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# 6. Modern Physics and the Study of the Photoelectric Effect

**Dr. Ashutosh Kumar**
*Assistant Professor (Guest),*
*Department of Physics,*
*B. R. B. College, Samastipur, Bihar.*

***ABSTRACT***

*The variations of photoelectric current with light intensity are discussed in this study. The photoelectric effect is affected by a number of factors, including light frequency, intensity, material type, light energy, and potential difference. Even if the photoelectric effect occurs, the photoelectric current produced as a result of it may vary if the intensity of light is changed, provided that the frequency of illumination is greater than the threshold frequency. An experiment was carried out to determine the effect of changing light intensity on photoelectric effect while keeping the other factors constant. The effect was observed by varying the distance between the light source and the photocell and recording the readings on a Microammeter. The results were drawn using correlation and graphical analysis. According to the correlation analysis, there is a significant positive relationship between photoelectric current and light intensity. A positive linear relationship was also revealed by the graphical analysis.*

***KEYWORDS:***

*Physics, Photoelectric Effect, electron-volt, light wavelength, electrical engineers, photosensitive cathode, Photocells, vacuum tube, solar cells, electromagnetic.*

## Introduction:

The photoelectric effect occurs when electromagnetic radiation, such as light, strikes a material and emits electrons. Photoelectrons are electrons emitted in this manner. Condensed matter physics, solid state chemistry, and quantum chemistry all study the phenomenon to draw conclusions about the properties of atoms, molecules, and solids. The effect is used in electronic devices that detect light and emit electrons at precise times.

The experimental findings contradict the predictions of classical electromagnetism, which states that continuous light waves transfer energy to electrons, which are then emitted when they accumulate enough energy. Light intensity changes theoretically change the kinetic energy of emitted electrons, with sufficiently dim light resulting in delayed emission. The experimental results, on the other hand, show that electrons are dislodged only when the light surpasses a certain frequency, regardless of the duration or strength of exposure. Because a high-intensity low-frequency beam does not accumulate the energy required for the generation of photoelectrons, Albert Einstein suggested that a beam of light is not a wave promoting through space, but a swarm of separate energy packets known as photons.

The emission of conduction electrons from typical metals necessitates the use of a few electron-volt (eV) light quanta, which correspond to short-wavelength visible or ultraviolet light. In extreme cases, photons approaching zero energy are used to induce emissions, such as in systems with negative electron affinity and emission from excited states, or a few hundred keV photons for core electrons in elements with a high atomic number.[1] Research into the photoelectric effect advanced our understanding of the quantum nature of light and electrons and influenced the development of the concept of wave-particle duality.[2] The photoconductive effect, photovoltaic effect, and photoelectrochemical effect are all examples of how light affects the movement of electric charges.

## Application of Internal Photoelectric Effect:

It is rather surprising that the internal photoelectric effect was discovered in 1873, much earlier than the external photoelectric effect, which was discovered around 1888. Willoughby Smith [3] discovered it in the photoconduction of crystalline selenium. R. E. Sale conducted more detailed follow-up experiments the same year and discovered some dependence of the effect on light wavelength [4]. It's fascinating that they used a gas-burner lamp and an electric arc lamp as light sources in some of their experiments, and that telegraph engineers, who were among the first generation of electrical engineers at the time, were heavily involved in basic research. However, for a long time, such photoconductive effects in semiconductors were rarely used in any applications. Meanwhile, theoretical solid-state physics advanced rapidly on the basis of quantum mechanics from the 1920s to the Second World War era, including the energy band theory of solids, the band model of semiconductors, and rectification theory in semiconductor contacts. Finally, in 1947, a major breakthrough was made when AT&T Bell Laboratories invented (or rather discovered) a point contact bipolar transistor. Following that, various types of semiconductor electronic and photonic devices were invented and developed at a breakneck pace [5]. One such novel device developed since the 1950s is the photodiode (PD). It operates on the principle of photoconduction across a reverse-biased pn or pin junction in semiconductors, or a metalsemiconductor Schottky contact.

