Determination of refractive index of a dispersing triangular prim for spectroscopic applications

Aim: Given the angle of the prism, aim of the experiment is to determine the angle of minimum deviation of the prism and hence calculate its refractive index.

Apparatus Required:

Spectrometer, Given Prism, Mercury Vapour lamp, etc.

Formula Used:

Refractive index (μ) of the prism is given by

$$\mu = \frac{\sin \frac{\alpha + \delta}{2}}{\sin\left(\frac{\alpha}{2}\right)}$$

where α is the angle of prism

δ is the angle of minimum deviation

Theory:

Refraction by a prism:

In a prism, the two surfaces are inclined at some angle α so that the deviation produced by the first surface is not annulled by the second but is further increased. The chromatic dispersion is also increased, which is the main function of the prism. Let us consider first the geometrical optics of the prism for a monochromatic light source.

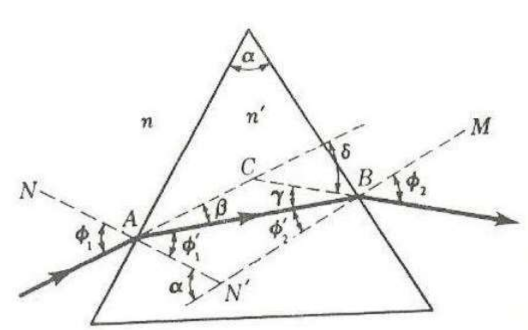


Fig. 1

The solid ray in fig. 1 shows the path of a ray incident on the first surface at the angle φ_1. Its refraction at the second surface, as well as at the first surface, obeys Snell's law, so that in terms of the angles shown

$$\frac{\sin\varphi 1}{\sin\varphi 1'} = \frac{n'}{n} = \frac{\sin\varphi 2}{\sin\varphi 2'}$$

The angle of deviation produced by the first surface is $\beta = \varphi 1 - \varphi 1'$, and that produced by the second surface is $\gamma = \varphi 2 - \varphi 2'$. The total angle of deviation δ between the incident and emergent rays is given by $\delta = \beta + \gamma$.

Since NN' and MN' are perpendicular to the two prism faces, α is also the angle at N'. From triangle ABN' and the exterior angle α, we obtain $\alpha = \varphi 1' + \varphi 2'$.

Combining the above equations, we obtain

$$\delta = \beta + \gamma = \varphi 1 - \varphi 1' + \varphi 2 - \varphi 2'$$

$$= \varphi 1 + \varphi 2 - (\varphi 1' + \varphi 2')$$

$$\delta = \varphi 1 + \varphi 2 - \alpha$$

Minimum Deviation:

When the total angle of deviation δ for any given prism is calculated by the use of the above equations, it is found to vary considerably with the angle of incidence. The angles thus calculated are in exact agreement with the experimental measurements. If during the time a ray of light is refracted by a prism, the prism is rotated continuously in one direction about an axis (A in fig.1) parallel to the refracting edge, the angle of deviation δ will be observed to decrease, reach a minimum, and then increase again as shown in fig. 2.

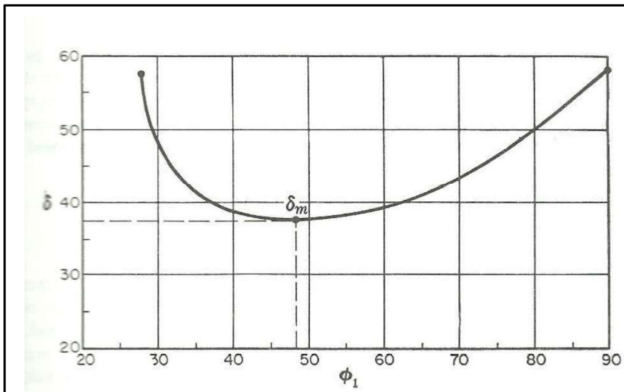


Fig. 2

The smallest deviation angle, called the angle of minimum deviation δ_m, occurs at that particular angle of incidence where the refracted ray inside the prism makes equal angles with the two prism faces (Fig. 3). In this special case,

$$\varphi 1 = \varphi 2; \qquad \varphi 1' = \varphi 2'; \qquad \beta = \gamma$$

To prove these angles equal, assume $\varphi 1$ does not equal to $\varphi 2$ when minimum deviation occurs. By the principle of the reversibility of light rays, there would be two different angles of incidence capable of giving minimum deviation. Since experimentally we find only one, there must be symmetry and the above equalities must hold.

