Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

DEPARTMENT OF PHYSICS

SCHOOL OF ADVANCED SCIENCES

VELLORE INSTITUTE OF TECHNOLOGY, VELLORE

LAB MANUALS

ENGINEERING PHYSICS LAB

(BPHY101P)

Steps to be followed by the students, while preparing the laboratory report

Prior preparation

1. Objective of the experiment :
2. Apparatus Required :
3. Formulae
4. Schematic diagram(s)
5. Model graph(s)
6. Table

During the lab session

7. Observations
8. Calculations

Before the due date

9. Inferences

Results and discussion

Submission of soft copy of the report in VTOP

Sonometer

Objective

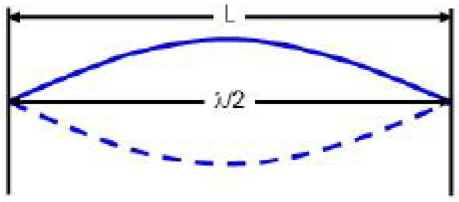
To determine the fundamental frequency (1st harmonic) of a stretched string, fixed at two ends and frequency of the AC source.

Apparatus to be used

- A sonometer with a magnetic wire stretched over it.
- An Electromagnetic coil
- Two sharp edge wedges
- Weights and weight hanger

Basic theory

In the fundamental mode of vibration of a stretched string, fixed at two ends, the wavelength (λ) of the wave so produced and the length of the wire (l) are connected by, $\lambda/2 = l$; or $\lambda = 2\,l$. ……....(1)



For a flexible and elastic wire, the velocity of wave propagation (v) in the wire is given by

The fundamental frequency (1st harmonic) ***n***, of a stretched string, fixed at two ends is given by

$$\boldsymbol{v} = \sqrt{\frac{T}{\mu}}\,. \qquad \text{………………..(2)}$$

T is the tension in the wire and μ is the mass per unit length of the wire.

The velocity of propagating wave (v) can be expressed in terms of it's wavelength and frequency as,

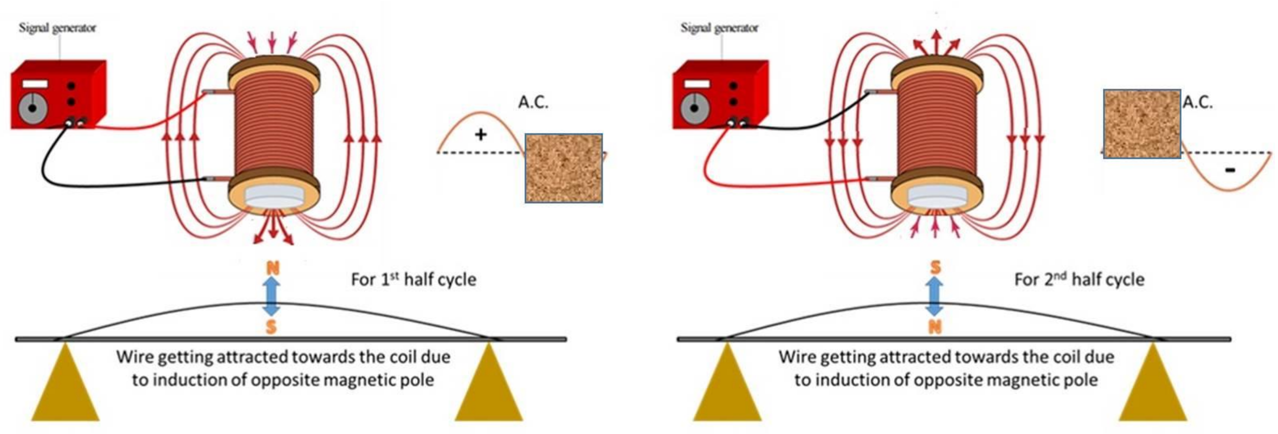
$$v = \lambda\, n. \qquad \text{…………………….(3)}$$

Hence, the frequency of the fundamental mode of vibration of a stretched string, fixed at two end is given by,

$$\boldsymbol{n} = \frac{1}{2l}\sqrt{\frac{T}{\mu}}. \qquad \text{……………….(4)}$$

When an alternating current is passed in the electromagnetic coil, the magnetic field produced in the coil is proportional to the instantaneous value of current passing through it. This electromagnetic coil is placed in such a way that the magnetic wire on the sonometer experiences the force of magnetic field twice in every full cycle of the alternating current and hence alternating magnetic field (as shown in the figure below).

Because the wire will be pulled twice in every cycle, at resonance, the wire will vibrate with a frequency twice that of the frequency of the alternating current in the coil.



So, the frequency of the alternating current (***f***) in the coil is half of the frequency of the wire in it's fundamental mode. i.e $f = \frac{1}{4l}\sqrt{\frac{T}{\mu}}$. ……………….(5)

From eq (4), $4n^2l^2\mu = T$ or $l^2 = \frac{1}{4n^2\mu}$. T ……………….(6)

If a graph is plotted between l^2 on y-axis and T on x-axis, it will be a straight line with slope equal to $\frac{1}{4n^2\mu}$. From the values of slope, ***n*** can be calculated with the help of equation

$$n = \frac{1}{\sqrt{4\mu\,(slope)}}$$ ……………….(7)

and hence the frequency of alternating current $f = n/2$.

The sources of errors in this measurement are

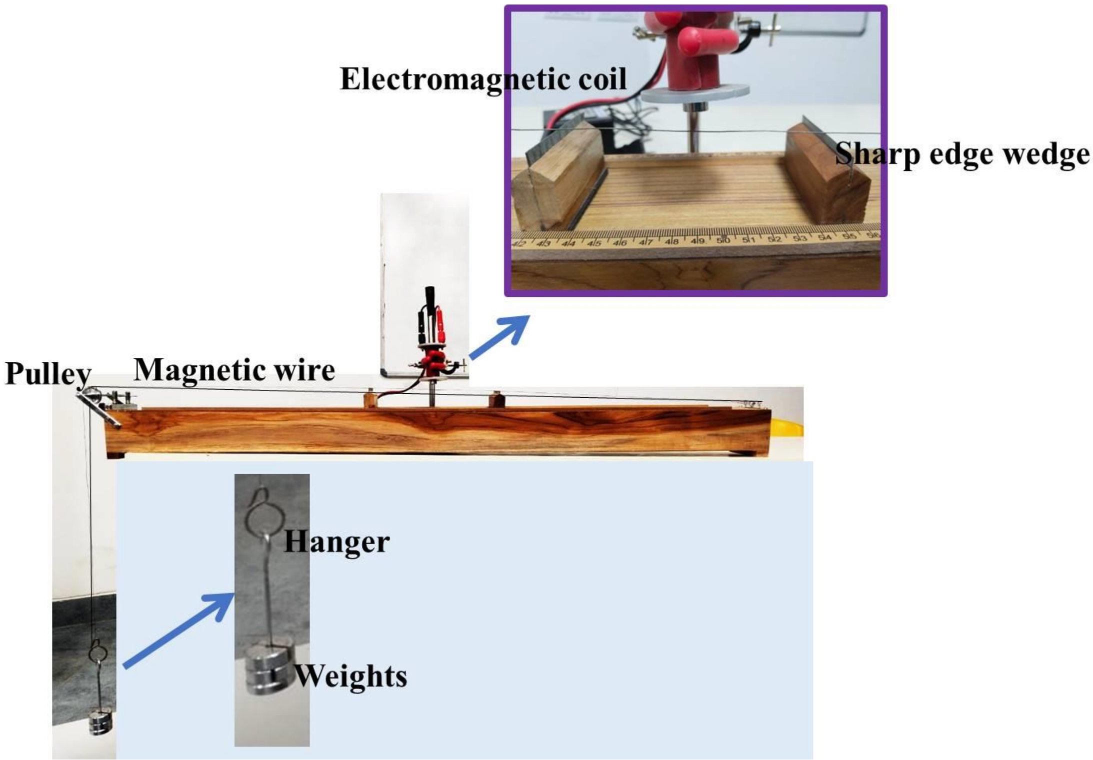
(1) Friction between the pulley and the magnetic wire passing over it. Because of this, the values of tension acting on the wire will be estimated less than that of the actual tension.
(2) Instability in the frequency of AC supply.

The error in the measurement can be estimated as follows.

% error in frequency of alternating current = $\frac{\text{Actual value} \sim \text{calculated value}}{\text{Actual value}} \times 100$.

Procedure

1. Set up the sonometer by carefully stretching the wire and adding a load on the hanger.
2. Adjust the position of electromagnetic coil in such a way it's pole lies close to the middle of the sonometer wire.
3. Switch ON the AC source and adjust the length of the vibrating portion of the wire by varying the positions of the wedges on both sides until the amplitude of the vibrating portion of the string reaches a maximum.
4. Measure the vibrating length and make a note of the tension in the string.
5. Increase the weight in steps (100 g) and repeat the measurement of vibrating length for every values of change in weight.
6. Make a note of the mass per unit length of the sonometer wire used.
7. Switch OFF the AC supply and remove the weights from the hanger.



Precautions

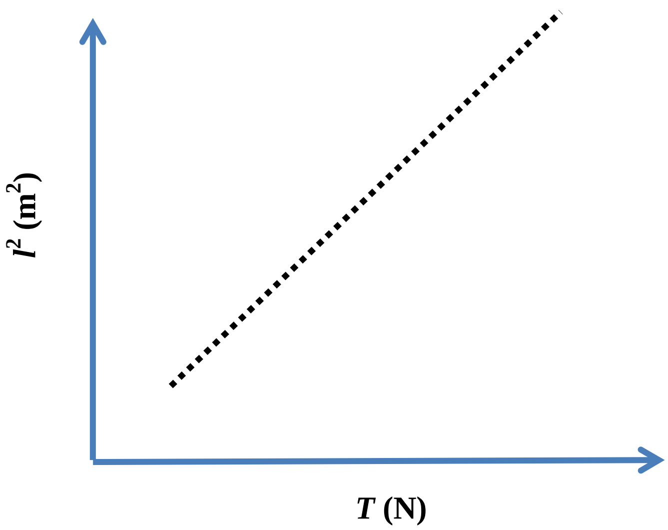
- ✓ Pulley should be as frictionless as possible.
- ✓ Edges of the wedge should be sharp.
- ✓ Tip of the electromagnetic coil should be close to the middle of the sonometer wire.
- ✓ The sonometer wire should not have any bends or kinks.