The photoelectric effect is used in a variety of practical applications, including photocells, photoconductive devices, and solar cells. Typically, a photocell is a vacuum tube with two electrodes. The first is a photosensitive cathode, which emits electrons when exposed to light, and the second is an anode, which is kept at a positive voltage relative to the cathode. When light strikes the cathode, electrons are drawn to the anode, causing an electron current to flow through the tube from cathode to anode. The current can be used to activate a relay, which can open a door or ring a bell in an alarm system. The system can be made to respond to light, as described above, or sensitive to light removal, such as when a light beam incident on the cathode is interrupted, causing the current to stop [6]. Photocells can also be used for exposure.

**Key Terms**

- Photocell— When light strikes the photosensitive cathode, an electric current flows through the vacuum tube.
- Photoconductivity— When certain materials are exposed to light, they gain a significant increase in conductivity.
- Photoelectric effect— Electron ejection from a material substance caused by incidental electromagnetic radiation.
- Photoelectron— The electron ejected in the photoelectric effect is given this name.

A solar cell is a device that converts sunlight into electricity.

Work function— The energy required to simply remove a photoelectron from a surface. This varies depending on the material.

In the case of cameras, the current in the tube would be measured directly on a sensitive metre.

When exposed to light, solar cells, which are typically made of specially prepared silicon, function similarly to batteries. Individual solar cells produce about 0.6 volts, but by connecting many solar cells together, higher voltages and large currents can be obtained. Solar cell electricity is still quite expensive, but it is very useful for providing small amounts of electricity in remote areas where other sources are unavailable. However, as the cost of producing solar cells falls, it is likely that they will be used to generate large amounts of electricity for commercial use [7].

## Review of Literature:

While researching the effect of light on electrolytic cells in 1839, Alexandre Edmond Becquerel discovered the photovoltaic effect.[8] Though not the same as the photoelectric effect, his work on photovoltaics was important in demonstrating a strong relationship between light and the electronic properties of materials. Willoughby Smith discovered photoconductivity in selenium in 1873 while testing the metal for its high resistance properties as part of his work on submarine telegraph cables.[9]

Students in Heidelberg, Johann Elster (1854-1920) and Hans Geitel (1855-1923), investigated the effects of light on electrified bodies and developed the first practical photoelectric cells that could be used to measure light intensity.[10][11]: 458 They arranged metals according to their ability to discharge negative electricity: rubidium, potassium, potassium-sodium alloy, sodium, lithium, magnesium, thallium, and zinc; the effects with ordinary light were too small to be measurable for copper, platinum, lead, iron, cadmium, carbon, and mercury. The metals were arranged in the same order as in Volta's series for contact-electricity, with the most electropositive metals producing the greatest photo-electric effect.

Heinrich Hertz discovered the photoelectric effect [12] and reported on electromagnetic wave production and reception [13] in 1887.[14] The receiver in his device was a coil with a spark gap, where a spark would be seen when electromagnetic waves were detected.

He placed the apparatus in a darkened box to better see the spark. He did notice, however, that the maximum spark length was reduced when he was inside the box. A glass panel placed between the source of electromagnetic waves and the receiver absorbed ultraviolet radiation, allowing electrons to jump across the gap more easily. The length of the spark would increase if it were removed. Because quartz does not absorb UV radiation, he saw no decrease in spark length when he replaced the glass.

The discoveries of Hertz prompted a series of studies on the effect of light, particularly ultraviolet light, on charged bodies by Hallwachs,[15][16] Hoor,[17] Righi [18], and Stoletov [19][20]. Hallwachs used an electroscope to connect a zinc plate. He exposed a freshly cleaned zinc plate to ultraviolet light and observed that the zinc plate became uncharged if it was initially negatively charged, positively charged if it was initially uncharged, and more positively charged if it was initially positively charged. Based on his observations, he concluded that the zinc plate emitted some negatively charged particles when exposed to ultraviolet light.

## Objectives:

- The primary goal of this project is to assess the effect of light source distance on current magnitude.
- I anticipate obtaining an inverse relationship between the two variables as a result of this project.
- The goal of this research is to help policymakers and energy producers understand the impact of factors affecting power generation, such as current.
- As a result, it is anticipated that this research will be extremely beneficial in understanding an important phenomenon of photoelectric effect and thus contributing to the environment.