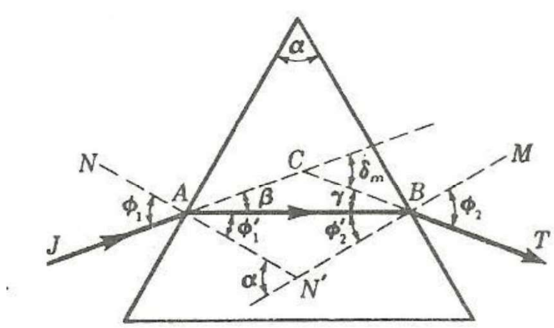


Fig. 3

In triangle ABC in fig. 3, the exterior angle δ_m equals the sum of the opposite interior angles $\beta + \gamma$. Similarly for the triangle ABN', the exterior angle α equals the sum of $\varphi 1' + \varphi 2'$. Consequently, $\alpha = 2\varphi 1'$; $\delta_m = 2\beta$; $\varphi 1 = \varphi 1' + \beta$

Solving these three equations for $\varphi 1$ & $\varphi 1'$ gives $\varphi 1' = (½)\alpha$ and $\varphi 1 = (½)(\alpha + \delta_m)$

Since by Snells's law $n'/n = (\sin\varphi 1)/(\sin\varphi 1')$, we have

$$n'/n = \sin[1/2(\alpha + \delta))] / \sin[1/2\,\alpha] = \mu$$

Here, for mathematical representation, δ is equated to δ_m

Procedure:

(a) Following **preliminary adjustments** should be made before starting any experiments with the spectrometer.

(i) ***Focusing the eyepiece on the cross-wires:*** The telescope is turned towards the wall and by looking through the eye-piece, its positions are adjusted till the vertical and horizontal cross-wires are seen most distinctly.

(ii) ***Adjusting the telescope for parallel rays:*** The telescope is then turned towards a distant object and by means of the rack and pinion arrangement, the length of the telescope is carefully adjusted till the image of the distant object coincides, without parallax, with the cross-wires.

(iii) ***Adjusting the collimator for parallel-rays:*** The telescope is then brought in line with the collimator. The slit is opened sufficiently wide and illuminated by any source of light. The image of the slit is viewed through the telescope, and the length of the collimator is adjusted till the clear, well-defined image of the slit coincides without parallax with the cross-wires. Since the telescope is already adjusted for parallel-rays, the well-defined image of the slit can be formed at the cross-wire, only if the rays of light from the slit falling on the telescope are parallel. The width of the slit is adjusted to make the image sharp.

(iv) ***Levelling the prism table:*** Spirit level is used to level the prism table. Spirit level is placed between the adjacent screws on any one side and then the screws are adjusted such that the liquid level stays in the centre of the spirit level. Same procedure is repeated by placing the spirit-level on the sides corresponding to other two adjacent screws. Finally, the liquid level should be in the centre of the spirit-level in all the sides.

(b) To determine the angle of minimum deviation:

Having made the preliminary adjustments, the given prism is mounted vertically on the prism table with the edge of the prism turned away from the collimator, as shown in the fig. 4. On looking through the prism in the proper direction, the refracted image of the slit is seen. The telescope is adjusted to obtain this image in its field of view. The prism table (and therefore also the prism) is then slightly rotated in either directions, with the view to finding out the direction in which the prism should be rotated in order to decrease the angle of deviation. The prism table is then slowly rotated in this direction, following the image with the telescope. In a particular position, the image is found to remain stationary for the same direction as before, to turn back and move in the opposite direction. The position where it just turns back is the minimum deviation position and the telescope is fixed in this position, and finer adjustments are made with the tangential screw for the exact position. The readings of the scale and vernier are taken. The prism is then removed. The telescope alone is then released, brought in a line with the collimator and the direct reading is taken. The difference between these two readings gives D, the angle of minimum deviation.

