Date :

1. Photoelectric effect

Background

Photoelectric effect
Planck's constant
Work function
Photocell

Aim of the experiment

To determine the Planck's quantum of action from the stopping potentials measured at different wavelengths, and to study the effect of the incident intensity on the photocurrent and the stopping potential at a fixed wavelength.

Apparatus required

Photocell
Interference filter set
Spectral lamp Hg
Power supply for spectral lamps
Mounting plate
Nanoammeter
Digital multimeter
DC regulated power supply
Connecting cords

Theory

The photoelectric effect is the key experiment in the development of modern physics. In this experiment, the light from a Hg vapour lamp is spectrally filtered by an interference filter and illuminates a photocell. Inside the photocell there is a metal coated cathode. The annular anode is placed opposite to the cathode. When a photon of frequency ν strikes the cathode, then an electron can be ejected from the metal (external photoelectric effect) provided the photon has sufficient energy. Under the condition of single photon absorption by an electron

$$h\nu - W = \frac{1}{2} m \mathrm{v}^2 \quad \text{(Einstein equation)}$$

where, h = **Planck's constant**, W = work function of the cathode surface, v = electron velocity and m = rest mass of the electron.

The maximum energy of the ejected electrons depends only on the frequency of the incident light, and is independent of its intensity. This law appears to be in contradiction with the electromagnetic wave theory of the light, but it becomes understandable in the frame of the corpuscular theory of light. The kinetic energy for the emitted electrons is determined using the stopping electric field method: A negative bias with respect to the cathode is applied on the photoelectric cell anode. This decelerates the electrons and thus decreases the photoelectric current intensity *I*, since not all the electrons have maximum energy but they have an energy distribution. The value of the bias where no electron reaches the anode and *I* becomes zero is called the stopping voltage (*V*). Thus, the electrons will reach the anode as long as their kinetic energy is equal to the potential energy associated with the applied reverse bias:

$$eV = \frac{1}{2} m \mathrm{v}^2$$

with, *e* is the electron charge.

An additional contact potential ϕ occurs, because the surfaces of the anode and cathode are different:

$$eV + \phi = \frac{1}{2} m \mathrm{v}^2$$

If we assume that *W* and 'ϕ' are independent of frequency, then there will be a linear relationship between the voltage *V* and the light frequency ν,

$$V = -\frac{W + \phi}{e} + \frac{h}{e}\nu$$

A plot *I* over the applied bias voltage V_{bias}, at different light frequencies, reveals the dependence of *V* on the wavelength λ of the incident light. Finally, the Planck's quantum of action is determined from the plot of stopping voltage *V vs* ν. A straight line is drawn through the experimental points (i.e. $V = a + b\nu$). One can determine the value of Planck's constant from the slope of the straight line, the literature value of which is $h = 6.63 \times 10^{-34}$ Js.