Observations

- Mass per unit length of the wire, μ = …. g/cm = …..kg/m.
- Acceleration due to gravity, g = …..m/s^2.
- **Table**

Sl. No.	Load (kg)	Tension T= mg (N)	Resonant length l (m)		Mean l (m)	$n = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ (Hz)
			Trial-1 (m)	Trial-2 (m)		

Model graph



Calculations

1. For each set of T and l, calculate the value of n using the formula and find the mean of these values.
2. Plot a graph of l^2 Vs. T (l^2 on the y-axis and T on the x-axis). Determine the slope of the graph and n.

Results

1. The graph of l^2 Vs. T is a straight line, with the slope $\frac{1}{4n^2\mu}$ = ……..
2. Frequency of the stretched string in the fundamental mode (n) from calculations …… and from the graph ……….
3. Frequency of the AC supply (f) from calculations …… and from the graph ……….

Inferences/Conclusions

1. ……………………………………………….
2. ……………………………………………….
3. ……………………………………………….

Questions on related concepts (Self-assessment)

1. What is the difference between AC and DC?
2. How does the magnetic field generated by the electromagnetic coil look like (schematic drawing)?
3. What is the force that makes the sonometer wire to vibrate?
4. Why do we need two wedges to perform this experiment?
5. Why is the electromagnetic coil preferably placed in the middle of the two wedges?

Determination of Planck's constant and work function of a metal using Photoelectric Effect

Objective

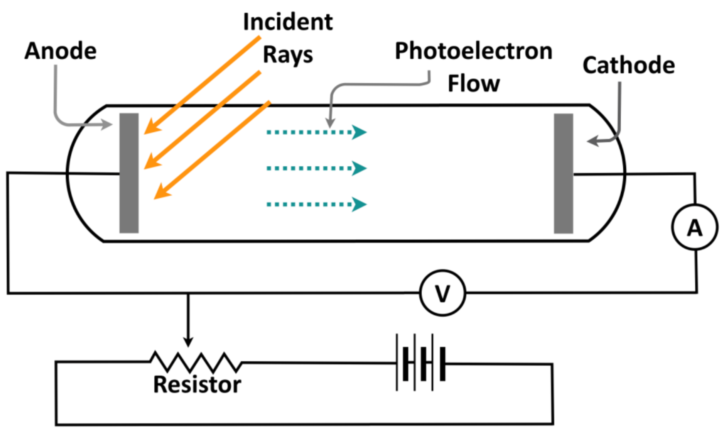
To determine Planck's constant and work function of a given metal using the photoelectric effect.

Apparatus to be used

Photoelectric equipment, filters of different colours

Basic theory

It was observed as early as 1905 that most metals emit electrons when their surface is irradiated with radiation. This phenomenon of emission of electrons from the metal surface exposed to the light of suitable frequency is known as the photoelectric emission/photoelectric effect. The electrons emitted in this process are known as photoelectrons, and the current constituted by these electrons is known as photoelectric current. The basic experimental set up explaining the photoelectric effect is given below.



The detailed study of this effect has shown:

1. That the emission process depends strongly on the frequency of radiation.
2. For each metal, a critical frequency exists such that light of lower frequency cannot eject electrons, whilst light of higher frequency always does irrespective of light intensity.
3. The emission of electrons occurs within a very short time interval after the arrival of the radiation
4. The number of electrons is directly proportional to the intensity of this radiation.

The experimental results obtained from this experiment are among the most substantial evidence which prove that the electromagnetic radiation is quantized, and each quanta consisting of packets of energy, $E = h\nu$, where ν is the frequency of the radiation and h is Planck's constant. These quanta are called photons.

Further, it is assumed that electrons are bound inside the metal surface. The minimum energy required to eject the electrons from the metal surface is known as the work function (W) of the metal. The work function can be expressed in terms of radiation frequency as:

$$W = h\nu_0 \quad (1)$$

where h is the Planck's constant and ν_0 is the threshold frequency (minimum frequency for photoelectric effect). It then follows that if the frequency (ν) of the light (photon) is such that

$h\nu > h\nu_0$, it will be possible to eject photoelectron, while if $h\nu < h\nu_0$, it would be impossible. In the former case, $h\nu > h\nu_0$, the excess energy of light will appear as the kinetic energy of the ejected electron. According to Einstein, the photoelectric equation must obey the following equation:

$$h\nu = KE + W \quad (2)$$

where $h\nu$ is the energy of the incident photon, KE is the kinetic energy of the ejected electron (photoelectron), and W is the work function of the given metal. If we apply a retarding potential to stop the flow of these photoelectrons completely, it is known as stopping potential, V_s. The maximum kinetic energy of the photoelectron is equal to charge of the electron (e) times the stopping potential, i.e. $KE = eV_s$ and the Eq. (2) can be written as:

$$h\nu = eV_s + W \quad (3)$$

Further on rearranging Eq. (3), we obtain the expression of stopping potential:

$$h\nu = eV_s + W \quad (4)$$

$$eV_s = h\nu - W \quad (5)$$

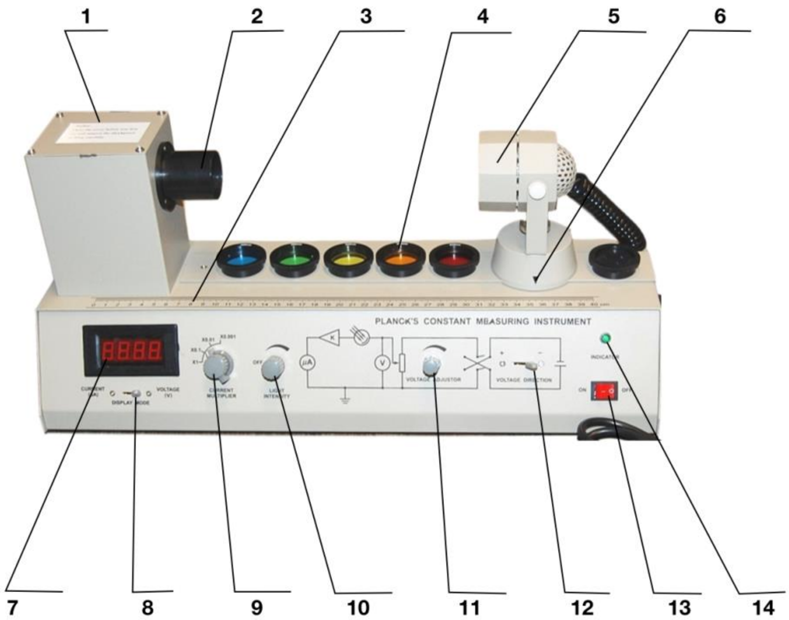
$$V_s = \frac{h}{e}\nu - \frac{W}{e} \quad (6)$$

The above equation represents a straight line $y = mx + c$. So, when we plot a graph V_s as a function of frequency (ν), the slope of the straight line will be $m = \frac{h}{e}$ and the intercept of the extrapolated point at $\nu = 0$ gives the work function of the given Metal. Further, the value of Planck's constant can be established from the obtained slope.

Work functions of certain metals are given as an example in the below table for reference:

Metals	Work Functions (eV)
Platinum (Pt)	6.4
Silver (Ag)	4.7
Sodium (Na)	2.3
Potassium (K)	2.2
Caesium (Cs)	1.9

Procedure



The structure of the experimental set-up and its basic functionalities are demonstrated as:

1. Vacuum Phototube. The sensitive component.
2. The removable forepart is used to install the colour filters and a focus lens fixed in the back end.
3. A scale of 40 cm in length. The centre of the vacuum phototube is used as the zero point.
4. Colour filter Set. Five pieces
5. Light Source, 12V/35W halogen tungsten lamp.
6. To move the light source to adjust the distance between the light Source and the vacuum phototube.
7. Digital Meter. Show current (μA), or voltage (V).
8. Display mode switch. For switching the display between voltage and current.
9. Current Multiplier.
10. Switch to adjust the appropriate intensity of incident light.
11. Accelerate voltage adjustor. Knob for adjusting accelerate voltage.
12. Voltage direction switch. Switch for choosing stopping potential.
13. Power switch.
14. Power indicator.

For determination of Planck's Constant and work function:

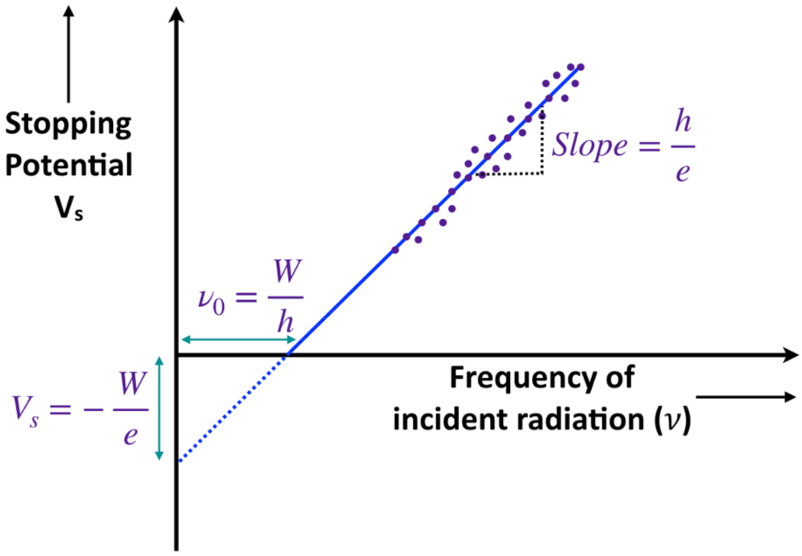
1. Adjust the distance between the Light Source enclosure and the Photodiode enclosure so that the general spacing is between 20.0 cm to 40.0 cm. NOTE: The recommended distance is 25.0 cm. (3 & 6)
2. Turn ON the light source by pressing the power switch (13). Make sure the power indicator (14) turns green LED On.
3. Allow the light source and the apparatus to warm up for 10 minutes.
4. Insert the red colour filter (635 nm) into the port (2), set the light intensity switch (10) at strong light for an appropriate photocurrent, voltage direction switch (12) at '+', accelerating voltage knob (11) at the minimum position and display mode switch (8) at current display.
5. Set the current multiplier switch (9) for a suitable amount of current on display.
6. Set the voltage direction switch (12) at '-', then increase the de-accelerating voltage using the knob (11)to decrease the photocurrent to zero.
7. Measure the de-accelerating voltage/stopping potential (Vs) corresponding to zero current of 635nm wavelength by setting the switch (8) into Voltage display mode.
8. Repeat steps 4-6 for other colour filters of different wavelengths and measure the corresponding stopping potential.
9. Once all measurements are done, remove the colour filters, Put back the blank cap to nozzle (3), Set the voltage direction switch (12) at '+', the accelerating voltage knob (11) to zero, switch (8) to current display mode, and TURN-OFF the power switch (13).
10. Return the colour filters.
11. Do the calculation and plotting figures from the obtained experimental data.

