Planck's constant (Photo Electric Effect)

Aim:

1. To determine Planck's Constant and work function using photo electric effect.
2. To verify inverse square law of radiation.

Apparatus used:

Light source, Digital voltmeter and ammeter, Vacuum photo tube, filters of different colors.

Formula used:

Stopping potential is given by

$$V_s = \frac{h}{e}\upsilon - \phi$$

where

V_s = Stopping potential
e = Electronic charge
υ = Frequency of light used
ϕ = Work function
h = Planck's constant

The slope of straight line obtained by plotting a graph V_s as a function of υ yields $\frac{h}{e}$ and the intercept of extrapolated point $\upsilon = 0$ gives the work function of Cesium Antimony film (Cs-Sb)

Theory:

It was observed as early as 1905 that most metals under influence of radiation, emit electrons. This phenomenon was termed as photoelectric emission. The detailed study of it has shown:

1. That the emission process depends strongly on frequency of radiation.

2. For each metal there exists a critical frequency such that light of lower frequency is unable to liberate electrons, while light of higher frequency always does.

3. The emission of electron occurs within a very short time interval after arrival of the radiation and number of electrons is strictly proportional to the intensity of this radiation.

The experimental facts given above are among the strongest evidence that the electromagnetic radiation is quantified and the radiation consists of quanta of energy E= hυ where is υ the frequency of the radiation and h is the Planck's constant. These quanta are called photons.
Further it is assumed that electrons are bound inside the metal surface with an energy eϕ , where ϕ is called the work function. It then follows that if the frequency of the light is such that
hυ> eϕ, it will be possible to eject photoelectron, while if hυ<eϕ, it would be impossible.
In the former case, the excess energy of photon appears as kinetic energy of the electron, so that

$$h\upsilon = \frac{1}{2} mv^2 + e\phi \quad ......(1) \quad \text{or} \quad \frac{1}{2} mv^2 = h\upsilon - e\phi$$

which is the famous photoelectric equation formulated by Einstein in 1905.
If we apply a retarding potential V_0 so as to stop the photo electrons completely, it is known as stopping potential V_s. At that instant

$$\frac{1}{2} mv^2 = eV_s \quad \text{or} \quad eV_s = h\upsilon - e\phi$$

Or

$$V_s = \frac{h}{e}\upsilon - \phi .$$

So when we plot a graph V_0 as a function of υ, the slope of the straight line yields $\frac{h}{e}$ and the intercept of extrapolated point at υ =0 gives work function ϕ.

To verify inverse square law of radiation using a photoelectric cell

If L is the luminous intensity of an electric lamp and E is the illuminiscence (intensity of illumination) at point r from it, then according to inverse square law.

$$E = \frac{L}{r^2}$$

If this light is allowed to fall on the cathode of a photo-electric cell, then the photo-electric current (I) would be proportional to E.

$$E = \frac{L}{r^2} = K.I$$

Hence a graph between $\frac{1}{r^2}$ and I is a straight line, which verify the inverse square law of radiation.

<u>Apparatus Used :</u>

The apparatus consists of the following :

1. **Photo Sensitive Device** : Vacuum photo tube.

2. **Light source** : Halogen tungsten lamp 12V/35W.

3. **Colour Filters** : 635nm, 570nm, 540nm, 500nm & 460nm

4. **Accelerating Voltage** : Regulated Voltage Power Supply
   Output : ±15 V continuously variable through multi-turn pot
   Display : 3 ½ digit 7-segment LED
   Accuracy : ±0.2

