

VL-M1: DETERMINATION OF THE THRESHOLD FREQUENCY FOR THE MATERIAL OF A PHOTOCATHODE AND HENCE FIND THE VALUE OF THE PLANCK'S CONSTANT

Objectives:

- To explore what happens when light interacts with matter.
- To explore the fundamentals of the phenomenon of photoelectric effect.

System requirement:

Computer (Desktop/Laptop), Operating systems: Windows with latest version of Java, Photoelectric_en (zipped) File.

Advise:

Students are advised to follow the **procedures written in this manual very strictly** while performing the experiment. **Do not try to explore anything else in the experiment.**

Photoelectric effect

When electromagnetic wave of suitable wavelength (frequency) falls on metal surfaces, electrons are ejected from these metals. This phenomenon is called the photoelectric effect. Electrons emitted in this process are not different from ordinary electrons and the emitted electrons are usually referred to as photoelectrons.

From experimental studies the following characteristics of photoelectric effect are established:

- i. **Photoelectric current** is directly proportional to the intensity of radiation.
- ii. For every metal there is a limiting or critical value of frequency of the incident radiation, below which no photoelectrons are emitted. This limiting frequency is called **threshold frequency**, whose value depends on the nature of the material irradiated, *i.e.*, threshold frequency is different for different materials.
- iii. The **stopping potential** is independent of the intensity of the incident radiation but is directly proportional to the frequency of the radiation. The stopping potential is defined as that value of the retarded potential difference between two electrodes with the photocathode positive, which is just sufficient to halt the most energetic photoelectrons emitted *i.e.*, to reduce the photoelectric current just becoming zero.

Theory:

Einstein's photoelectric effect equation

Einstein explained the photoelectric effect based on Planck's quantum theory of light. According to quantum theory, light consists of energy of quanta as expressed by

$$E = h\nu \dots \dots \dots (1)$$

Here ν is the frequency of the incident light and h is the Planck's constant. These quanta are known as photons. Thus, according to Einstein, radiation is regarded as a shower of photons each of energy $h\nu$ moving in space with the speed of light. When a single photon is incident on a metal

surface as shown in Fig. 1, it is completely absorbed by atom. The energy is subsequently imparted to one of the electrons of the atom. This energy is utilized for two purposes:

- (i) Partly for getting the electron free from the atom. This energy is known as photoelectric work function of the metal and is represented by $\phi = h\nu_{th}$, where ν_{th} is the threshold frequency for the material of the photocathode.
- (ii) The balance (rest) of the photon energy is used by the free electron to gain a kinetic energy of $E_k = \frac{1}{2} m v_{max}^2$, where m is the mass of the electron and v_{max} is the velocity of the most energetic photoelectron.

Einstein expressed this assumption in his photoelectric equation as

$$h\nu = \phi + \frac{1}{2} m v_{max}^2 \dots \dots \dots (2)$$

where, $h\nu$ = energy of the incident photon
 ϕ = work function of the photocathode material
 $\frac{1}{2} m v_{max}^2$ = the maximum kinetic energy of the emitted electrons.

Now, if V_s is the stopping potential for the frequency ν of the incident radiation, then the maximum kinetic energy of the emitted photoelectron is

$$\frac{1}{2} m v_{max}^2 = eV_s \dots \dots \dots (3)$$

where, e is the electronic charge.

So, $h\nu = h\nu_{th} + eV_s$
 or, $V_s = (h/e)\nu - (h/e)\nu_{th} \dots \dots \dots (4)$