## Research Methodology:

This research is an experimental study. It focuses on the variation of photoelectric current caused by varying light intensity. The quantitative experimental approach was used to investigate the relationship between the two variables. In addition, the findings of previous research studies and theories have been consulted to support the findings of this research study. The experiment was carried out in a laboratory setting to investigate the effect of the independent variable on the dependent variable. It is a one-point in time study rather than a continuous study.

## Result and Discussion:

This effect can be attributed to the transfer of energy from light to an electron in the metal, according to classical electromagnetic theory. From this vantage point, changes in the intensity or wavelength of light would cause changes in the rate of electron emission from the metal. Furthermore, a sufficiently dim light would be expected to exhibit a time lag between the initial shining of its light and the subsequent emission of an electron, according to this theory. However, the experimental results did not match either of the classical theory's two predictions.

Electrons are only dislodged by photon impingement when the photons reach or exceed a threshold frequency. Below that threshold, no electrons are emitted from the metal regardless of the intensity of the light or the length of time exposed to it.

To account for the fact that light can eject electrons even when its intensity is low, Albert Einstein proposed that a beam of light is a collection of discrete wave packets (photons), each with energy hf. This shed light on Max Planck's previous discovery of the Planck relation (E = hf), which connects energy (E) and frequency (f) as a result of energy quantization. The Planck constant is known as the factor h:

$E = hf = h(c/\lambda) > We$

h: Planck Constant

f: frequency

$\lambda$: wavelength

c: light speed

We: minimum energy threshold

- The following is the quantum interpretation of the photoelectric effect:
- Photons are packets of energy E = hf carried by electromagnetic radiation of frequency.
- The number n of transported packets determines the radiation intensity.
- In the photoelectric effect, a photon is completely absorbed by an electron, increasing its energy by hf.
- Ekin = hf - We is the kinetic energy of the emitted electrons.

    a. a. We = energy required to extract an electron from the material
    b. b. hf = radiation energy

- if hf W there is insufficient energy to extract electrons threshold
- An electron can only receive energy from a quantum; the kinetic energy of the emitted electron is independent of the incident radiation intensity.
- increasing the intensity of the radiation increases the number of energy packets
- increasing the intensity increases the number of emitted electrons
- Ekin = hf - We As the frequency of the incident radiation increases, so does the energy of a single electron.

The photoelectric effect demonstrates, in a way unrelated to black-body radiation, that electromagnetic radiation is made up of quanta of energy hf.

These experimental facts are easily verified by measuring the stopping potential V0, which is the electrical voltage required to stop the flow of electrons produced by the photoelectric effect:

Ecin = hf – We

Ecinmax = eV0

V0 = (hf – We)/e

The measurements should be taken at various wavelengths.

The following constant values will be used:

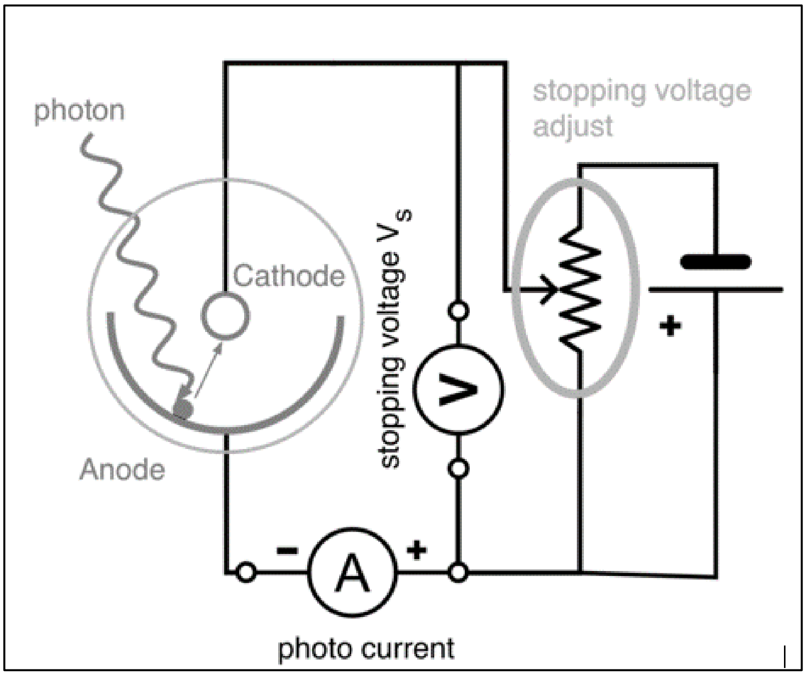
h = 6.626×10-34 Js

e = 1.602×10-19 C

h/e = 4.136×10-15 Js/C

## Experimental Setup:

We used the setup depicted in the diagram below for experimental verification of the photoelectric effect:



## Setup Scheme:

As a phototube, we used the model 1P39, which has an anode coated with Sb - Cs and a spectral response of type S -4, making it suitable for this application:

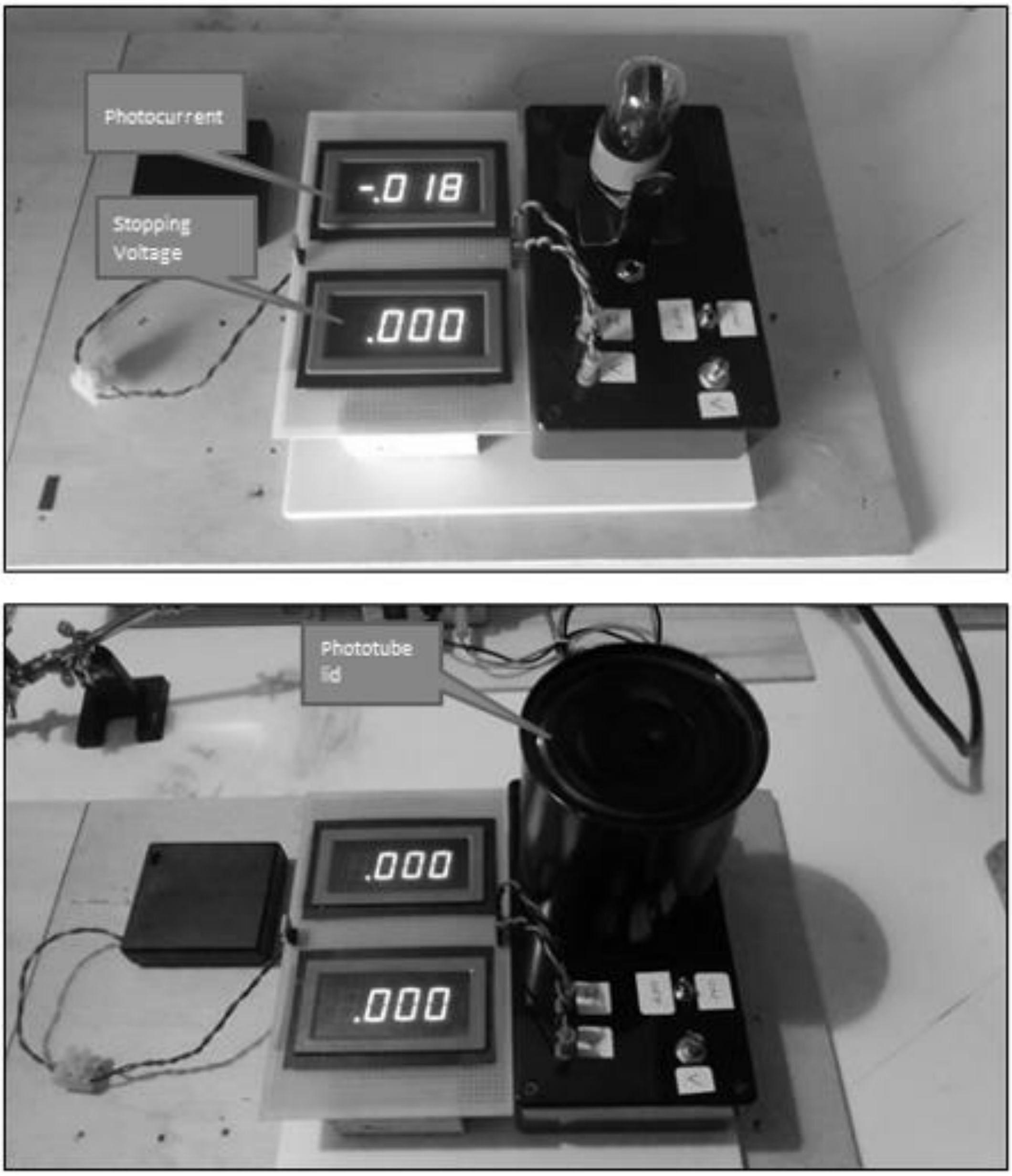
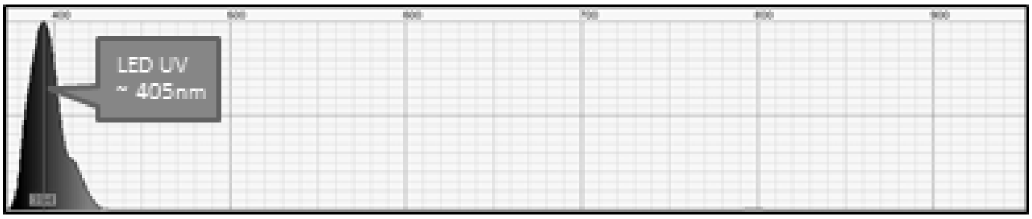
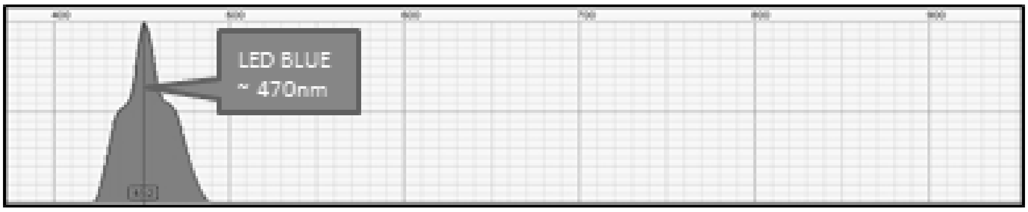