Observations

Sl. No.	Incident Photon Wavelength (Filters)	Frequency (Hz) $\nu(sec^{-1} \times 10^{14})$	Stopping Potential (V_s in Volts)
1	Red (635 nm)		
2	Orange (570 nm)		
3	Yellow (540 nm)		
4	Green (500 nm)		
5	Blue (460 nm)		

Model graph

1. Plot a graph of Stopping Potential (V_s) versus Frequency ($\nu \times 10^{14}$ Hz).
2. Find the slope of the best-fit line through the data points on the graph.



Calculations

From the graph V_s vs ν we can get the value of slope and the intercept

$$Slope = \frac{h}{e}$$

$$h = Slope \times e$$

$$h = \frac{\Delta V_s}{\Delta \nu} \times e$$

Substituting the values of ΔV_s and $\Delta \nu$ from the graph, the Planck's Constant (h) can be calculated as, h = ………………Joule-sec.

Standard value of $h_0 = 6.626 \times 10^{-34}$ Joules-sec.

Again, from the same graph, the intercept at $\nu = 0$, can be calculated

Work function of metal, $W = intercept\ on\ y - axis \times e =$ ………….. eV

Compare your calculated value of Planck's Constant, h to the standard value, $h_0 = 6.626 \times 10^{-34}$ Joules-sec. The error % can be calculated as:

$$\%\ \mathbf{Error} = \left|\frac{h - h_0}{h_0}\right| \times 100$$

Results

1. Planck's constant 'h' is found to be h = ...J-sec
2. Work function of the given metal found to be, W = ………eV

Inferences/Conclusions

1. ……………………………………………..
2. ……………………………………………..
3. ……………………………………………..

Precautions

1. This instrument should be operated in a dry, cool indoor space.
2. The instrument should be kept in a dust- and moisture-proof environment; if there is dust on the phototube, colour filter, lens, etc., clean it using absorbent cotton with a few drops of alcohol.
3. The colour filter should be stored in a dry and dust-proof environment.
4. Do not play with the knobs for random movements.
5. Do not put scratch marks on colour filters
6. While applying the negative potential, move the knob slowly and wait 2 secs after each move.
7. After finishing the experiment, remember to switch off the power (14) and cover the drawtube (2) with the lens blank cover provided. Phototube is a light-sensitive device, and its sensitivity decrease with exposure to light and due to aging.

Questions on related concepts (Self-assessment)

Q1. What are the applications of photoelectric effect?

Q2. What is the significance of work function?

Q3. Are all the metals useful for photoelectric effect? Justify your answer.

Q4. Why photoelectric effect cannot be explained by classical physics?

Q5. What will be the stopping potential if intensity is tripled?

Q6. Explain the relationship between the intensity of radiation and photoelectric current.

Q7. What is the difference between photoelectric current and photocurrent?

Q8. How does light intensity affect the Stopping Potential?

Q9. How does your calculated value of h compare to the accepted value?

Q10. What do you think may account for the difference – if any – between your calculated value of h and the accepted value?

Further references

1. https://javalab.org/en/photoelectric_effect_2_en/ (Simulation)
2. https://applets.kcvs.ca/photoelectricEffect/PhotoElectric.html# (Simulation)
3. https://youtu.be/kS4ECdzONfE
4. https://youtu.be/5QRR0JIzSX4
5. https://drive.google.com/file/d/10pespgTuNxCA-186EMShDaMwiFjU57YB/view?usp=share_link (Video Demonstration)

Determination of the wavelength of a LASER source using diffraction grating

Objective

To determine the wavelength of a given laser source using an optical transmission grating element.

Apparatus to be used

He-Ne laser source, transmission grating element, and scale with measurements.

Basic theory

Single slit diffraction:

When light passes through a slit, the width of which is comparable as the wavelength of the incident light, it will spread out in the region of geometrical shadow beyond the slit. This phenomenon is known as the diffraction, a characteristic of wave property of light. Huygens proposed each point along a wave front to be the source of a secondary disturbance, forming secondary wavelets (Fig. 1a). Diffraction is due to the constructive and destructive interference of these secondary wavelets, forming maximum and minimum intensity patterns respectively (Fig. 1b).

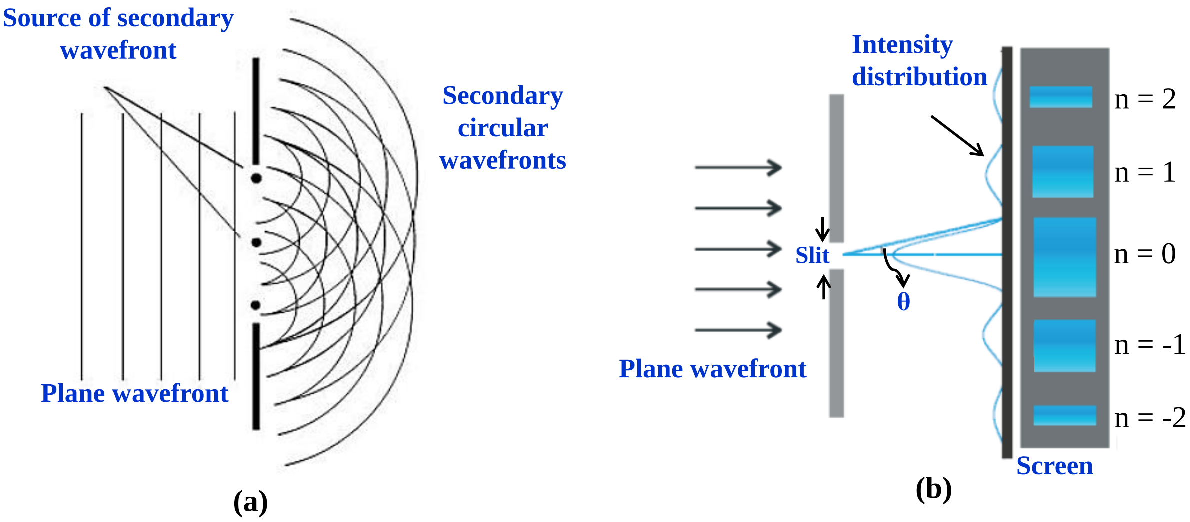


Figure1. **Single slit diffraction**. **(a)** Huygens's principle, wherein each point of the primary plane wavefront acts as the secondary wavefront. **(b)** Intensity distribution pattern due to the diffraction. θ: angle of diffraction, n: order of diffraction maxima.

The diffraction grating:

Grating is a repetitive array of ***diffracting elements, either apertures or obstacles***, which has the effect of producing periodic alterations of phase, amplitude, or both of an emergent wave. The simplest example of a grating is a ***multiple-slit configuration***. Mostly used multiple-slit configuration modulate the amplitude of the incident wavefront; and known as transmission amplitude grating. Similarly, depending on design, we can also have transmission phase grating,as well as reflection grating. Figure 2 shows fabricated diffraction grating element. Here, it is optically plane glass plate on which numbers of equidistant parallel slits are drawn using a pointer diamond. The region where the lines are drawn becomes opaque to the light; while the space between the two lines is transparent.

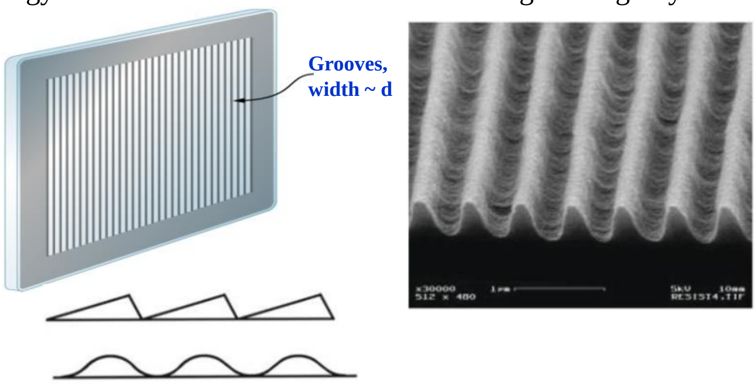


Figure 2. The diffracting grating element. Depictions of a diffraction grating showing groove pattern (left, top) and side view showing different groove profiles (left, bottom). Scanning electron microscope (SEM) image of diffraction grating (right).