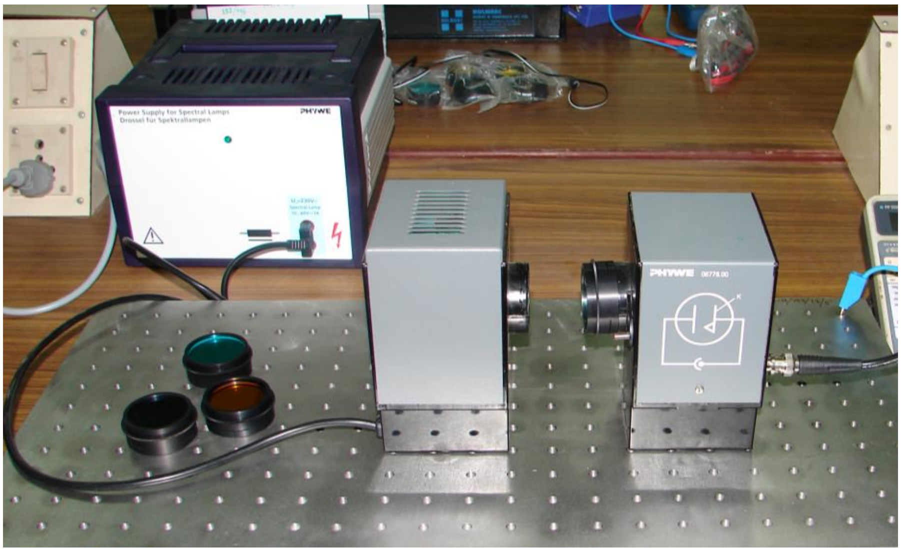

Fig. 1: Experimental set-up for determining Planck's quantum of action

Procedure

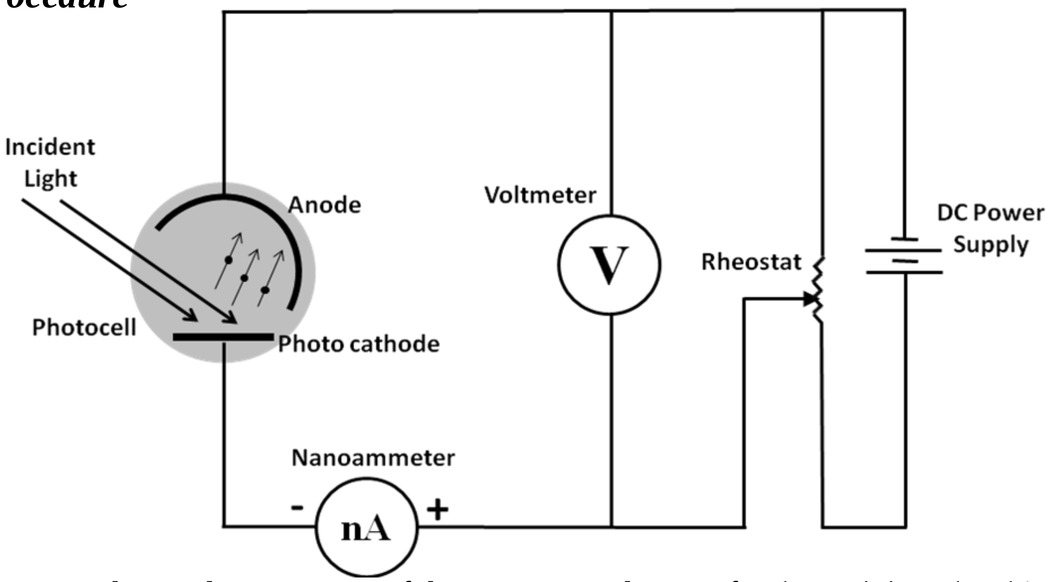

Fig. 2: Electrical connections of the experimental set-up for determining Planck's quantum of action

1. Make the electrical connections carefully as per Figure 2.
2. Keep the slider of the rheostat at one end (marked red) to have minimum voltage drop across the phototube.
3. Set the DC power supply voltage to 2V, to start with.
4. Keep the exit-slit of the lamp enclosure along the same line and facing the entrance-slit of the phototube enclosure. For the first part of the experiment (Table 1), keep the separation between the lamp and filter compartments < 5 cm.
5. Close the photocell entrance-slit and adjust the nanoammeter reading to ~ zero using the 'Zero adj.' knob.
6. Mount the $\lambda = 366$ nm interference filter on the entrance-slit of the phototube enclosure and open the slit.
7. Increase the photocell bias voltage (V_{bias}) in small steps by using the rheostat.
8. Record the values of the photo current (I) on the nanoammeter as a function of the increasing photocell bias voltage, till the photo current reduces to zero.
9. Plot a graph of V_{bias} *vs* I to obtain the point where the plot intersects the horizontal axis, and thus provides the value of the stopping voltage (V) for the light at $\lambda = 366$ nm.
10. Repeat steps 5 to 9 for various filters to determine the value of the stopping voltage (V) for different frequencies of incident light. If the expected stopping voltage for a given frequency is less than 1V then, set the DC power supply voltage to 1V (or lower), before the start of the experiment for the given filter, to precisely identify the bias voltage wherein the photo current reduces to zero. *While varying the DC power supply voltage, disconnect the chords connected to the output terminals of the power supply for safety*.
11. Plot frequency *vs.* stopping voltage using the least squares fitting method and find the value of h from the slope of the graph.
12. Repeat the experiment for two different lamp – photocell separations, keeping the wavelength of the incident light fixed at $\lambda = 366$ nm. (Change the lamp-photocell separations in steps of 1 cm.)