Having determined α & δ, the refractive index of the prism is calculated from the formula,

$$\mu = \frac{\sin\frac{\alpha+\delta}{2}}{\sin\left(\frac{\alpha}{2}\right)}$$

Experiment is repeated for **atleast three different wavelengths** and the refractive index of the prism is calculated corresponding to all these three wavelengths.

Result:

The Refractive index (μ) of the given prism is calculated to be …………

Tabulations:

Angle of prism =

(i) Wavelength of light =

Least count of spectrometer = 0.5°

	Vernier I			Vernier II		
	MSR	**VSC**	**TR**	**MSR**	**VSC**	**TR**
Reading of Refracted Image (i)						
Reading of Direct Ray (ii)						
Difference between (i) & (ii) (D)						
Mean Value of D						

Figure 4 - Schematic Representation for angle of minimum deviation

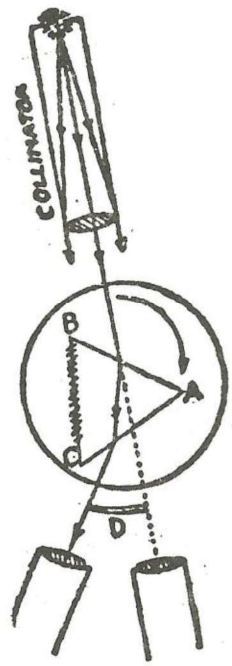


Fig. 4

Determination of Planck's constant using electroluminescence process

Aim: To determine the value of Planck's universal constant using LEDs.

Apparatus: LEDs, digital voltmeter, micro-ammeter, and ten turn linear potentiometer.

Principle: LED is a p-n junction and it works on the principle of electro-luminescence; a phenomenon in which materials emit light in response to the passage of electric current. The primary carriers in p and n-type semiconductors are holes and electrons respectively. When a junction is formed from these materials, free electrons near the junction diffuse across the junction into the P region and combine with holes. Filling a hole makes a negative ion and leaves behind a positive ion on the N side. These two layers of positive and negative charges form the depletion region; the region depleted of charge carriers. As electrons diffuse across the junction a point is reached where the negative charge repels any further diffusion of electrons; thus forming a potential barrier. External energy must be applied to get the electrons to move across the barrier of the electric field. The potential difference required to move the electrons through the electric field is called the barrier potential. Barrier potential, V_o of a PN junction depends on the type of semiconductor material, amount of doping and temperature. In an LED, the PN junction is used in forward bias condition which helps in injecting large number of electrons with additional potential energy required to overcome the barrier potential thus leading to large flow of current through the junction. The recombination of electrons in the conduction band with the holes of the valence band results in release of photons and the wavelength of the light emitted depends on the band gap of the semiconductor material used in the LED.