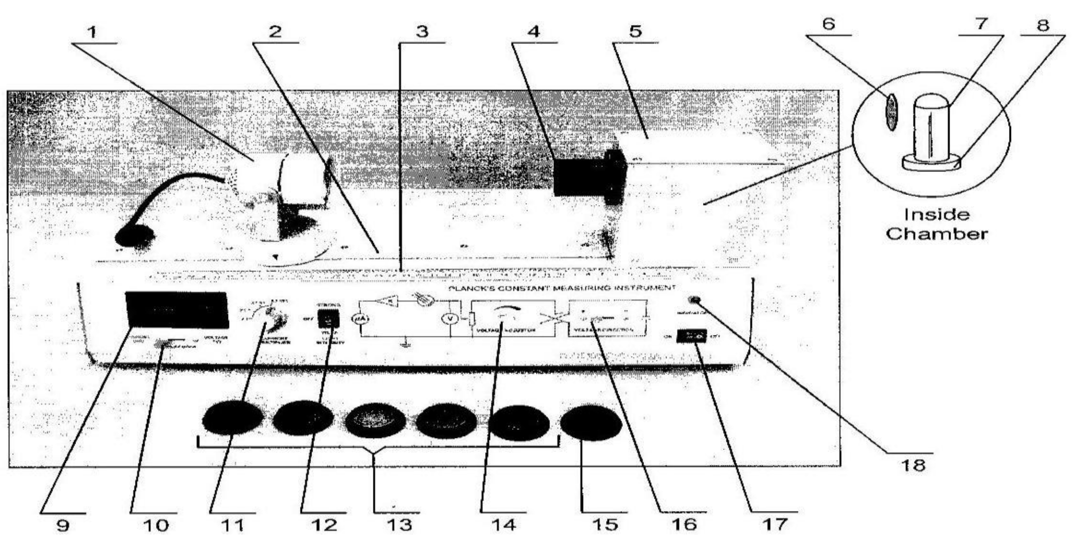
5. **Current Detecting Unit** : Digital Nanoammeter
   It is high stability low current measuring instrument
   Range : 1000 [A, 100 [A, 10 [A & 1[A with 100 % over ranging facility]
   Resolution : 1nA at 1 [A range]
   Display : 3 ½ digit 7-segment LED
   Accuracy : ±0.2%

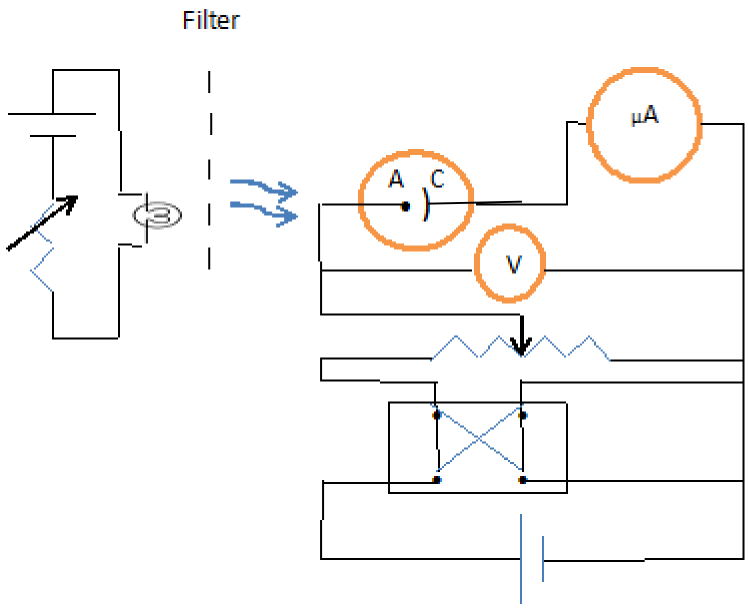
5. **Power Requirement** : 220V ± 10%, 50Hz.

6. **Optical Bench** : The light source can be moved along it to adjust the distance between light source and phototube. Scale length is 400 mm. A drawtube is provided to install colour filters, a focus lens is fixed in the back end.