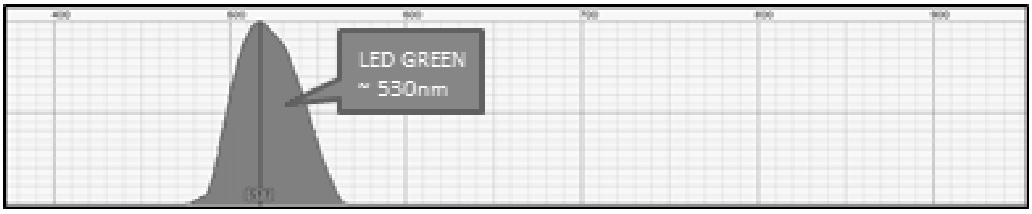

**Figure 1: Picture of the Equipment**

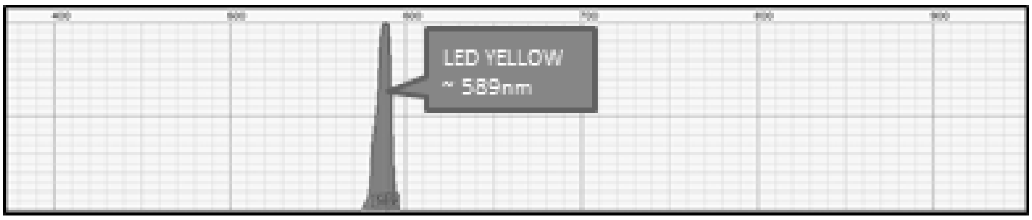
## LED Spectra:

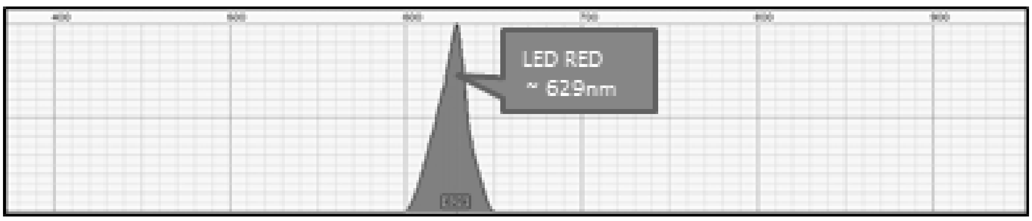
We used LEDs of various colours as photon sources, and the spectra were collected using the Spectrometer DIY and the software Theremino Spectrometer.

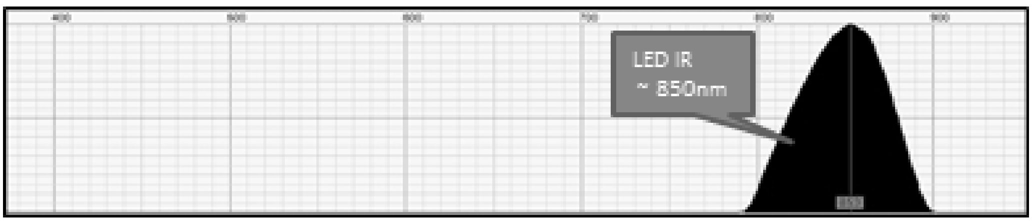


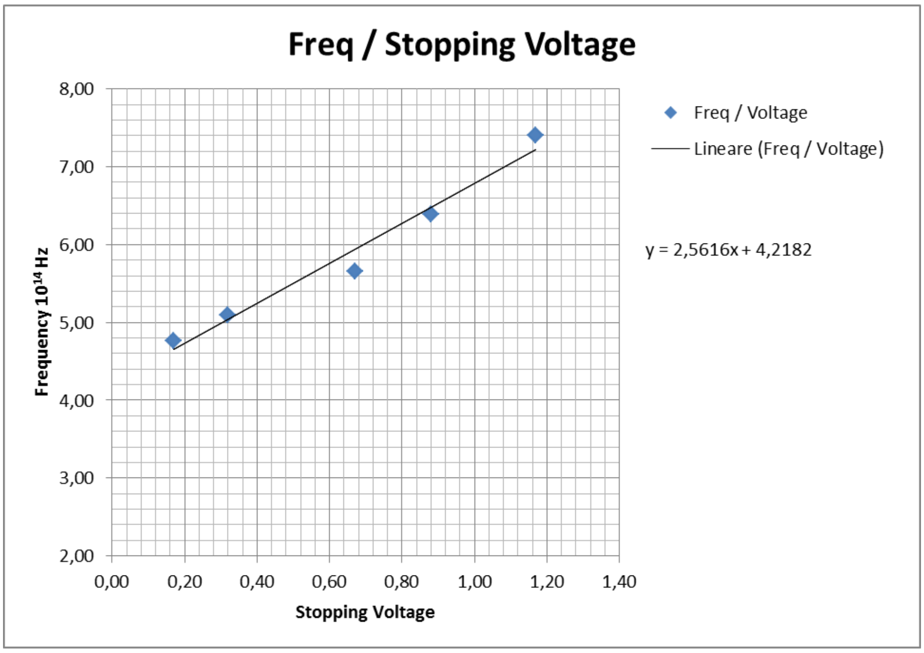



## LED Spectra:




The following values of the ratio h/e and the work function are obtained from the graph's linear regression line:

h/e = 3.9×10-15 Js/C while the correct value is 4.136×10-15 Js/C

We = 4.218 x h x 1014 = 1,74eV

The agreement with the correct values seems good.

## Conclusion:

When photons in the light energy that strikes the metal surface interact with electrons in the metal, the photoelectric effect occurs. Each photon interacts with a single electron. The method I used to explain the effect of light intensity on photoelectric current revealed a positive linear relationship with only minor deviations. I believe that these issues could have been resolved by changing the distance more precisely and taking more precise Microammeter readings.

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