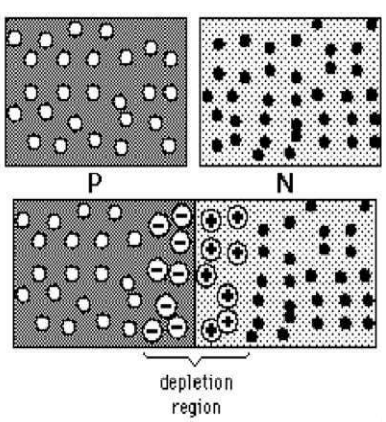


Fig. 1 Formation of Depletion Layer in a p-n junction

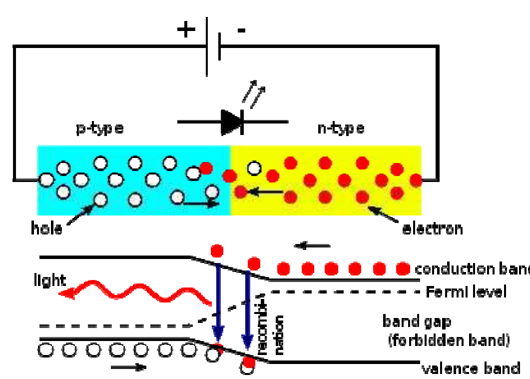


Fig. 2 The foward-bias of the p-n junction leads to large current. The energy diagram below shows the recombination of electrons and holes producing photons

From the conservation of energy,

$E=eV_o$ (electron) $=h\nu= h(c/\lambda)$ (photon)

$h=(eV_o\lambda)/c$ (1)

Where e and h are the charge of electron and Planck's constant respectively while λ and ν , are the wavelength or the color and the frequency of the photons emitted from the LED.

The Eq. (1) can also be expressed as $V_o = \frac{hc}{e}\lambda^{-1}$ (2)

Therefore, the value hc/e and hence the Planck constant, h can be obtained from the slope of V_o-λ^{-1} curve which can be obtained from the V_o values obtained for each LED from its V-I plots. The V-I plot for four different LED's is obtained and the V_o-λ^{-1}curve is obtained from the barrier potential V_o obtained from V-I plot of each LED. If the linear portion of the V-I plot is extrapolated back to x-axis the intercept represents the barrier potential (the potential above which, I becomes independent of V).

Circuit: The LED circuit is shown in Fig. 3 and it consists of 5V supply; a ten turn potentiometer to vary voltage across the LED from 0 to 5 V that is measured using voltmeter and an ammeter to measure current through the LED. A 33 kΩ resistor is connected in series with the LED (find out why).

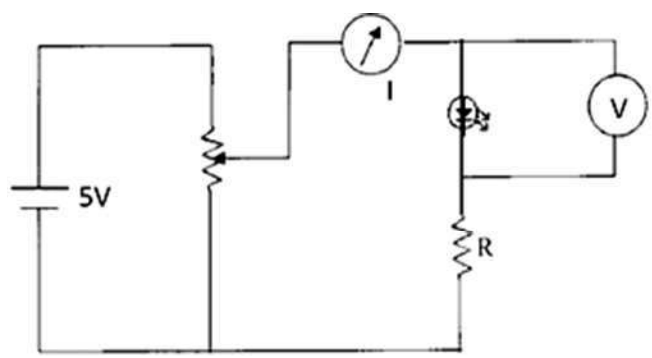


Fig. 3 Circuit diagram

Procedure:

1. Connect an LED (you have been given four LEDs) to the jack provided on the front panel and switch on the unit.
2. Vary the voltage V (decide the appropriate step size) across the LED and note the corresponding current I and tabulate as shown in Table 1 for V-I characteristic of LED.
3. Repeat step 2 for the remaining LEDs.
4. Plot the V (along x-axis)-I (along y-axis) characteristics of all the LEDs on a single graph sheet and obtain the V_o for each LED
5. Enter the values in Table 2.
6. Plot a graph of voltage V_o versus $1/\lambda$ for LED's of different wavelength and determine the slope (=hc/e) of the line. Calculate h using standard values of c and e.
7. Calculate the slope also using least square fit method:

   $slope = \frac{N\sum x_i y_i - \sum x_i \sum y_i}{N\sum x_i^2 - (\sum x_i)^2}$ where N is the number of points. From the slope

obtain the value of h.

Table-1 : I-V Characteristics of 4 different LEDs

	Colour		Colour		Colour		Colour	
Sl. No.	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)	**V** (volts)	**I** (mA)

Table 2 : Barrier Potential Vs. inverse of wavelength of the photons emitted.