Diffracting grating equation:

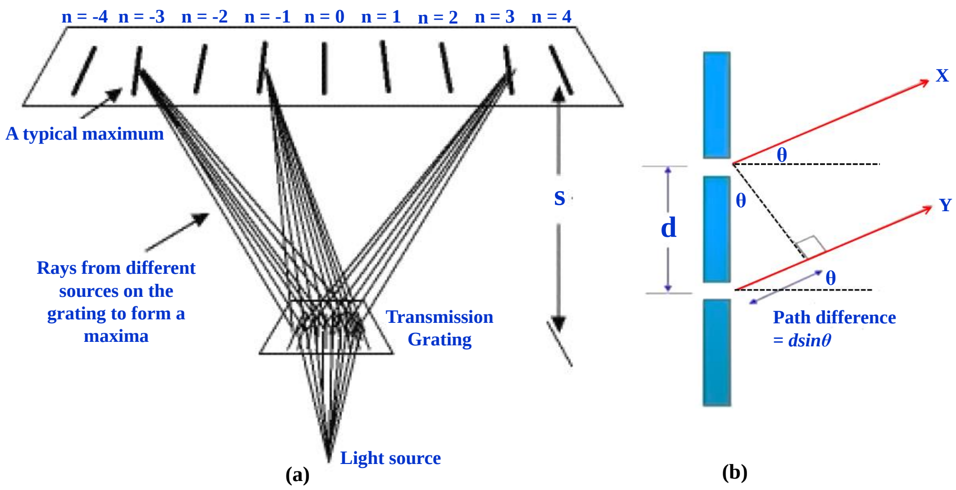


Figure 3. Diffraction of light from a transmission grating element. (a) Secondary wavelets from different sources in the grating form particular intensity maxima on the screen. n: maxima diffraction order, "-" sign just is indicative of the side on which a certain maxima point about the central maxima point, n=0. (b) Zoomed illustration of a section the diffraction grating and the path difference between two diffracted rays, X and Y, and the corresponding path difference between them.

S = the distance from the grating to the screen.

d = the spacing between every two lines (same thing as every two sources, refer Fig. 2)

If there are ***N*** lines per mm of the grating, then ***d***, the space between every two adjacent lines or (every two adjacent sources) is given by:

$$d = \frac{1}{N} \qquad (1)$$

For a typical diffraction grating, ***d***, which is also known as ***the pitch of the element***, is usually of the order of the wavelength of light.

For normal incidence of light on the transmission grating element, pitch **d**, diffraction angle **θ**, and wavelength of light **λ** is related for a diffraction principal maxima as follows:

$$d\sin\theta = n\lambda \qquad (2)$$

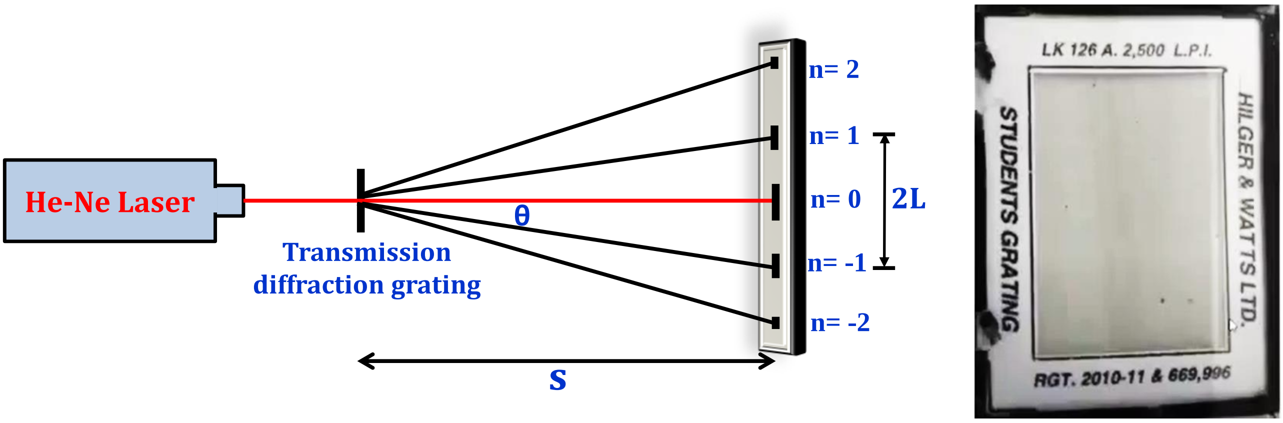
where, ***n*** is an integer (=1, 2, 3…..) and specify the order of the various principal maxima. The above equation is known as ***"Diffraction grating equation" for normal incidence***.

Combining (1) and (2); and rearranging, we can obtain the wavelength of the light source from the following relation:

$$\lambda = \frac{\sin\theta}{Nn} \quad (3)$$

Procedure

The schematic of the experimental set up is shown in Fig. 4. The diffraction pattern is made to incident on a ruler.



(a) (b)

Figure 4. The schematic of the experimental set up. (a) Laser light from He-Ne laser source is normally incident on the transmission diffraction grating. Different principal maxima are observed on a ruler, which is acting as a screen in this experiment. S: distance between grating and screen (ruler), θ: angle of diffraction, and n: diffraction order. (b) Photograph of a transmission diffraction grating used in the experiment.

Warning: Never look directly into a laser beam

1. Switch on the AC power button of the He-Ne laser.
2. Switch on the power switch of the He-Ne laser unit.
3. Place the transmission diffraction grating on the grating stand, so that laser is normally incident on it.
4. Properly keep a wooden ruler horizontally on the other side of the grating so that the diffraction pattern falls on it. This wooden ruler will act as a screen for this experiment.
5. Measure the separation (2L) between the two 1^{st} order (n = 1) principal diffraction maxima on either side of the zeorth order maximum for a distance of “S” between the grating and screen.
6. Repeat the step for 2^{nd} order and 3^{rd} order principal diffraction maxima for the distance “S”.
7. Repeat the above steps 5 & 6 for two more different values of “S”. Here, you can keep the scale (screen) at the same position; but only change the position of the grating. Care should be taken that light is falling normally on the grating after each adjustment.
8. Calculate the value of wavelength using equation 3.
9. Compare your average calculated value of wavelength to the given value for the He-Ne laser (λ_0 = 632.8 nm).

Observations

- Number of lines per meter on the grating, N: ……………

	S (cm)	2L (cm)	L (cm)	$\tan\theta = \left(\frac{L}{S}\right)$	$\theta = tan^{-1}\left(\frac{L}{S}\right)$	sin θ	Mean	λ (nm)

Calculations

First order principal diffraction maxima, n= 1

Perpendicular distance between the grating and the scale (**S**) = …….. **cm**

Distance of the spot from the central maximum (**L**) = …….**cm**

Angle of diffraction, $\theta = tan^{-1}\left(\frac{L}{S}\right)$

Calculate $\sin\theta$

Repeat the above steps other two distances between the grating and the scale

Mean $\sin\theta$ =

Wavelength of the laser light, $\lambda_1 = \frac{sin\theta}{Nn}$

Repeat the above calculations for n = 2 and 3 to obtain λ_2 and λ_3.

- Average calculated wavelength of the laser light, $\lambda_{avg} = \frac{\lambda_1+\lambda_2+\lambda_3}{3}$= **……m =…….nm**

% error calculation

Compare your calculated wavelength to the given value of the He-Ne laser wavelength (λ_0), 632.8 nm;

$$\% \, error = \left| \frac{\lambda_{avg} - \lambda_0}{\lambda_0} \right| \times 100$$

Results

1. Wavelength of the laser light = **λ_{avg} (nm) ± % error**

Inferences/Conclusions

- ✓ **……...**
- ✓ **……….**
- ✓ **……….**

Precautions

- ✓ Care should be taken not to mount the laser at eye level.
- ✓ Do not allow the laser light to fall on your eyes.
- ✓ Do not look head on at the beam or its reflection from the back surface of the diffraction grating; or from any shiny surface.
- ✓ Never aim the laser at any other persons around accidently.
- ✓ Do not move the laser when it is ON.
- ✓ Keep the laser switch off when NOT in USE.
- ✓ Wait for few minutes before switching on the laser after switching it off.
- ✓ The diffraction grating is a delicate component. So carefully handle it.
- ✓ Do not touch the surface of the grating; it might induce scratches; or oily deposition from the fingers. Hold the diffraction grating at the edges only.
- ✓ Remove the grating from the mount after switching off the laser.

Questions on related concepts (Self-assessment)

Q1. Distinguish between the phenomenon of interference and diffraction of light.

Q2. Mention two types of diffraction. In your present experiment, what is the type of diffraction studied?

Q3. What is diffraction grating? Classify them according to their construction.

Q4. Define grating element and pitch of a diffraction grating.

Q5. How the commercial gratings are made?

Q6. What are the conditions of maxima and minima in a diffraction grating?

Q7. Write down some applications of grating.

Q8. As we change the distance between the diffraction grating and the screen, will the separation between the principal diffraction maxima spots will remain same, or change. Explain.

Q9. What will happen to the diffraction pattern when the spacing between the slits is decreased in the grating, or, we increase the number of lines in the grating?

Q10. If instead of laser light, white light is used in the experiment, what will be the appearance of the zero, 1st, 2nd, etc. orders in the diffraction pattern? Explain.

Q11. Why the red color does deviate the most in case of diffraction grating?

Q12. Why does the intensity of the diffraction spots diminish as the order of the principal maxima increases?

Q13. If you encounter a difference between the accepted and experimentally obtained value of the wavelength of the laser source, write down the reasons for this.

Q14. How laser light source is different from ordinary light source.

Q15. What is the working principle of He Ne laser?

Q16. Discuss some of the scientific and engineering applications of Laser light source.

