Original Article
Bulletin of Pure and Applied Sciences.
Chemistry , Vol.45 C, No.2
July-December 2026: P.1-5

http://www.bpasjournals.com/chemistry
Print version ISSN 0970 4620
Online version ISSN 2320 320X

Planck Constant by Photocell

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ABSTRACT

This study presents the experimental measurement of Planck's constant through photoelectric effect with a photocell. When monochromatic light of different wavelength is incident on a photosensitive surface, photoelectrons are emitted, and their maximum kinetic energy is measured through the stopping potential. By recording the stopping potential for different frequencies and plotting a linear graph, the slope is used to determine the value of Planck's constant. The experimental results are consistent with Einstein's photoelectric equation, confirming that the maximum kinetic energy of the emitted photoelectrons depends on the frequency of the incident radiation rather than its intensity. The value of Planck's constant obtained from the experiment is in close agreement with the accepted value within the limits of experimental uncertainty. These findings provide strong experimental evidence for the quantum theory of light and support the concept that electromagnetic radiation is emitted and absorbed in discrete packets of energy, known as photons.

Keywords: Photoelectric effect; Planck's constant; Photocell; Energy; Stopping potential

Received on 25.04.2026, Revised on 25.05.2026, Accepted on 04.07.2026

How to cite this article: Tripathi A.D. and Dhiman A. Planck Constant by Photocell. *Bulletin of Pure and Applied Sciences-Chemistry*, 2026;45C (2), 1-5.

INTRODUCTION

The photoelectric effect [1] is a phenomenon in which electrons are emitted from the surface of a metal when light of sufficiently high frequency falls on it. This effect played a very important role in the development of modern physics because it proved that light behaves not only as a wave but also as a stream of particles called photons. In 1905, Albert Einstein [2] explained the photoelectric effect by proposing that light energy is quantized. According to his theory, the energy carried by each photon is given by $E = hv$, where h refers to Planck's constant and v is the frequency of light.

When light falls on the photosensitive cathode of a photocell, photons transfer their energy to electrons present in the metal surface. In case the energy given by the photon is more than the work function of the metal, electrons are emitted with a certain kinetic energy. The maximum kinetic energy of the emitted electrons is given by Einstein's photoelectric equation: $Ek = hv - W$, where W refers the work function of the metal.

In this experiment, monochromatic light of different frequencies is allowed to fall on a photocell. The emitted photoelectrons produce a photoelectric current. A reverse potential, called the stopping or limit potential U_0, is applied to stop the flow of electrons. At this potential, the kinetic energy of the fastest electrons becomes equal to the electrical energy eU_0. Therefore, $eU_0 = h\nu - W$.

By measuring the stopping potential for different frequencies of incident light and plotting a graph between stopping potential and frequency, the value of Planck's constant [3,4] can be determined experimentally. This experiment also verifies that the kinetic energy of photoelectrons depends on the frequency of light and is independent of its intensity [5].

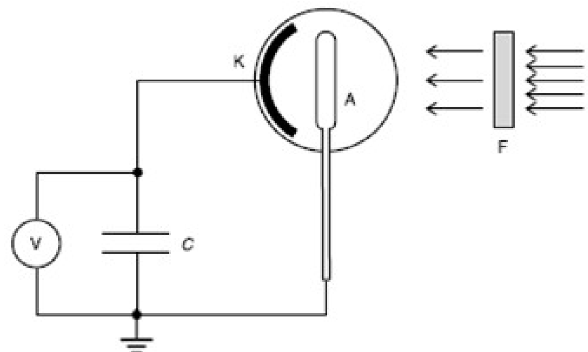


Figure 1: Schematic representation of an experiment for measuring Planck's constant h with the aid of the photoelectric effect. *Monochromatic light (produced by wavelength filter F) falls on cathode K of a photocell. The photoelectrons stimulated here travel to anode A and charge capacitor C up to the limit voltage U_0.*

APPARATUS DETAILS

The following apparatus and instruments are used in the experiment for determining Planck's constant using a photocell:

- Optical bench (1 m)
- Fixed saddles
- Transversal saddle
- Photocell with holder
- Mercury light source with mercury bulb
- Convex lens (f = +200 mm) with holder
- Iris diaphragm
- Electrometer amplifier
- Colour filters for monochromatic light
- Capacitor (100 pF and 1 pF)
- Push switch
- Digital multimeter
- Power supply unit (0–12 V AC/DC)
- Flexible connecting leads
- Ground lead and earthing plug
- A-base, rod, and boss head
- Power cords

The mercury lamp provides monochromatic light of various wavelengths with the help of colour filters. The photocell emits photoelectrons when brightened by light of appropriate frequency. The electrometer amplifier and multimeter are used to measure the stopping potential developed due to the emitted photoelectrons. The optical bench, lens, and diaphragm help in proper alignment and focusing of light on the sensitive surface of the photocell. The experiments can be performed by using necessary equipment and is given in Fig. 2.