STRUCTURE:

1. Light Source, 12V/35W halogen tungsten lamp.
2. Guide. Move the light source along it, the distance between light source and receiving dark box can be adjusted.
3. Scale, 400mm total length. The center of the vacuum phototube is used as zero point.
4. Drawtube. The forepart is used for installing color filter; a focus lens is fixed in the back end.
5. Cover. Used to cover chamber containing Phototube.
6. Focus lens. Make a clear image of light source on the cathode area of phototube.
7. Vacuum Phototube. The sensitive component.
8. Base for holding the Phototube.
9. Digital Meter. Show current (μA), or voltage (V).
10. Display mode switch. For switching the display between voltage and current mode.
11. Current Multiplier.
12. Light Intensity Switch. Switch for choosing light intensity. Up is of strong, middle is of off; down is for weak.
13. Filter Set. Four pieces.
14. Lens Cover. (For protecting the phototube from stray light during ideal period).
15. Accelerate voltage adjustor. Knob for adjusting accelerate voltage.
16. Voltage direction , switch. Switch for choosing voltage direction. ±15V accelerated voltage is provided.
17. Power switch.
18. Power indicator.





Schematic Diagram
(Draw in practical note book)

Procedure:

For determination of Planck's Constant and work function:

1. Insert the red color filter (635nm), set light intensity switch (12) at strong light, voltage direction switch (16) at '-', display mode switch (10) at current display.

2. Adjust to de-accelerating voltage to 0 V and set current multiplier (4) at X0.001. Increase the de-accelerating to decrease the photo current to zero. Take down the de-accelerating voltage (V_s) corresponding to zero current of 635nm wavelength. Get the V_s of other wave lengths, the same way. (Repeat for at least 2 distances say 40cm and 30cm)

For verification of inverse square law:

1. The connection would be same as before except a positive voltage would be applied to the anode with respect cathode.

2. Place a filter in front of the photoelectric cell.

3. Keeping the voltage constant and position of photocell fixed, increase the distance of lamp from photo-cell in small steps (of 2 cm). In case note the position of the lamp r on the optical bench and the current I.

4. The experiment may be repeated with other filters (at least 2 filters).

Observation:

Table 1 For determination of Planck's Constant and work function

S.No.	Filters	υ (sec^{-1}x10^{14})	Stopping Voltage (V_s in Volts)	
			d = 40 cm	d = 30 cm
1	Red (635nm)	4.72		
2	Yellow I (585nm)	5.13		
3	Green (500nm)	6.00		
4	Blue (460nm)	6.50		

Table 2 For verification of inverse square law:

S,No.	Distance between lamp and photo-cell (r)	$\frac{1}{r^2} X10^3$	I (μA)	
			Red filter	Green filter
1	18cm	3.09		
2	20cm	2.50		
3	22cm	2.07		
4	24cm	1.74		
5	26cm	1.48		
6	28cm	1.28		
7	30cm	1.11		

Calculations :

From graph (1) V_s vs υ

$$h = e \times \text{slope of graph}$$

$$h = e\,\frac{\Delta Vs}{\Delta \upsilon}$$

Substituting the values of ΔV_s and $\Delta\upsilon$ from graph (1)
h can be found, h = ….. Joule– sec.
Standard value of h = 6.62x10^{-34} Joules-sec
Again from graph (1) intercept at $\upsilon = 0$.
Work function ϕ = intercept on y axis = ………………volts.

Result:

1. Planck's constant 'h' is found to be work function h = ……..J-sec
   ϕ = ……..V.
2. Graph between $\frac{1}{r^2}$ along X axis and I along Y axis is a straight line hence proves the inverse square law of radiation.

Precautions:

1. This instrument should be operated in a dry, cool indoor space.

2. Phototube particularly should not be exposed to direct light, particularly at the time of installation of phototube; the room should be only dimly lit.

3. The instrument should be kept in dust proof and moisture proof environment, if there is dust on the phototube, color filter, lens etc. clean it by using absorbent cotton with a few drops of alcohol.

4. The color filter should be stored in dry and dust proof environment.

5. After finishing the experiment remember to switch off power and cover the drawtube (4) with the lens cover (15) provided. Phototube is light sensitive device and its sensitivity decrease with exposure to light and due to ageing.