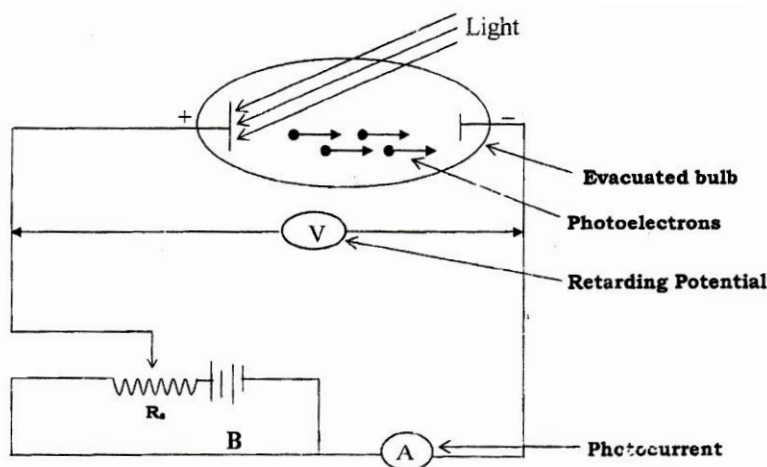


Fig. 1. An schematic of the experimental arrangement for the photoelectric effect.

Procedures:

1. Unzip “Photoelectric_en” file and then install “JavaSetup8u251”. Now click right button on the “Photoelectric_en” file and select open with “Java Platform”, then a window will open as shown in Fig. 2.
2. Choose target metal sodium as photocathode from the upper right-hand box as shown in Fig.2.
3. Keep battery voltage at 0.00 V and turn the light intensity to 100% (Say this is I_1).
4. Choose a wavelength of light in the UV region (100 – 400 nm) so that the photocurrent become maximum. Note down the values of wavelength & photocurrent in Table 1 for I_1 .

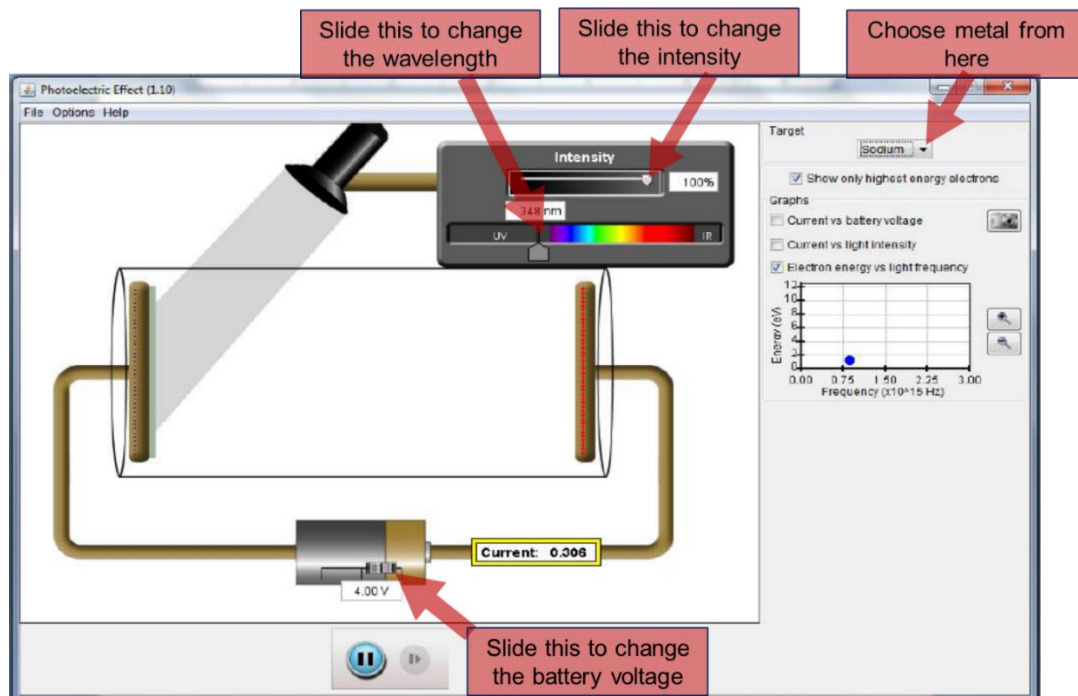


Fig. 2

5. Find the stopping potential, V_s , by changing the battery voltage to make the photocurrent zero. For this, slide the battery or put your desired values in the box below the battery so that the photocurrent just become zero.
6. Keeping the wavelength same, reduce the intensity to 80% (I_2), 60% (I_3), 40% (I_4), 20% (I_5), and note down photocurrents for each intensity (Please note that during this, the applied battery voltage must be kept zero). For each intensity of light find V_s using the same step described in 4, and note down the values in Table 1.
7. Choose another wavelength from the UV region and take readings for above five different intensities again and note the required values (as described in steps 4 and 5) in Table 1. In this way, take readings for more three wavelengths so that in total you will take reading for five different wavelengths.
8. Draw a curve taking the frequency of radiation in the X-axis and the average stopping potential in the Y-axis. The resulting curve will be a straight line as shown in Fig. 3.

