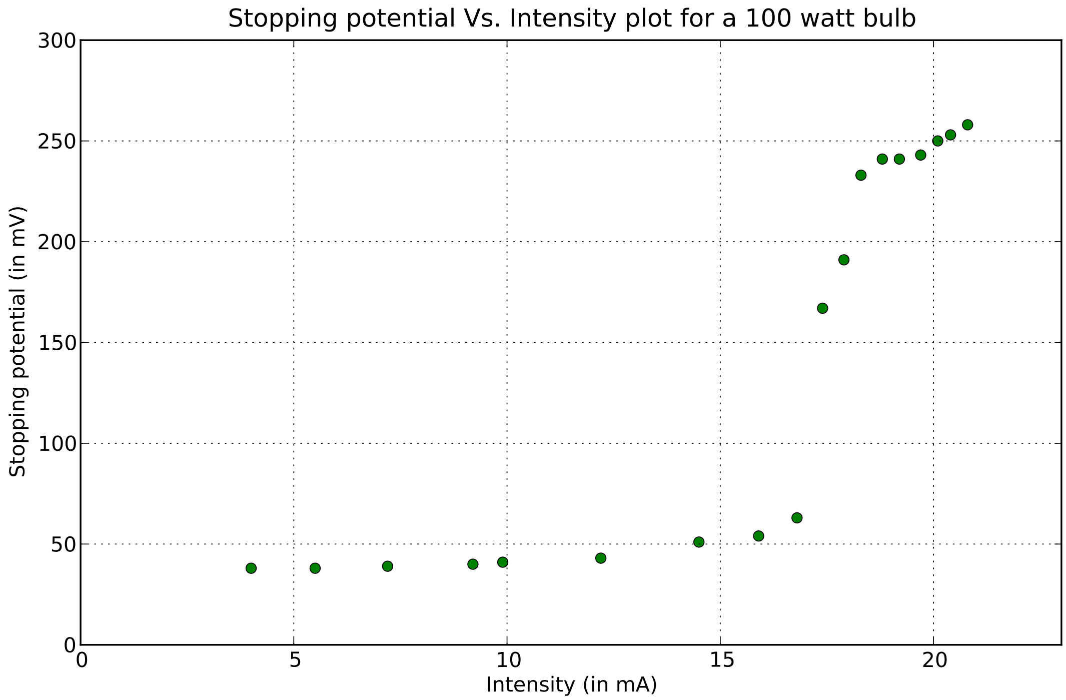
Gradually, the photocachode attains higher and higher positive potential. As a result, less and less electrons would reach AN, decreasing the current. Ultimately, when the voltage across the capacitor reaches the stopping potential for the matal, current in the circuit would stop.

### 1.2.2 Results:

**Table 1.1: Table shows the value of stopping potential for different intensities**

| I(mA) | $V_s$(mV) | I(mA) | $V_s$(mV) |
|---|---|---|---|
| 20.8 | 251.8 | 16.8 | 52.8 |
| 20.4 | 250.3 | 15.9 | 50.2 |
| 20.1 | 250.0 | 14.5 | 50.0 |
| 19.7 | 249.7 | 12.2 | 49.8 |
| 19.2 | 249.3 | 9.9 | 49.6 |
| 18.8 | 249.2 | 9.2 | 49.6 |
| 18.3 | 248.1 | 7.2 | 49.7 |
| 17.9 | 197.6 | 5.5 | 49.6 |
| 17.4 | 153.2 | 4.0 | 49.7 |

The corresponding plot is also given below:




### 1.2.3 Explanation for the results:

This is very unsettling. 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! We must find out what went wrong. Fortunately, we found out two very serious problems with our experimental setup which could cause such anomalous results.

1) Firstly, 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.

2) Secondly, 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.

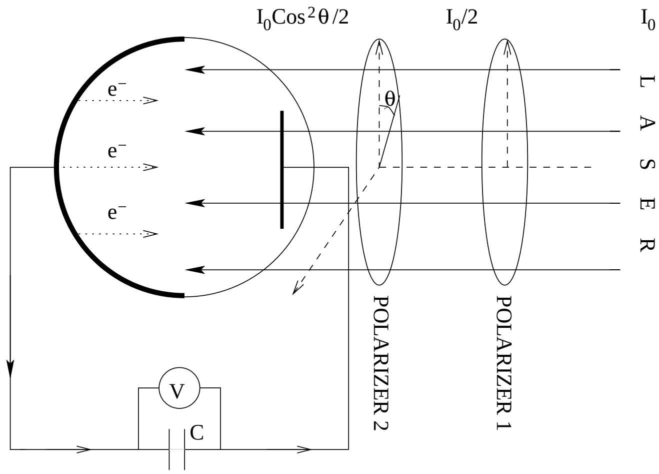
So it is quite possible that at low intensities , the rate of approaching the stopping potential was so low that we concluded that the stopping potential had been reached when indeed it had not.

## 1.3 Refining the experiment using a laser instead of a light bulb:

### 1.3.1 Experimental setup

We needed a monochromatic light source whose intensity we could vary. Unfortunately, such a device was not readily available in the lab. But we figured out how to make such a setup.