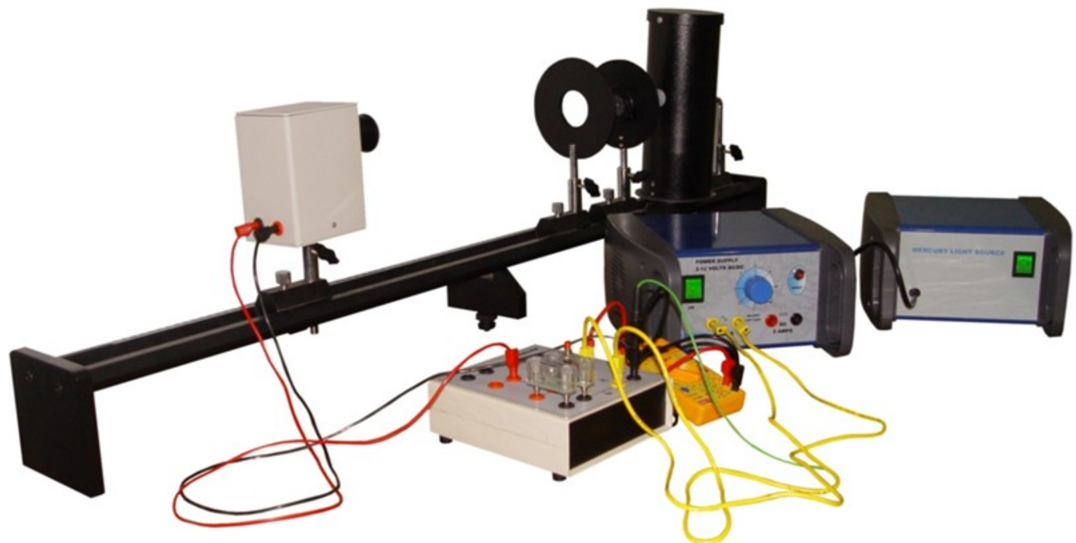


Figure 2: Planck constant measurement by Photocell

EXPERIMENTAL PROCEDURE

1. Switch on the mercury lamp and allow it to warm up for about five minutes so that it reaches full intensity.
2. Arrange the optical setup on the optical bench by mounting the mercury lamp, iris diaphragm, convex lens, and photocell in their marked positions.
3. Adjust the lens and iris diaphragm so that a sharp and uniform light spot falls only on the black coated sensitive surface of the photocell.
4. Place the required colour filter in front of the photocell to obtain monochromatic light of a particular wavelength.
5. Connect the electrical circuit properly using the electrometer amplifier, capacitor, photocell, multimeter, and power supply.
6. Turn on the multimeter and set it to the 20 V DC range for measuring the stopping potential.
7. Now discharge the capacitor completely by pressing the push switch until the voltmeter reading becomes zero.
8. Release the push switch and allow the capacitor to charge due to the emitted photoelectrons.
9. Wait for about 30 seconds to 1 minute until the voltmeter reading becomes constant. Note this value as the stopping or limit potential U_0.
10. Repeat the experiment for different colour filters corresponding to different wavelengths of light.
11. Record the stopping potential for each wavelength and calculate the corresponding frequency of light using $\nu = c/\lambda$.
12. Plot a graph between stopping potential U_0 and frequency ν. The slope of the graph gives the value of h/e, from which Planck's constant h is calculated.Repeat the measurements by varying the intensity of light using the iris diaphragm and verify that the stopping potential remains unchanged. A plot between stopping voltage and frequency is plotted in Fig.3, by which a slope can be calculated.

SAFETY NOTES

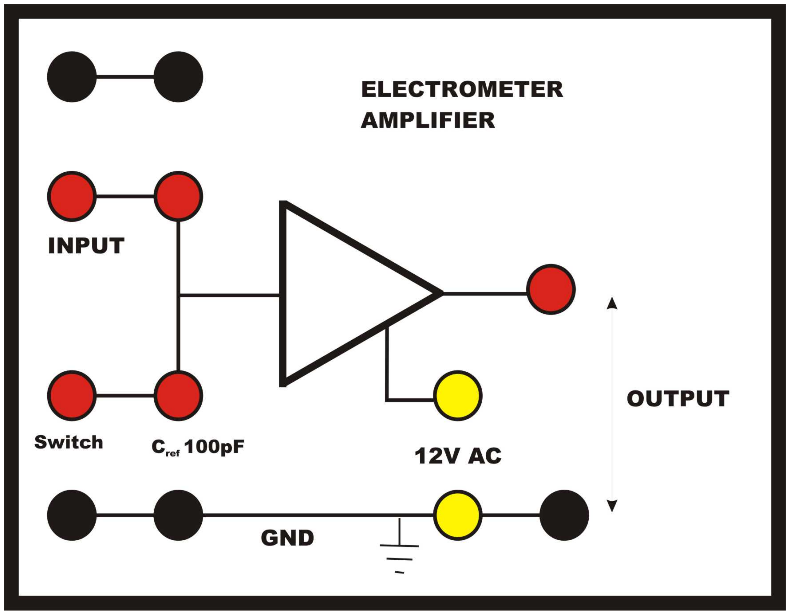
Additionally, the mercury lamp emits UV radiation, which can harm eyes. Avoid staring at the high pressure mercury lamp's direct or reflected light beam. Note: Make sure not to modify the experiment setup once you have made the necessary adjustments.