Observations

Least count of the voltmeter: ……………. ; Least count of the ammeter: …………….
Separation between lamp and filter compartments: …………….

Table 1
Determination of Stopping Potential

Wavelength, Frequency	V (*V*)	I (*nA*)	Wavelength, Frequency	V (*V*)	I (*nA*)
λ = 366 nm Frequency ($\nu = c/\lambda$) = …………(s^{-1})			λ = 405 nm Frequency ($\nu = c/\lambda$) = ……… (s^{-1})		
λ = 436 nm Frequency ($\nu = c/\lambda$) = …………(s^{-1})			λ = 546 nm Frequency ($\nu = c/\lambda$) = …………(s^{-1})		

Wavelength, Frequency	V (*V*)	I (*nA*)	Wavelength, Frequency	V (*V*)	I (*nA*)
λ = 578 nm					
Frequency					
($\nu = c/\lambda$) =					
…………(s^{-1})					

Values of the stopping potentials from the plot of V_{bias} *vs* I for different wavelengths:

V (for λ = 366 nm) = ……………….. V (for λ = 405 nm) = ………………..

V (for λ = 436 nm) = ……………….. V (for λ = 546 nm) = ………………..

V (for λ = 576 nm) = ………………..

Table 2

Dependence of the photocurrent on the intensity of light

λ = 366 nm; Frequency ($\nu = c/\lambda$) = …………………(s^{-1})

Separation between lamp and filter (*cm*)	V (*V*)	I (*nA*)	Separation between lamp and filter (*cm*)	V (*V*)	I (*nA*)

Results and Calculations

Value of *h* from the plot …………………………J. sec.

Error Calculation: If the slope is calculated using voltages V_1 and V_2 from the graph, then

$$\frac{\delta h}{h} = \frac{\delta V_1 + \delta V_2}{V_1 - V_2}$$

Discussion

i. The view that the light propagates as a series of little packets of energy (photons) is directly opposed to the wave theory of light. According to the wave theory, which provides the sole mean of explaining the optical effects like interference and diffraction, the energy carried out by the light is distributed continuously through out the wave pattern. According to the quantum theory, which is strikingly successful in explaining photoelectric effect, light spreads out from the source as a series of localized concentration of energy.

ii. In a specific event light exhibits either a wave or a particle nature, never both simultaneously. *The wave theory of light and the quantum theory of light are complement to each other*.

Questions

1. What is the value of Planck's constant?
2. What are the sources of error in this experiment?
3. What is photoelectric effect?
4. Define "work-function".
5. What is the time lag between the arrival of light at a metal surface and the emission of photoelectron?
6. What do you mean by stopping potential/extinction voltage/cut off voltage?
7. What type of material should be chosen for photoelectron emission?
8. What is photoelectric cell?
9. What do you know about the structure of photovoltaic cell?
10. Can you name a recent method of a very accurate determination of Planck's constant?
11. Interpret thermionic emission in light of photoelectric effect.
12. In which phenomenon do you see the inverse photoelectric effect?

References

1. PHYWE, TEP 5.1.05-02 "External photoelectric effect and Planck's constant – wavelength selection with grating spectrometer."
2. Prospective of Modern Physics by A. Beiser   539 BEI/P N69
3. The Feynman Lectures on Physics (Vol III) by R.P. Feynman   530 FEY/L

Graphs:

1. Plot V_{bias} *vs* I for different wavelengths from Table 1 to obtain the stopping potentials at each wavelength.

2. Plot frequency *vs* stopping voltage using the least squares fitting method and find the value of h from the slope of the graph.

3. Plot V_{bias} *vs* I for different separation between lamp and phototube to study the effect of the incident intensity on the photocurrent and the stopping potential at a fixed wavelength.