Further references

1. Eugene Hecht, "Diffraction," Chapter 10 in the book "Optics" 4th Global Edition, Pearson education Ltd. (2017).
2. https://ophysics.com/l5b.html (Simulation)
3. http://micro.magnet.fsu.edu/primer/java/diffraction/basicdiffraction/index.html
4. http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html
5. https://drive.google.com/drive/folders/1-EzDHoG3sCKRn8-48qYuakPUG2Msrzcg

Integrated Optics – Refractive Index of glass prism

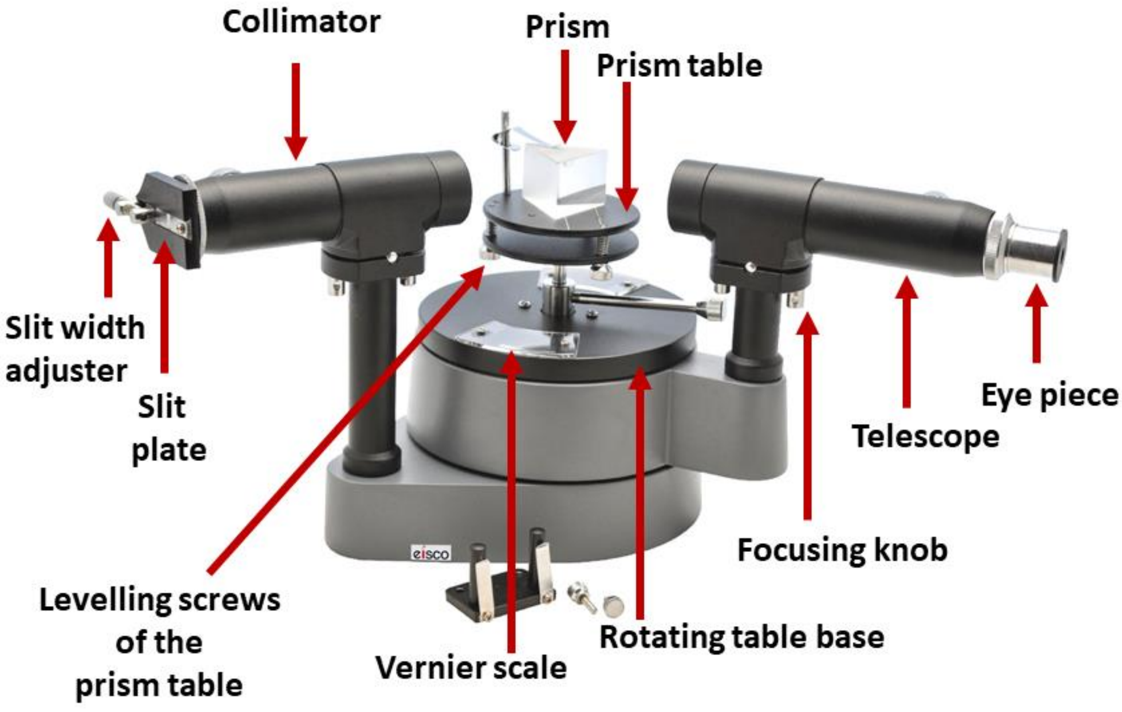
Objective

To determine the refractive index of the glass prism using spectrometer for a given colour.

Apparatus to be used

- Spectrometer
- Spirit level
- Magnifying glass
- Glass prism
- Mercury vapour lamp

Basic theory



The spectrometer is an instrument for analysing the spectra of radiations. The glass-prism spectrometer is suitable for measuring ray deviations and refractive indices. When a beam of light strikes on the surface of transparent material (Glass, water, quartz crystal, etc.), the portion of the light is transmitted and another portion is reflected. The transmitted light ray has small deviation of the path from the incident angle. This is called refraction.

Refraction is due to the change in speed of light while passing through the medium. It is given by Snell's Law.

$$\frac{\mathrm{Sin(i)}}{Sin(r)} = \frac{n_2}{n_1} \quad \text{----------------- (1)}$$

Where 'i' is the angle of incidence, 'r' is the angle of refraction, n_1 is the refractive index of the first face and n_2 is the refractive index of the second face.

The refractive index of the prism can be calculated by the formula

$$n = \frac{\sin\left[\frac{A+D}{2}\right]}{\mathrm{Sin}\left[\frac{A}{2}\right]} \quad \text{------------------ (2)}$$

Where, D is the angle of minimum deviation (Degree), A is the angle of the Prism (Degree), n is the refractive index of the prism.

Least Count (LC):

$$\text{Least Count} = \frac{\text{Value of one main scale reading}}{\text{Total number of vernier scale divisions}} = \frac{30'}{30} = 1'$$

Procedure

Initial adjustments

The following adjustments must be made before doing the experiment with spectrometer.

(i) Adjustment of the eyepiece

The telescope is turned towards an illuminated surface and the eyepiece is moved to and fro until the cross wires are clearly visible.

(ii) Adjustment of the telescope

The telescope is focused on a distant object by adjusting the focus screw, and once the object is clearly visible, the telescope should not be disturbed again.

(iii) Adjustment of the collimator

The telescope is brought along the axial line with the collimator. The slit of the collimator is illuminated by a source of light. The distance between the slit and the lens of the collimator is adjusted until a clear image of the slit (Slit thickness should be as narrow as possible) is seen at the cross wires of the telescope. Since the telescope is already adjusted for parallel rays, a well-defined image of the slit can be formed, only when the light rays emerging from the collimator are parallel.

(iv) Levelling the prism table

The horizontal level of prism table is adjusted using a spirit level and levelling screws.

NOTE:

- Once the telescope is focused at the distant object it should not be disturbed throughout the experiment.
- The verniers (Vernier A and Vernier B) should not be interchanged throughout the experiment.
- The Spectrum obtained for the Mercury lamp that was visible with the resolution of the prism is as follows, given from Left to Right as observed: Red (Weak, 623.437nm), Yellow 1 (Weak, 579.065nm), Yellow 2 (Strong,576.959nm), Green (Very Strong, 546.074nm), Blue Green (Very Weak,491.604nm), Blue (Very Strong,435.835nm), Violet (Strong,404.656nm). All the reported wavelength values are information that was gathered from books and articles.
- **Only figure 3 is to be drawn in the lab note book.**

To Determine the Angle of Minimum Deviation (D)

- Mount the prism on the prism table, with the refracting edge turned away from the collimator. So that light falling on the refracting face AB emerges out through the face AC.

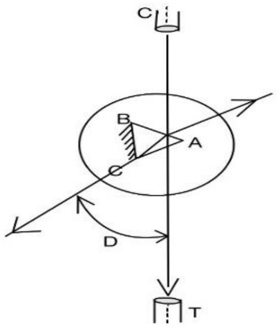


Figure 1

- Now slowly rotate the telescope towards the side BC and obtain the spectrum by placing the telescope at C.

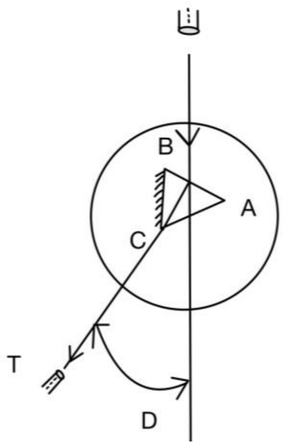
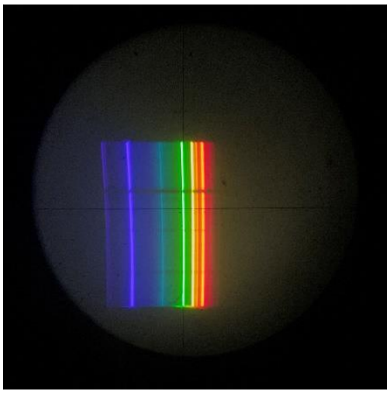


Figure 2



- Observe the spectrum by rotating the prism table while looking through the telescope. As you move the prism table the spectrum will also start to move but at one particular position (Minimum deviation position) the spectrum will retraces its path although the rotation of the table is continued in the same direction. Lock the telescope in this position, coincide the cross wire with the spectral line (particular colour) and note the readings on both the vernier scales (Reading for minimum deviation position).

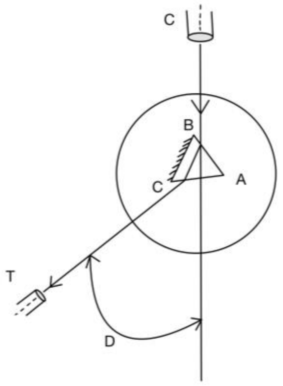
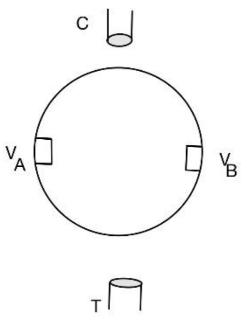


Figure 3

- Release the telescope and remove the prism from the prism table. Rotate the telescope to capture the direct ray (slit image). Note the readings on both the vernier scales (Reading for direct ray).



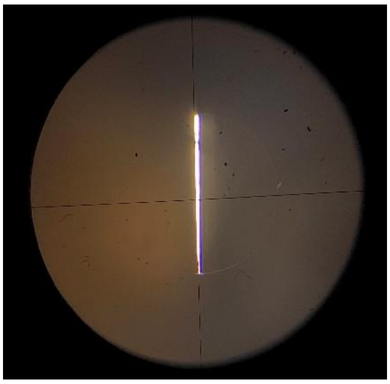


Figure 4

- The difference between the reading for minimum deviation position (R_1) and the reading for direct ray (R_2) gives 'D', the angle of minimum deviation.

- Then calculate the refractive index of the glass prism using the formula.

Observations

Least count = 1' Angle of prism = 60 °

Vernier	**Reading for minimum deviation position (R_1)**			**Reading for direct ray (R_2)**			**D = $R_1 \sim R_2$**	**n**
	MSR	**VSR**	**TR**	**MSR**	**VSR**	**TR**		
A								
B								

Average **n =** ………….

TR = MSR + VSR

VSR =VSC x LC

Results

The refractive index of the glass prism for a given colour is ……………

Inferences/Conclusions

Precautions

1. The telescope and collimator should be individually set for parallel rays.
2. Slit should be as narrow as possible.
3. While taking observations, the telescope and prism table should be clamped with the help of clamping screws.
4. The levelling screws of prism table is adjusted with the help of spirit level to make it horizontal.

Questions on related concepts (Self-assessment)

1. Which colour in the spectrum is having more refractive index?
2. How does refractive index vary with wavelength?
3. What is the principle behind using a glass prism to measure refractive index?
4. Which source of light are you using? Is it a monochromatic source of light?
5. Can we use sodium lamp instead of mercury lamp?
6. How does the angle of minimum deviation help in finding the refractive index?
7. What is Snell's law? What is the formula to calculate refractive index using Snell's law?
8. Is it necessary to use a specific type of glass prism for the experiment?
9. What happens if the incident angle is less than the angle of minimum deviation?
10. Can we use this experiment to find the refractive index of other materials?

