Planck's Constant and Inverse Square Law

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1 Aim

Determination of Planck's Constant and Verification of Inverse Square Law

2 Apparatus Required

- Light with intensity adjustment knob
- Uninterrupted power supply
- Vaccum photo tube
- Colour filters

3 Theory

The electromagnetic radiation consists of quanta of energy,

$$E = h\nu, \tag{1}$$

where E is energy, h is Planck's constant (to be determined) and ν is the frequency of radiation. These quanta are called photons. Further, it is assumed that electrons are bound inside the metal surface with an energy W , which is called work function of that particular metal. It then follows that if frequency of the light is such that $h\nu > W$, it will be possible to eject photoelectron, while if $h\nu < W$, it will not be possible.

In the former case, the excess energy of photons appears as *kinetic energy* of the phototelectrons, so that

$$\frac{1}{2}mv^2 = h\nu - W \tag{2}$$

where m is mass of photoelectron and v is velocity of photoelectron.
If we can apply a retarding potenial V_0 to stop the photoelectrons completely, then it is known as the *stopping potenial* V_s. At that instant

$$\frac{1}{2}mv^2 = eV_s \tag{3}$$

and

$$eV_s = h\nu - W \tag{4}$$

where e is electron's charge equal to 1.6×10^{-19} , V_s is in Watts and W is in Joules.
So, when we plot graph V_0 as function of ν , the slope of straight line yields h and the intercept of extrapolated point at $\nu = 0$ gives $-W$. So one can calculate value of Planck's constant and work function from the slope and intercept of the graph. ν_0 is the threshold frequency; radiation of frequency lower than that would not help electrons to come out of surface.
If L is the luminous intensity of an electric lamp and E is the *illuminiscence*, intensity of illumination at a distance r from it, then according to inverse square law

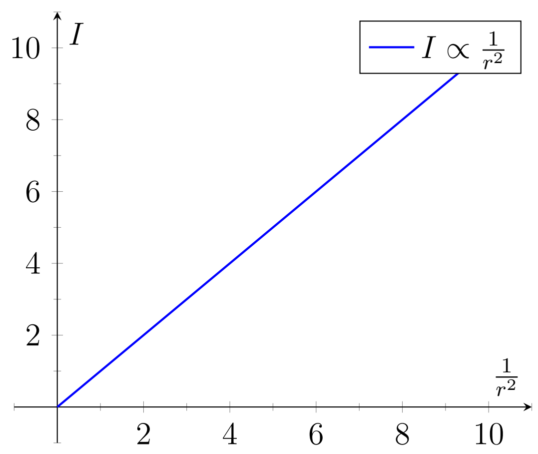
$$E \propto \frac{1}{r^2} \tag{5}$$

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.

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

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

Representative plot of I vs $\frac{1}{r^2}$



4 Tables

Table 1: Determination of Planck's constant and Work function

Colour	Wavelength (in nm)	Frequency$\times\frac{1}{10^{14}}$ (in sec^{-1})	Stopping Potential V_s (in V)
Red	640	4.6	$r_{10cm} = 0.077$, $r_{20cm} = 0.146$
Orange	670	5.2	$r_{10cm} = 0.172$, $r_{20cm} = 0.198$
Green	500	6	$r_{10cm} = 0.205$, $r_{20cm} = 0.255$
Blue	405	7.4	$r_{10cm} = 0.245$, $r_{20cm} = 0.341$

Table 2: Calculation of Planck's constant from graph

Slope, $\frac{\Delta V_s}{\Delta \nu}$ (in V.s)	Planck's constant, $e \times slope$ (in J.s)	Mean value $h = (h_1 + h_2)/2$
$m_1 = 1.37$	$h_1 = 2.192$	$h_{avg} = 2.28$
$m_2 = 1.48$	$h_2 = 2.368$	

Table 3: Calculation of Work function from graph

Intercept, $\frac{W}{e}$ (in J/s)	Work function, $e \times intercept$ (in J)	Mean value $W = (W_1 + W_2)/2$
$c_1 = 0.230$	$W_1 = 0.368$	$W_{avg} = 0.344$
$c_2 = 0.200$	$W_2 = 0.320$	

Table 4: Verification of inverse square law of radiation

Position of lamp and photo -cell		Current (μA)	
Distance between lamp and photo cell (r in cm)	$\frac{1}{r^2} \times 10^3$ (in cm^{-2})	Filter: Green	Filter: Orange
5	40	0.55	0.51
7	20	0.40	0.44
9	12	0.30	0.35
11	8	0.24	0.28
13	5	0.18	0.22
15	4	0.15	0.18

5 Final Result

So the value of Planck's constant is 2.28×10^{-34} J.s .
Work function of the material is 0.344 J.

6 Error Calculation

We know the value of Planck's constant is $6.626 \times 10{-}34$ J.s (h). In our experiment, the value comes out to be $2.28 \times 10{-}34$ J.s ($h_{exp)}$. So, percentage error,

$$
\begin{aligned}
\% \, error &= \frac{h - h_{exp}}{h} \times 100 \\
&= \frac{6.62 \times 10^{-34} - 2.28 \times 10^{-34}}{6.62 \times 10^{-34}} \times 100 \\
&= 65.5\%
\end{aligned}
$$