• **Put the photocell's cover on.**

• Position the filter perfectly in front of the photocell.

ELECTRICAL CIRCUIT

A capacitor receives charge from the photoelectrons hitting the metal ring of the photocell,generating the threshold voltage U0 required for determining the kinetic energy. The electrical potential at theThe electrometer amplifier is used to measure the capacitor.



- Link the 100 pF capacitor to Cref and the push button to Switch.
- Connect 100cm red lead on input of electrometer amplifier and photocell positive terminal.

OBSERVATION TABLE

Wavelength (nm)	Stopping Potential U_0 (V)	Frequency ($\times 10^{14}$ Hz)	Planck Constant h ($\times 10^{-34}$ Js)
630	0.22	4.7619	—
580	0.4	5.1724	7.02
550	0.53	5.4545	7.37
520	0.68	5.7692	7.63
510	0.73	5.8823	7.07
470	1.05	6.383	10.23

Constant Values

Speed of light, $c = 3 \times 10^{8}$ m/s

Electronic charge, $e = 1.6 \times 10^{-19}$ C

Experimental value of Planck's constant, $h \approx 8.06 \times 10^{-34}$ Js

Literature value of Planck's constant = 6.626×10^{-34} Js

Sample Calculation

Using two readings:

$\Delta U_0 = 0.40 - 0.22 = 0.18$ V

$\Delta v = (5.1724 - 4.7619) \times 10^{14}$ Hz

$\Delta v = 0.4105 \times 10^{14}$ Hz

$h = e(\Delta U_0 / \Delta v)$

$h = (1.6 \times 10^{-19}) \times (0.18 / 0.4105 \times 10^{14})$
$h \approx 7.02 \times 10^{-34}$ Js

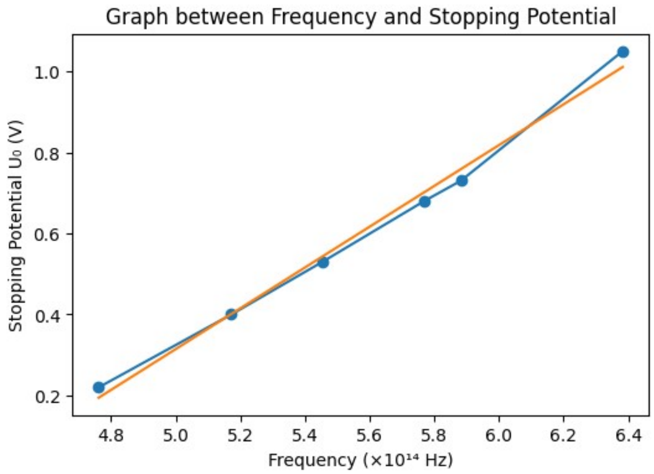


Figure 3: Graph between Frequency and Stopping Potential

CONCLUSION

The experiment on Planck's constant using a photocell successfully verified the photoelectric effect and supported Einstein's quantum theory of light. It was observed that the stopping potential increased with an increase in the frequency of incident light, showing that the kinetic energy of photoelectrons depends on the frequency of light and not on its intensity. The graph plotted between stopping potential and frequency was found to be a straight line, confirming Einstein's photoelectric equation [6].

Using the slope of the graph and the known value of electronic charge, the value of Planck's constant was calculated experimentally. The obtained value was reasonably close to the accepted standard value of 6.626×10^{-34} Js. Small differences between the experimental and theoretical values may have occurred due to instrumental limitations, alignment errors, leakage currents, or observational inaccuracies.

Therefore, the experiment confirmed that light behaves as a stream of particles called photons and demonstrated that energy transfer takes place in discrete packets.

ACKNOWLEDGEMENT

Authors are thankful to Mr.Ajay Sagar, Managing Director, Osaw Industrial Products Pvt.Ltd. Ambala Cantt(India) for providing equipments and laboratory facilities during course of this investigation.

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