Further references

1. https://drive.google.com/file/d/1uXXDEaAl4CDVc-Jqe7YkOKoF8PKh3ki9/view?usp=sharing
2. https://drive.google.com/file/d/1NS3yzvHa-k-aatJnnir7Fjm9dIzP0uiU/view?pli=1

Demonstration of wave nature of electrons through electron diffraction

Objective

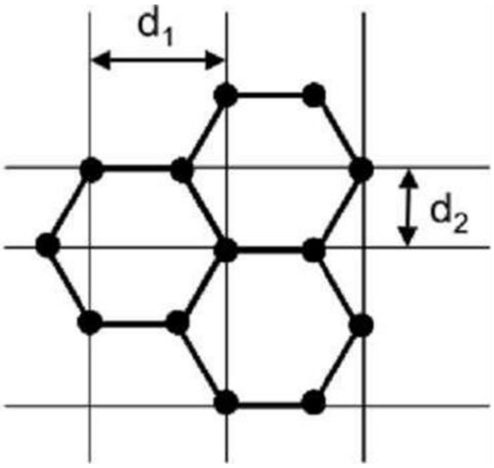
To calculate the interplanar spacing of polycrystalline graphite from electron diffraction pattern and to obtain de Broglie wavelength of electrons at different accelerating voltages.

Apparatus to be used

Electron diffraction tube, High voltage (up to 10 kV) power supply, Connecting wires, ruler.

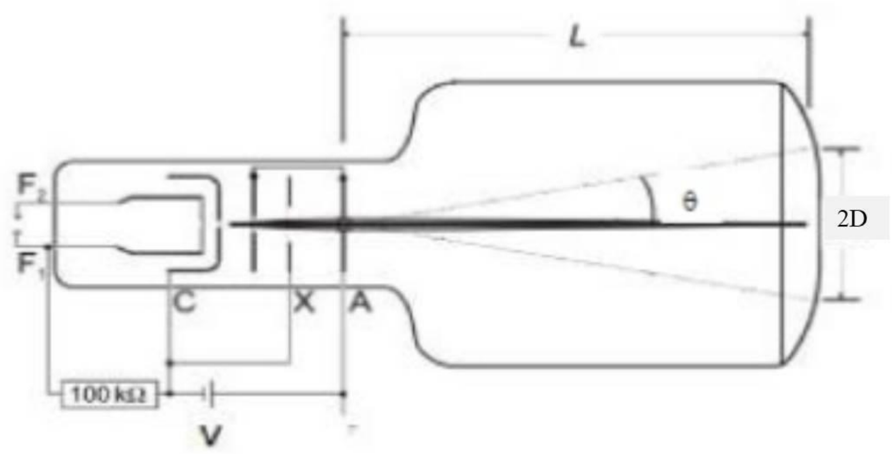
Basic theory

In this experiment we form an electron diffraction pattern consisting of circular rings, after the electron gets transmitted through a very thin polycrystalline graphite sheet. Figure shows sheet of graphite with hexagonal arrangements of carbon atoms.



Consider this arrangement as two sets of inter-penetrating planes of atoms each with its own interplanar distances d_1 and d_2 in order of Angstroms. These planes can be further considered as two sets of inter-penetrating multiple slits. If electrons behave like waves and if they are allowed to pass through these slits, they would get diffracted just as EM waves get diffracted (provided their wavelength is comparable to interplanar distances).

The apparatus shown in the figure below depicts that electrons are produced at filament, accelerated and passed through the thin graphite crystal. To accelerate electrons, a power supply is used. There are sets of circular disks inside evacuated tube in which the right most is anode with graphite crystal and left most is cathode. Remaining disks are to focus electrons. Electrons passing through the graphite hit the florescent screen on the right end of the tube. As graphite has two different lattice spacing, two diffraction rings are seen at each voltage.



Now, we can apply Bragg's law to this case. For the first order diffraction

$$\lambda = d \sin\theta \quad (1)$$

From theory, de Broglie wavelength of an electron accelerated through a potential V is

$$\lambda = 12.3/\sqrt{V}\ \text{Å} \quad (2)$$

From the geometry of the above figure,

$$\sin\theta = \frac{D}{\sqrt{D^2 + L^2}} \quad (3)$$

Procedure

First, turn ON the voltage controller and make sure the initial voltage is set to zero. After that, turn the voltage knob slowly so that we can see a set of two rings on the florescent screen. Since diffraction is property of waves, we demonstrate that electrons too exhibit wave nature. By this demonstration, interplanar distances can be also be found by measuring the diameter of the rings. For the inner ring, first measure the diameter in vertical and then in the horizontal direction using a ruler. Find out the average diameter (D_1). Similarly for outer ring, measure the vertical and horizontal diameters and find out the average (D_2). Now, Repeat these steps for different accelerating voltages 3.5 to 5 kV, at voltage intervals of 0.5 kV.

Precautions

- Never accelerate beyond 5 kV.
- Never touch any controls on the power supply other than the "ON/OFF" switch and thevoltage varying knob.
- Never apply force while measuring the ring diameters.
- Keep a ruler gently over the tube to measure the diameters of rings. Metalrulers are strictly prohibited.

Observations

Distance between graphite sheet and screen (***L***) = 13.5 cm. For inner ring, d_1 =

V (kV)	$\frac{1}{\sqrt{V}}$ $(kV)^{-1/2}$	D_1 (vertical) (cm)	D_1 (horizontal) (cm)	D_1 (Average) (cm)	λ_{exp} (nm)	sinθ	d_1(Å)

For outer ring, d_2 =

V (kV)	$\frac{1}{\sqrt{V}}$ $(kV)^{-1/2}$	D_2 (vertical) (cm)	D_2 (horizontal) (cm)	D_2 (Average) (cm)	λ_{exp} (nm)	sinθ	d_2(Å)

Calculations

- By using the values from table, calculate sin θ, λ, d_1 and d_2 with the help of equations (3), (2) and (1), respectively. And then calculate the average of d for inner and outer rings.

Results

Interplanar distances of the graphite are found to be_______________and _____________

Inferences/Conclusions

- ✓ …………………
- ✓ …………………
- ✓ …………………

Questions on related concepts (Self-assessment)

Q1. Why cannot we explain diffraction by assuming particle nature of electrons?

Q2. What is/are the source of error in this experiment?

Q3. Why does the diameter change with voltage?

Q4. What does the inner and out circle indicate?

Q5. How can you get the interplanar spacing graphically?

Q6. Why do we have a circular pattern?

Further references

[1] https://www.youtube.com/watch?v=IYnU4T3jbgA

[2] https://www.youtube.com/watch?v=AM8LcaKxZGg

[3] https://www.youtube.com/watch?v=l2OXawoAD6M

HEISENBERG'S UNCERTAINTY PRINCIPLE

OBJECTIVE:

To calculate the uncertainty in position (slit width) and momentum of photons from the single-slit diffraction pattern.

APPARATUS TO BE USED:

Optical rail, Kinematic laser mount, Detector mount with X-translation stage, Cell mount and single slits, Diode laser with power supply, Detector with output measurement unit.

BASIC THEORY:

When light passes through a single slit of width '***d***', that is, of the order of the wavelength of light (λ), we can observe a single slit diffraction pattern on a screen placed at a distance ***D***(***D*** >> ***d***) away from the slit. Huygens's principle tells us that each part of the slit can be considered as a source of light, and all these waves interfere to produce a diffraction pattern. The intensity of the light distribution due to the interference is a function of angle of diffraction, θ_m (***m*** is the order of the diffraction and in this experiment, we take ***m =1***).

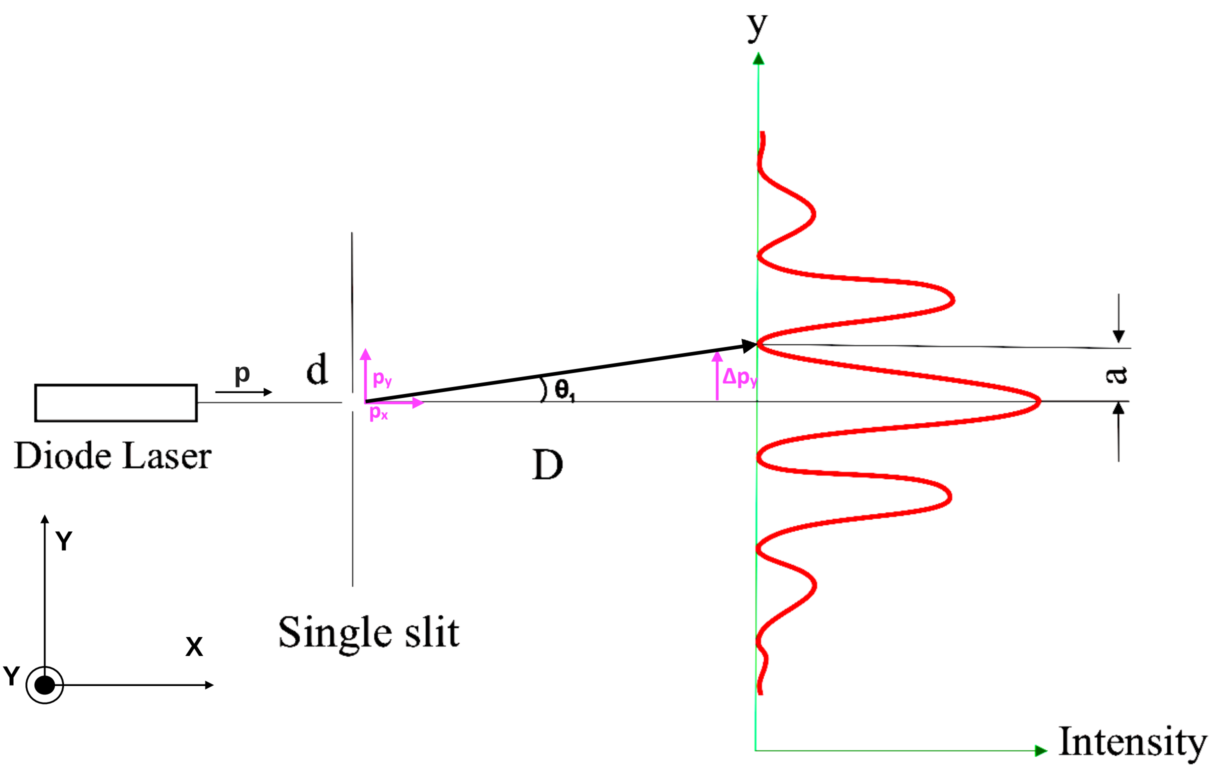


Figure1: *Schematic of the single-slit diffraction pattern with a laser beam of initial momentum p and the spread in the momentum Δp_y along the y-direction for the diffracted beam.*