Sl. No.	LED color	Wavelength λ (nm)	$1/\lambda$ (nm -1)	Barrier Potential V_o

Slope of the $1/\lambda$- V_o curve (hc/e) : S =
Coefficient (c/e) : C=
Planck Constant S/C : h=

Result: The value of Planck's constant was found to be ______________________

Conclusions

Hint for Error Analysis: Estimate the error in V at which I become nearly independent of V.

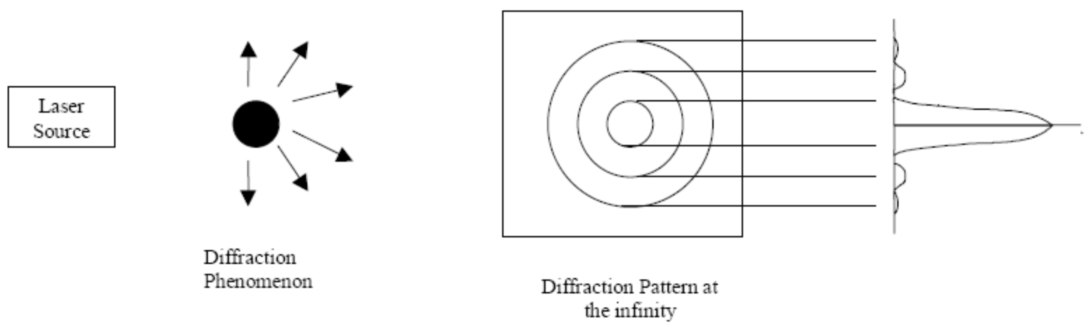
Questions

1. Suggest a method to measure h without using the value of any other universal constant.
2. Identify the sources of systematic errors and random errors
3. Speculate the consequences if h were zero in our universe.
4. How is h useful to engineers?
5. Can you make LED like device using metals?
6. Can we think of LED as a device which annihilates mass (electron) to give energy (photon)?
7. Principle explained above is rather over-simplified. Please look to a textbook on semiconductor devices (Streetman, S. M Ze) to obtain more information on energy diagram of LED.

DETERMINATION OF SIZE OF FINE PARTICLE USING LASER DIFFRACTION

Aim: To find particle size from laser diffraction pattern

Principle: This method is based on diffraction phenomenon and is based on Fraunhofer theory. When a particle is lightened by a monochromatic source (laser source), a diffraction pattern, called Airy`s pattern is obtained at the infinity.



This diffraction pattern gives the light scattering intensity (I), in the function of diffraction angle. It is composed of concentric rings. The distance between the different rings depends on the particle size. The size (***D***) of the particle is

$$D = 1.22\lambda\, n \frac{d}{r}$$

where λ is wavelength of source, ***n*** is order of dark ring, ***d*** is distance between particle and the screen, r is the radius of the dark ring. The factor 1.22 is derived from a calculation (Bessel function) of the position of the first dark ring surrounding the central Airy disc of the pattern.

Assumptions:

1. Particles are spherical in nature and they do not absorb light
2. Particle diameter must be at least 3-5 times bigger than the λ –value (normally μm size)
3. The distance between 2 particles must be 3-5 times bigger than their diameter

Procedure:

1. Place the imprinted diameter screen at the edge of the measuring bench.
2. Keep the glass plate (having particle of uniform diameter dispersed on it) in between the laser source and screen.
3. Adjust the relative positions of laser and glass plate to get clear concentric circular rings of bright and dark fringes on the screen
4. For three different position of glass plate with respect to screen estimate the diameters of first and second order fringes

Data Table: To find the size of particle

Sl. No.	Order of diffraction	d (cm)	Diameter of dark ring (cm)	Radius of dark ring, r (cm)	Size of particle, D (μm)
1	1				
	2				
2	1				
	2				
3	1				
	2				

Mean D value =

Suggestion: It is better to adjust distance (d) to make one of the two dark rings match with imprinted diameter and make approximation in the size of diameter of other ring.

Result:

Interpretations:

Error estimation: Analysis should be done for diameter estimation by standard deviation process for one position of ***d*** and measuring diameter of first dark ring for at least for 10 times.