Planck's Constant

Aim:

To determine Planck's Constant 'h' by measuring radiation in a fixed spectral range.

Apparatus used:

The complete experimental arrangement as shown in figure (1) consists of filament bulb with a filter fitted to it, its power supply (0-12 V dc) , a Photo cell fitted on mini optical bench, one Ammeter (0- 2 A) and one voltmeter (0-10 V) to read filament current and voltage, one digital D.C. Microammeter (0-200 μA.).

Formula Used :

Planck's Constant 'h' can be calculated as:

$$h = 2.303\frac{\lambda_0 k}{c} * slope \quad , \qquad slope = \frac{\Delta \log \theta}{\Delta \frac{1}{T}}$$

Refer eq no (5) and eq. no. (6)

λ_0 = 6000A^0 (mean wavelength of light)

k = 1.38 x $10^{-2.3}$ Joules/Kelvin (Boltzmann's constant)

c = 3*10^8 meter/sec. (velocity of light)

θ = Current

T = Absolute Temperature

Theory:

Experiment aims at measuring radiation from a black body at different temperatures. All objects emit radiation above absolute zero. A black body is a theoretical object that absorbs 100% of the radiation that hits it. Therefore it reflects no radiation and appears perfectly black.
It also emits a definite amount of energy at each wavelength for a particular temperature. The black body radiation curve shows that the black body does radiate energy at every wavelength. At each temperature the black body emits a standard amount of energy. This is represented by the area under the curve.

1. Graph drawn below shows how the black body radiation curves change at various temperatures. These all have their peak wavelengths in the infra-red part of the spectrum as they are at a lower temperature.

2. As the temperature increases, the peak wavelength emitted by the black body decreases.

3. As temperature increases, the total energy emitted increases, because the total area under the curve increases.

4. The relationship is not linear as the area does not increase in even steps. The rate of increase of area and therefore energy increases as temperature increases.

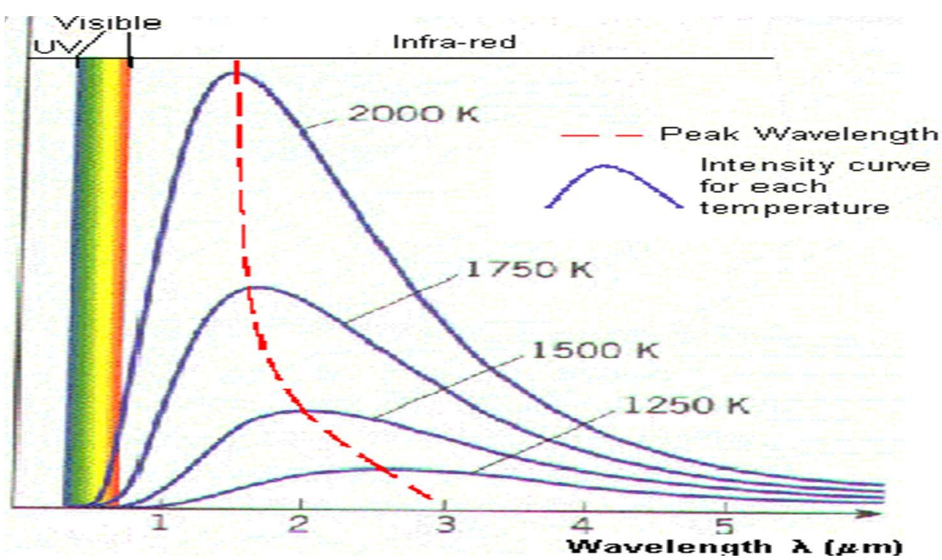


Figure 1

In 1900, the German Physicist Max Planck suggested that an atom can absorb or reemit energy only in discrete bundles (*quanta*). If the energy of these quanta are proportional to the radiation frequency, then at large frequencies the energy would similarly become large this put an effective cap on the high-frequency radiancy. Using this reinterpretation of the nature of energy, Planck found the following equation for the radiancy:

$$P_\lambda = \frac{2\pi hc^2}{\lambda^5\{e^{(hc/\lambda kT)} - 1\}}$$

P_λ=Power (per m² area per m wavelength) λ = Wavelength (m)
k = Boltzmann Constant (1.38 * 10^{-23} J/K) c = Speed of light (3*10^8 m/sec)
T = Temperature (K) h = Planck's constant (6.626 * 10^{-34} Js)

For a black body at temperature 'T' the total radiations as well as the spectral distribution for this radiation are functions of temperature T alone. The spectral distribution involves Planck's constant 'h'.