We have lots of lasers in our lab, which are perfectly monochromatic light sources. But there's no mechanism of changing their intensity. So we decided to use a couple of polarizers in a setup like this:




By varying the angle $\theta$ we could achieve our goal of changing the intensity since the light passing through the second polarizer will have the intensity

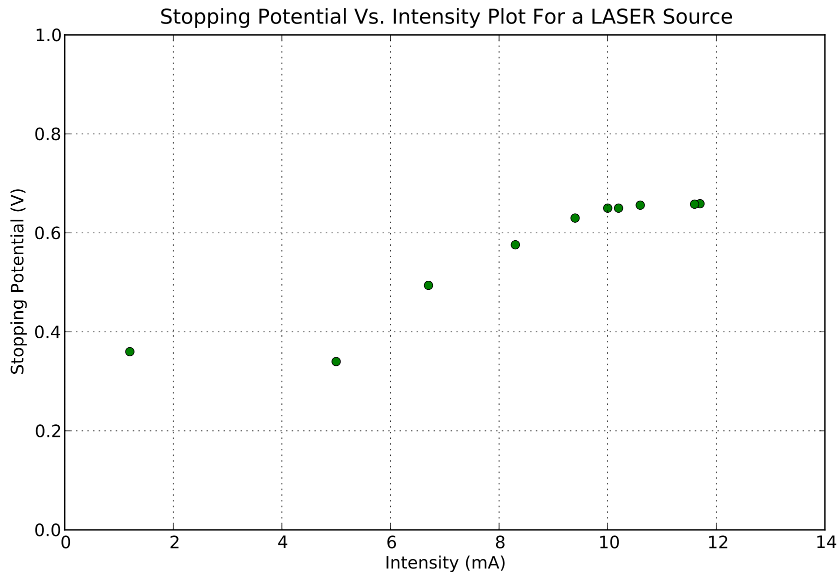
$$I = \frac{I_0 Cos^2\theta}{2}$$

### 1.3.2 Experimental results:

**Table 1.2: Table shows the value of stopping potential for different intensities**

| $\theta$ | I(mA) | $V_s$(mV) |
|---|---|---|
| 0 | 11.6 | 658 |
| 10 | 11.7 | 659 |
| 20 | 10.6 | 656 |
| 30 | 10.2 | 650 |
| 40 | 10.0 | 650 |
| 50 | 9.4 | 630 |
| 60 | 8.3 | 576 |
| 70 | 6.7 | 494 |
| 80 | 5.0 | 340 |
| 90 | 1.2 | 360 |

And the corresponding plot is given below:




### 1.3.3 Explanation:

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.

# 2 To study the rate of charging up of the capacitor for various intensities

## 2.1 Theoretical discussions

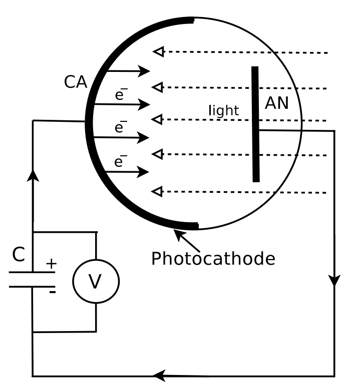



Figure 1:

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

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

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

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

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

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

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 $V$)

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:

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

## 2.2 Experiment

### 2.2.1 Setup

We used the same setup as the last experiment with laser. But this time, for each intensity, we measured the time taken by the capacitor to reach 300 mV.

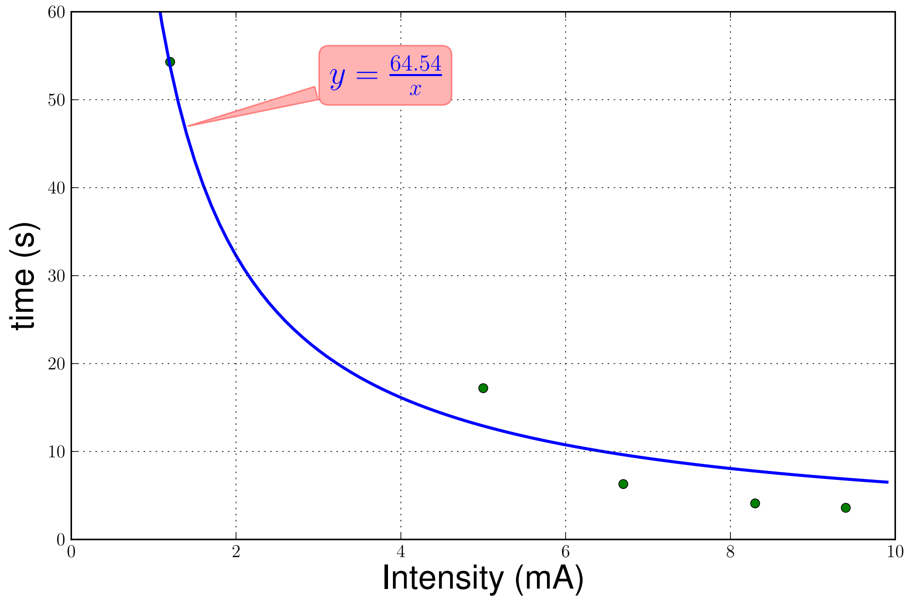
### 2.2.2 Results

**Table 2.1: $T_{300}$ the time taken by the capacitor to reach 300 mV for various intensities**

| I (mA) | $T_{300}$(s) |
|---|---|
| 9.4 | 3.6 |
| 8.3 | 4.1 |
| 6.7 | 6.3 |
| 5.0 | 17.2 |
| 1.2 | 54.3 |

We plotted the data and fitted with the theoretically obtained equation: $y = C/x$

**Fig 2.1: The plot of the time taken for the potential to reach 300 mV against the corresponding intensities**




We obtained a quite good fit of the theoretical eqiation to the experimental data.

# 3 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.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