We can estimate the slit width, *d*, from the diffraction condition as:

$$d = \frac{\lambda}{Sin\theta} \qquad (1)$$

THE UNCERTANITY PRINCIPLE:

The uncertainty principle of quantum mechanics describes the inherent uncertainties in a particle's properties, such as position and momentum, due to the particles' wave nature. The uncertainty principle states that it is impossible to calculate a particle's exact position (y) and momentum (p_y) along the same direction, simultaneously. Mathematically, we described this as follows:

$$\Delta y \, . \, \Delta p_y = \frac{h}{4\pi} \qquad (2)$$

Where, Δx, is the uncertainty in the position, Δp, is the uncertainties in the momentum, and h is Planck's constant ($h = 6.626 \times 10^{-34}\ Js$).

When a monochromatic light (photons) passes through a single slit of width d, we don't know where the photons strike in that vertical slit. Hence, we can define an uncertainty in position for the beam is equal to the slit width d. That is:

$$\Delta y = d \qquad (3)$$

When a laser beam travels to a single slit, it has a definite momentum, p in x - direction, before it gets into the slit. Once the slit diffracts it, the diffracted photons will have momentum both in the x- and y- directions (See Fig-1). From the diffraction intensity profile, it is clear that as photons travel through a single slit, they acquire momentum in y - direction, p_y. It is because some photons go straight, and others fall at an angle θ_1 from the normal to the screen. And using trigonometric relations, the uncertainty in the momentum of the diffracted beam can be calculated as:

$$\Delta p_y = p. sin\theta_1 \qquad (4)$$

From the single slit diffraction equation for first minima (n=1),

$$sin\theta_1 = \frac{\lambda}{d} \qquad (5)$$

Comparing equations (3) and (5),

$$d = \frac{\lambda}{Sin\theta_1} = \Delta y$$

Therefore,

$$\Rightarrow \Delta y \ . \ \Delta p_y = p. Sin\theta_1 \, . \frac{\lambda}{Sin\theta_1} = p\lambda \qquad (6)$$

From de Broglie relation,

$$\lambda = \frac{h}{p} \qquad (7)$$

From equations (6) and (7) for the minimum uncertainty we can write,

$$\Delta y \ . \ \Delta p_y = h \qquad (8)$$

So, by noting the angle between central maximum and first minimum we can get the de Broglie relation, here θ_1 being the angle of first minimum (see Fig-1), therefore,

$$tan\theta_1 = \frac{a}{D}$$

$$\Rightarrow \theta 1 = tan^{-1}\left(\frac{a}{D}\right) \quad (9)$$

from equations (4) and (7),

$$\Delta p_y = \left(\frac{h}{\lambda}\right) sin\left(tan^{-1}\left(\frac{a}{D}\right)\right) \quad (10)$$

Here, a is the distance between the central maximum and first order minimum and D is the distance between the slit and the detector.
Uncertainty in momentum can be calculated from equation (10) and further, Uncertainty in position, slit width, can be calculated using equation (8).

PROCEDURE:

1. Switch on the Laser power supply and output measurement unit.
2. Adjust the Laser beam so that it falls exactly at the centre of the pinhole photodetector, and the output measurement unit shows a maximum output (use kinematic knobs with laser mount to adjust the beam).
3. Insert the cell mount between the laser and the detector. Fix it on the rail and insert the single slit cell into the mount.
4. Remember to align the laser beam so that it falls directly on the slit and the diffracted beam falls on the detector.
5. Observe the diffraction pattern on the detector.
6. Note the micrometre readings at LHS first-order minima (a_1) and RHS first-order minima (a_2) and the corresponding output from the measurement unit. Use $a=(a_1-a_2)/2$.
7. Find the uncertainty of momentum and slit width or position from those values.
8. Repeat the experiment for other slits of different widths and calculate the corresponding change in momentum.

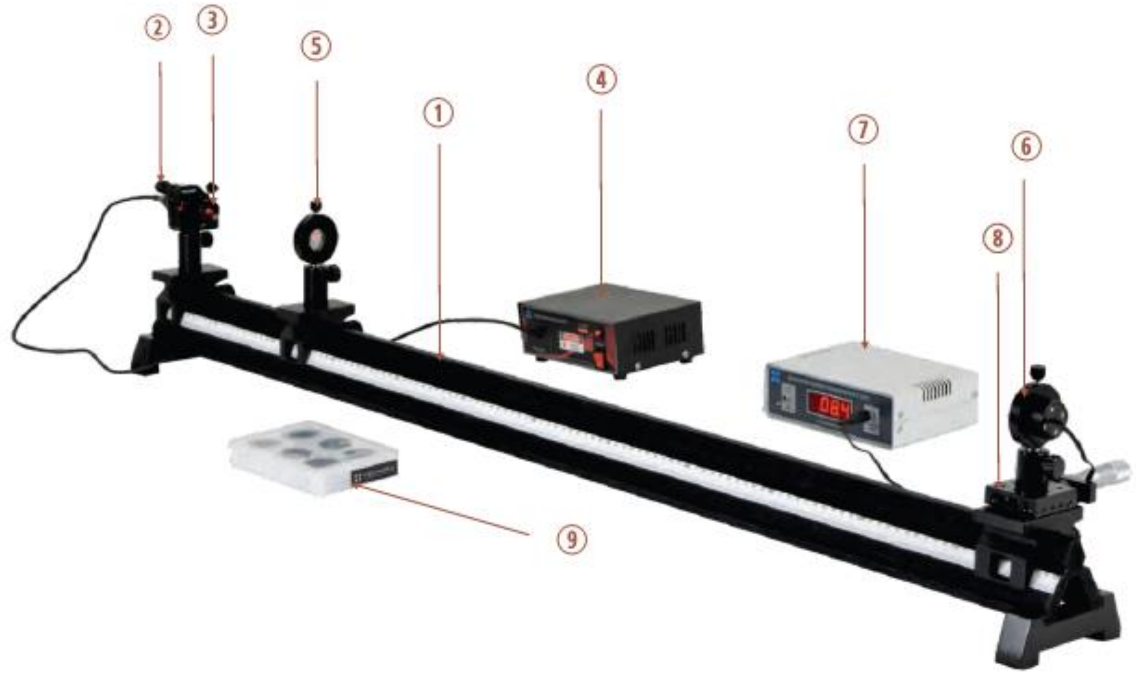


***Figure2**: Experimental set-up for the single-slit diffraction pattern*

1 Optical Rail, 2 Diode Laser, 3 Kinematic Laser Mount, 4 Power supply for laser, 5 Cell mount with Diffraction cell, 6 Pinhole detector, 7 Output Measurement Unit, 8 Linear translation stage, 9 Slit Box

OBSERVATION TABLE:

- Velocity of light = **3x 10^8 m / s**.
- Planck's constant = **6.626 x 10^{-34} Joule - Second**.
- Wavelength of the laser **λ = 650 nm**.
- Least count (LC) **= 0.01 mm**
- **a_1**- micrometer position reading at Maximum Intensity = **$MSR_1 + CSR_1 \times LC$**
- **a_2**- micrometer position reading at Minimum Intensity = **$MSR_2 + CSR_2 \times LC$**
- **a** is distance between central maximum and first order minimum

Slit No.	D (mm)	Micrometre Reading (mm)		Output Current (μA)		a (mm)	$\theta_1 = \tan^{-1}(a / D)$	Δp_y	d (Δy) (mm)
		At LHS first minima intensity (a_1)	At RHS first minima intensity (a_2)	LHS minima	RHS minima	$(a_1 - a_2)/2$			
1									
2									
3									
4									
5									

CALCULATIONS:

3. For each slit, calculate the distance between central maximum and first order minimum with the help of micrometer reading and output current.
4. Then, calculate the value of Δp_y using the equation (10) and slit width using equation (8).
5. Verify the Uncertainty principle from the momentum distribution.

RESULTS:

1. Momentum distribution of photons and slit widths are calculated.

INFERENCES/CONCLUSIONS:

1……………………………………………….

2……………………………………………….

3……………………………………………….

PRECAUTIONS:

8. Avoid directly looking into the laser, as it causes injury via thermal radiation.
9. Take good care while handling the single slits.

QUESTIONS ON RELATED CONCEPTS:

1. What is diffraction?
2. What is Heisenberg Uncertainty Principle?
3. How is the Heisenberg Uncertainty Principle is verified by single slit diffraction experiment?
4. What will happen to the spread in momentum, if the slit width is further increased?

OPTICAL FIBRE CHARACTERIZATION

OBJECTIVE:

To determine the numerical aperture of a given multimode optical fibre.

APPARATUS TO BE USED:

- Diode laser
- Optical fibre
- Laser - fibre coupler
- Optical rail
- Pinhole photo detector
- Power supply for laser and detector output measurement unit.