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}\left[\exp(\frac{hc}{\lambda kT}) - 1\right]^{-1} d\lambda \text{ ....(1)}$$

Working with visible light and temperature upto 2500 °K, we have $\frac{hc}{\lambda kT} >> 1$

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}\exp(-\frac{hc}{\lambda kT})d\lambda \text{ ....(2)}$$

If the radiation is received through a filter on a photocell connected to a microameter and its response $'\theta'$ is measured, we get:

$$\theta = 8\pi hcA\int \frac{B_\lambda}{\lambda^5}\exp(-\frac{hc}{\lambda kT})d\lambda \text{ ....(3)}$$

Where A is a factor depending on geometry of the arrangement and sensitivity of the galvanometer and B_λ is a function of λ which includes (i) transmission characteristics of the filter (T_λ) and (ii) wavelength wise response of the photocell (R_λ). The integral has to cover all range of λ for which B_λ is non zero.

If we have filter, which has, transmission characteristics schematically represented by figure 2 (a) and a photovoltaic cell with response schematically represented in figure 2 (b) then the B_λ function is given by product of ordinates (T_λ) and (R_λ) plotted against respective values of wavelength (λ) in fig 2(c).

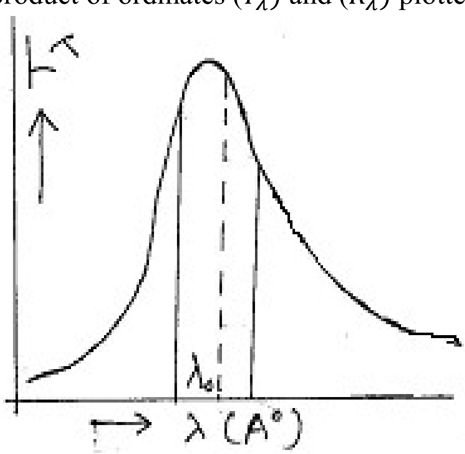


Figure 2(a)

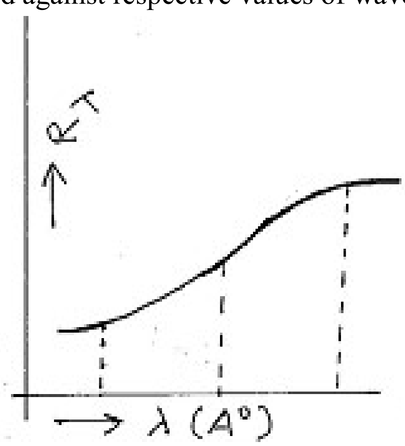


Figure 2(b)

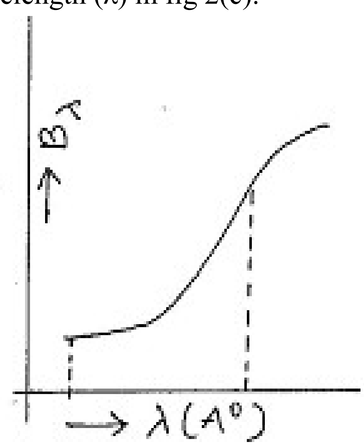


Figure 2(c)

However, if the filter has a narrow transmission band, one may drop the integral and reduce equation (3) to ,

$$\theta = 8\pi hcAC_{\lambda_0} \exp(-\frac{hc}{\lambda_0 kT})\Delta\lambda_0 \text{ ....(4)}$$

Where λ_0 is effective mean wavelength of filter, $\Delta\lambda_0$ is the effective band width for transmitting them through the filter and $C_{\lambda 0}$ is a constant depending on λ_0.

At two different temperatures T_1 and T_2 let the responses in microameter are θ_1 and θ_2, then

$$\frac{\theta_2}{\theta_1} = \exp\left[\frac{hc}{\lambda_0 k}(\frac{1}{T_1} - \frac{1}{T_2})\right] \text{..................................(5)}$$

where the constant A, B_λ and $\Delta\lambda_0$ all cancel out .

We note that unless the transmission band is narrow, the theory would not hold, further effective λ_0 is not just the center of transmission band of the filter, but it will be seriously affected by response curve of the photocell. In the photo voltaic cell the shift usually will be towards longer wavelength. Even more seriously, the term $\exp(-\frac{hc}{\lambda kT})$ increases rapidly with increasing λ . For T = 2000 °K, as we pass from λ = 5000 °A to λ = 7000 °A, this exponential term increases from exp (-3) to exp.(-2). This fact will also place effective λ_0 on the higher side of the mean transmission wavelength of the filter as the temperature (T) increases.