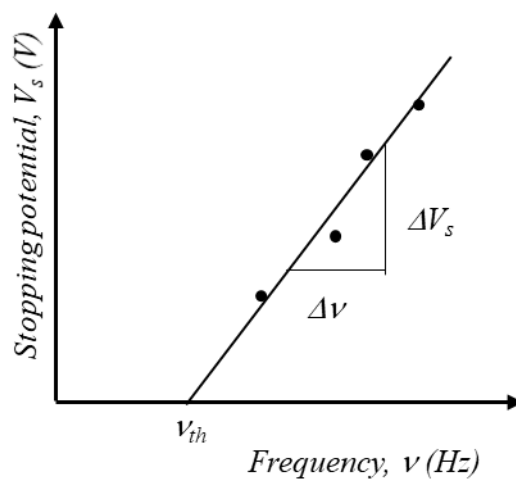


Fig. 3. Frequency vs stopping potential curve.

Data Collections:

Table 1: Data for the determination of threshold frequency and Planck’s constant

Intensity of light	Wavelength of the light, λ (nm)	Frequency of the light, ν (Hz)	Photocurrent, I (A or mA)	Stopping potential, V_s (V)	Average stopping potential, V_s (V)	Threshold frequency, ν_{th} (Hz) from graph
I ₁ I ₂ I ₃ I ₄ I ₅						
I ₁ I ₂ I ₃ I ₄ I ₅						
I ₁ I ₂ I ₃ I ₄ I ₅						
I ₁ I ₂ I ₃ I ₄ I ₅						
I ₁ I ₂ I ₃ I ₄ I ₅						

Calculations:

- When the straight line is produced backwards, the intercept with the X-axis gives the value of the threshold frequency, ν_{th} .
- Now from Eq. 4, you have

$$h = e \frac{V_s}{\nu - \nu_{th}} = e \frac{\Delta V_s}{\Delta \nu} \dots \dots \dots (5)$$

where ΔV_s and $\Delta \nu$ are the values to be taken from Fig. 2 as shown. From the average fitted line, choose such points on the line which are not the experimental points. Knowing the value of electronic charge, e , Planck’s constant, h , can be calculated.

Results:

Threshold frequency, ν_{th} =Hz

Planck’s constant, h =J.s

Error Analysis:

Find the percentage error for Planck’s constant considering the standard value of $h = 6.626 \times 10^{-34}$ J.s.

$$\% \text{ of error} = \frac{|\text{Measured value} - \text{Standard value}|}{\text{Standard value}} \times 100\% = \dots\dots\%$$

Discussion:

Based on your understanding from this experiment, answer the following questions:

- 1) For a particular metal choose a wavelength that ejects electrons at a reasonable speed. Increase or decrease the light intensity. Make note of the number of electrons ejected. Why does the number change?
- 2) Reset the battery to zero and for a light of particular intensity turn on the electron energy vs. light frequency graph at the right of the screen. Play with light wavelength to generate data for the graph. Explain the nature of the graph from the screen using photoelectric effect equation (You can zoom in or out the graph).
- 3) How the current flowing through the circuit changes with the number of emitted photoelectrons?
- 4) Set the battery voltage 0.00 V and the wavelength at 400 nm, observe the variation of current with intensity and note your understanding from the nature of the curve.
- 5) Leave the intensity at 50% and the wavelength at 400 nm. Change the voltage to -3.00 V. Explain what this change in potential difference means in this experiment. Why is there no current? Will increasing the intensity at the same wavelength and potential difference cause a current to flow? Why or why not?
- 6) Click to open the current versus battery voltage graph. Keeping the intensity at 50% and wavelength 400 nm, slide the battery voltage. Carefully observe the nature of the graph and mention why the curve changes like that? (You can zoom in or out the graph)