Within these limitations equation (5) gives

$$\log_e \theta = (\log_e 8\pi hcAC_{\lambda_0}) - (\frac{hc}{\lambda_0 k}\frac{1}{T})$$

Or,

$$2.303\log_{10}\theta = (2.303\log_{10} 8\pi hcAC_{\lambda_0}) - (\frac{hc}{\lambda_0 k}\frac{1}{T}) \text{ ....(6)}$$

Thus log θ vs 1/T graph should be a straight line from whose slope can be used to determine ‘h’.

The experimental task reduces to measure θ for different temperatures of the filament keeping the geometry and λ_0 constant.

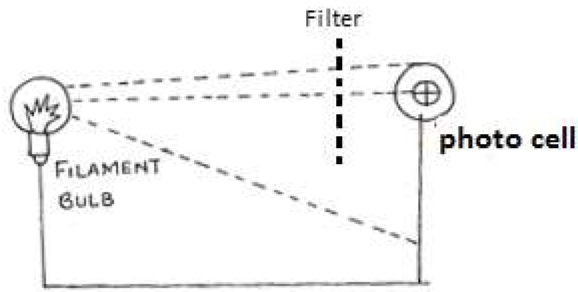


Figure 1(a)

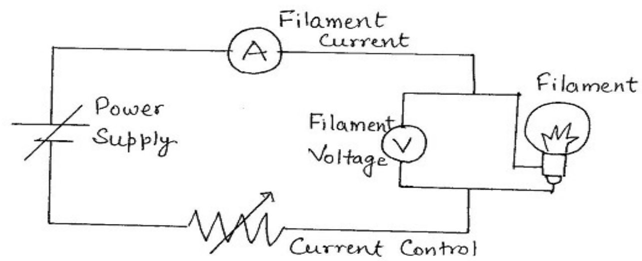


Figure 1 (b)

METHOD:-

(a) To determine the value of R_g and R_t/R_g with the V-I characteristics of Bulb.

1. To find R_g the resistance of the filament bulb when it just starts glowing: Connect the set-up with the mains and switched it ON. Apply filament current by the power supply control knob marked CONTROL on the panel such that the filament just starts glowing. Note the corresponding filament current and voltage and record these readings in table-I as shown below. Take at least three readings to the get the better' value of R_g.
2. To find R_t/R_g from the V-I characteristics of bulb: Further increase the filament current in steps of 0.1 amp. and note the corresponding values of filament voltage for each value of filament current. Record all these readings in table-II as shown below.
3. Calculate R_t and R_t/ R_g for each value of filament current and voltage.
4. Adjust the filament bulb at some distance 'd' from the solar cell on mini optical bench.

(b) Observations of θ and to determine the value of Planck's constant 'h'

5. Increase the filament current to such extent that the digital microammeter reads some photo-current say 2 μA to 3 μA. Note this value of filament current (I) and photocurrent (θ) and record it in table-III as shown below.
6. Increase the filament current in steps of 0.1 amp. As in previous case and note the corresponding photo-current for each value of filament current. Record these readings in table- III.
7. Note the value of $\mathbf{R_t/R_g}$ for each value of filament current from table-II and record these readings in table-III.
8. Note the corresponding temperatures for each value of R_t/ R_g from graph no I or table-IV for R_t /R_g vs
9. Temp T °K for tungsten.
9. Calculate $\log\theta$ and 1/T °K.
10. Plot graph between $\log\theta$ vs 1/T°K and find the slope of the curve.
11. Repeat the experiment for three values of 'd' between the bulb and solar cell.

Observations:

TABLE: -1 For Rg, the resistance of the filament when it just starts glowing.

S.NO.	Filament Current I (Amp.)	Filament Voltage V(Volts)	R_g(Ohms)	'Average R_g (ohms)
1				
2				
3				

Table-II For θ

For distance between the filament bulb and solar cell d_1, d_2 and d_3

Wavelength λ = 6000A^0

S. No.	Distance b/w the filament bulb and solar cell d	Filament current (I) Amp.	Filament voltage (V) volt	R_t=V/I (ohms)	Corresponding R_t/R_g from Table(I) .	Photo-Current 'θ ', μA	$\log\theta$	T°K (from graph-1) R_t/ R_g vs T°K	$\frac{1}{T}{}^oK^{-1}$
I	**d_1=……..cm**								
1									
2									
3									
..									
..									
II	**d_2=……..cm**								
1									
2									
3									
..									
..									
III	**d_3=……..cm**								
1									
2									
3									
..									
..									

Calculations:

From equation (6)

$$h = 2.303\frac{\lambda_0 k}{c} * slope$$

Where

λ_0 = 6000A^0 (mean wavelength of light)

k = 1.38 x 10^{-23} Joules/Kelvin (Boltzmann's constant)

c = 3*10^8 meter/sec. (velocity of light)

$$\frac{\Delta \log\theta}{\Delta(1/T)} = slope$$

Results:

1. The experimentally observed values of Planck's constant h = ...J-s.
2. The standard value of Planck's constant h =6.626 x 10^{-34} J-s

The experimentally observed value of (h) is always with in 10 to 15% of the standard value.

Table –III (No need of writing in Practical Note Book)

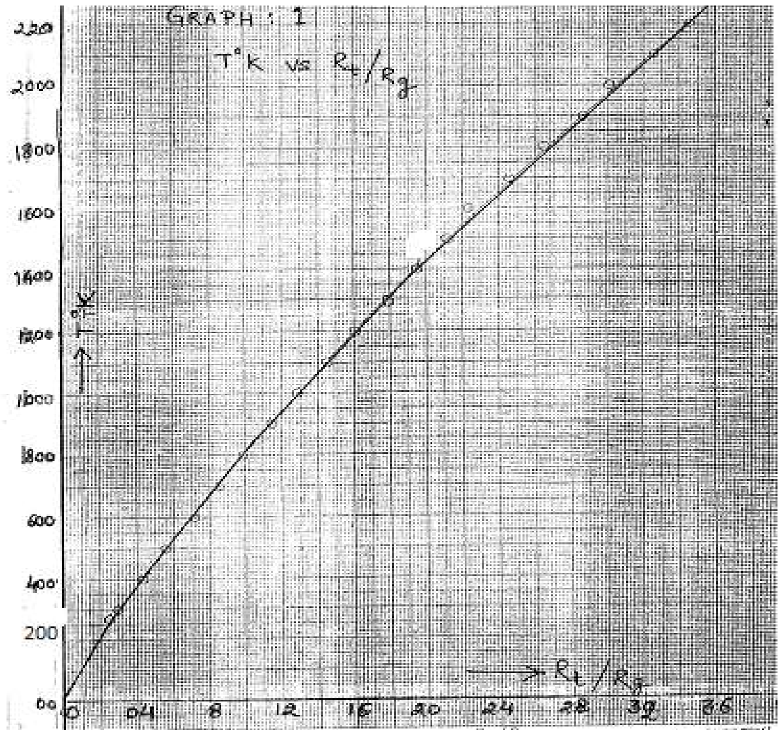
Relation Between R_t/R_g and Temperature(T) °K for Tungsten Filament.

S. No.	Temperature (K)	R_t/R_g	S. No.	Temperature (K)	R_t/R_g
01.	0273	0.25	11.	1200	1.61
02.	0300	0.29	12.	1300	1.79
03.	0400	0.43	13.	1400	1.95
04.	0500	0.55	14.	1500	2.11
05.	0600	0.71	15.	1600	2.30
06.	0700	0.85	16.	1700	2.46
07.	0800	0.99	17.	1800	2.65
08.	0900	1.15	18.	1900	2.85
09.	1000	1.29	19.	2000	3.05
10.	1100	1.45	20.	2100	3.26

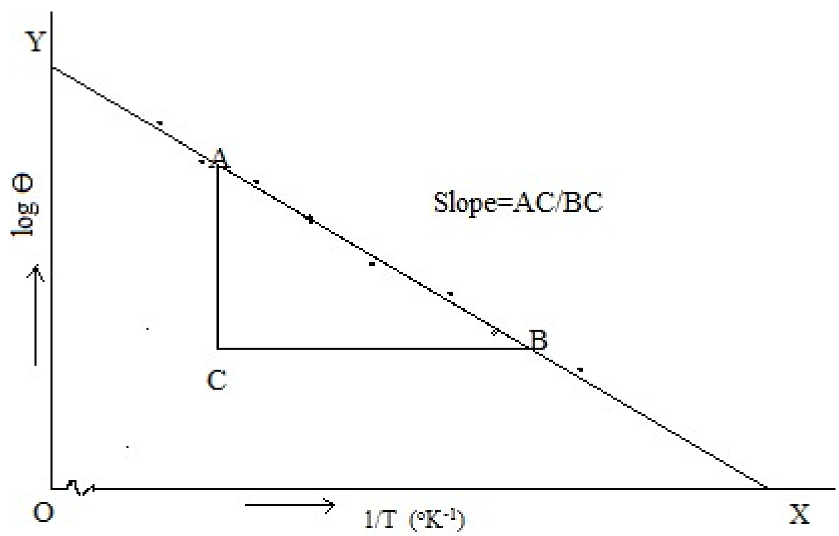
The above table is determined by the equation

$$\frac{R_t}{R_g} = \frac{1}{3.95}(1 + \alpha + \beta\, t + \beta\, t^2)$$

Where α and β are given for Tungston and R_g is the resistance of the filament when it start just glowing and '*t*' is the temperature in °C.



Graph 1



Graph 2