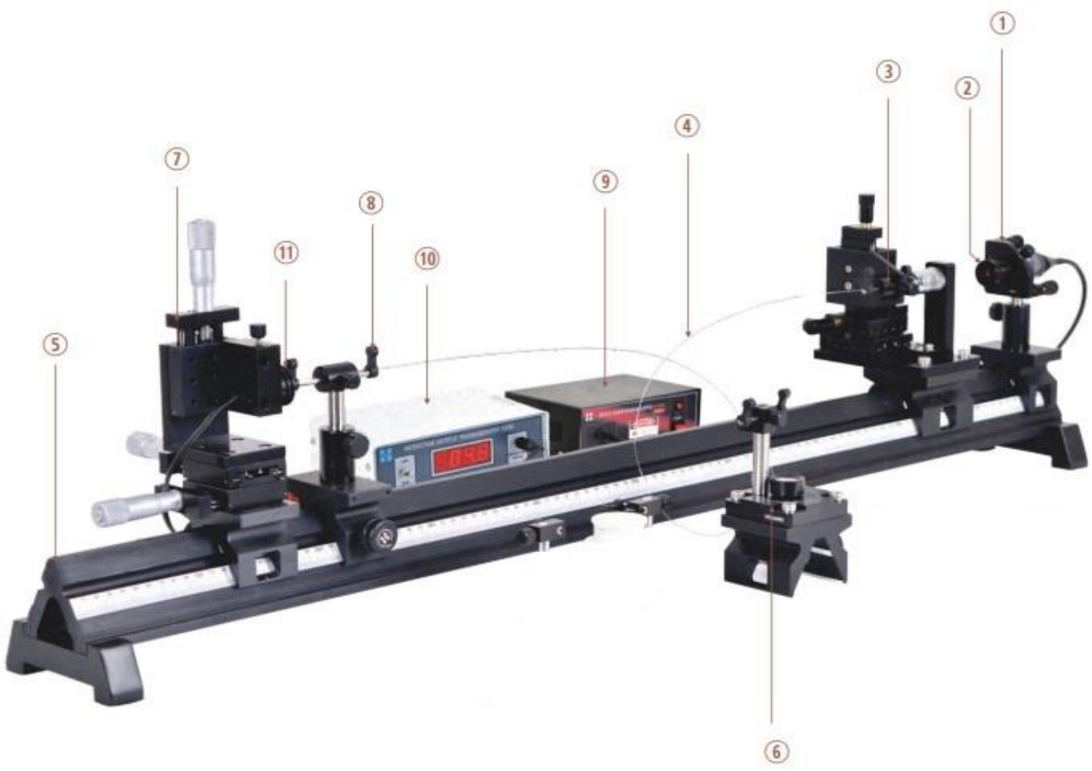


Fig.I Parts of optical fibre

1. Kinematic laser mount
2. Diode laser
3. Laser - fibre coupler with multi axis translation stage
4. Optical fibre
5. Optical rail
6. Rotation stage with fibre chuck
7. XYZ translation stage
8. Fibre chuck
9. Power supply for diode laser
10. Detector output measurement unit
11. Photo detector

BASIC THEORY:

- Optical fibres are optical waveguides used for data transmissions. They are made of low loss materials like glass and plastic. They have a central core through which the light is guided, embedded in an outer cladding of a slightly lower refractive index than the core (See Fig. 1).

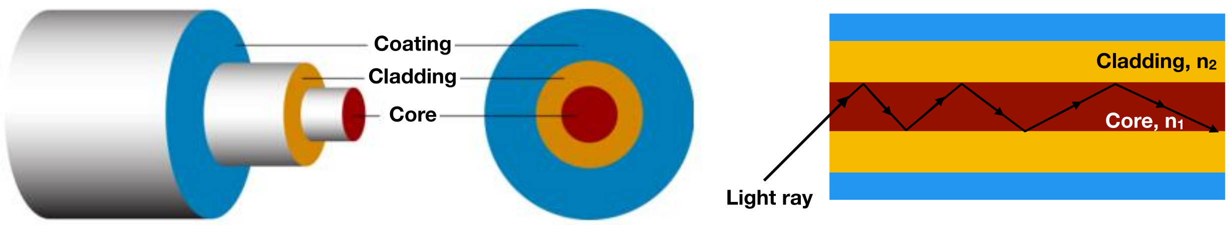


Fig.1: Schematic of optical fibre both in cross-section and lateral views

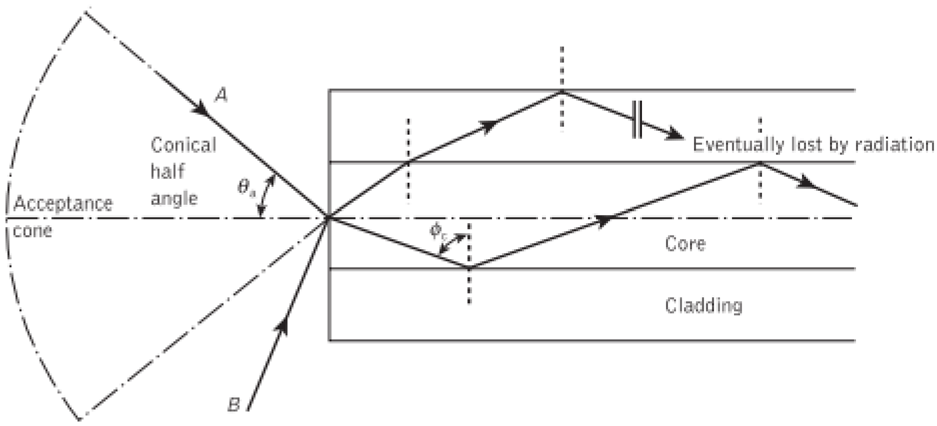


Fig.2

- The geometry of launching a light ray into an optical fibre is shown in Fig. 2, which illustrates a meridional ray A at the critical angle ϕ_c within the fibre at the core-cladding interface. It is observed that this ray enters the fibre core at an angle θ_a to the fibre axis and is refracted at the air-core interface before transmission to the core-cladding interface at the critical angle. Hence, any rays incident into the fibre core at an angle greater than θa will be transmitted to the core-cladding interface at an angle less than ϕ_c and will not be totally internally reflected. This situation is also illustrated in Fig. 2, where the incident ray B at an angle greater than θ_a is refracted into the cladding and eventually lost by radiation. Thus, for rays to be transmitted by total internal reflection within the fibre core, they must be incident on the fibre core within an acceptance cone defined by the conical half angle θ_a. Where, θ_a is the maximum angle to the axis at which light may enter the fibre to be propagated, and is referred to as the **acceptance angle** for the fibre.

- Numerical aperture (NA) is the light gathering capacity of an optical fibre. The NA is a measure of how much light can be collected by an optical system. NA varies according to an angle known as the acceptance angle θ_a, which gives the size of a cone of light that can be accepted by the fibre.
- From Fig. 3 **acceptance angle** can be defined as

$$\boldsymbol{\theta_a = \tan^{-1}\left(\frac{R}{Z}\right)}$$

R is the radius corresponding to 5% of the maximum attainable intensity

Z is the distance between fibre output end and the detector

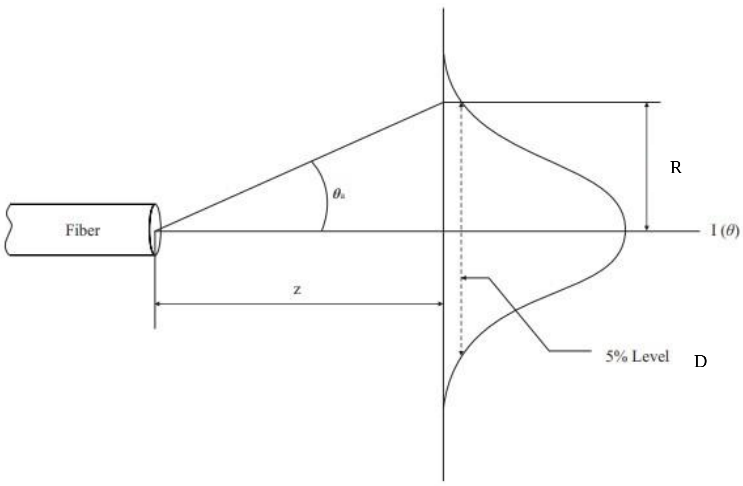


Fig. 3

- The sine of the acceptance angle is defined as numerical aperture (NA).

  Therefore,

$$\boldsymbol{NA = \sin\theta_a}$$

PROCEDURE:

- Switch on the Laser and output measurement unit. Using fine adjustment screws (Fig. 4) on the Laser mount make the beam to fall on the objective of the Laser fibre coupler.

Fig. 4

Fig. 5

- Couple maximum light into the fibre with the help of the multi axis translation stages (Fig.5)
- Also adjust the position of the detector using the XYZ micrometers (refer Fig.6) until the output measurement unit shows a maximum output (above 150 μA). Ensure that the distance between fibre tip and the pinhole detector is zero (Z=0) (refer Figures 7 & 8). (You should get maximum output in μA range)

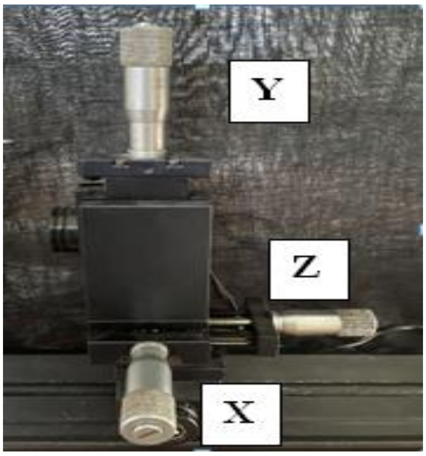


Fig.6

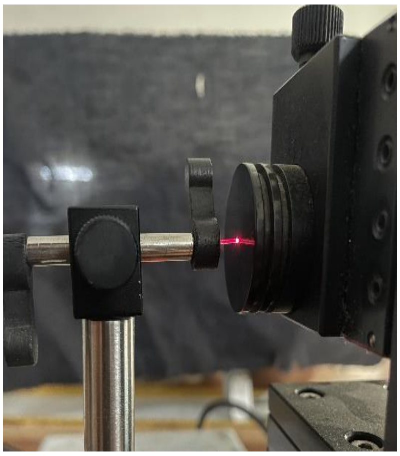


Fig.7

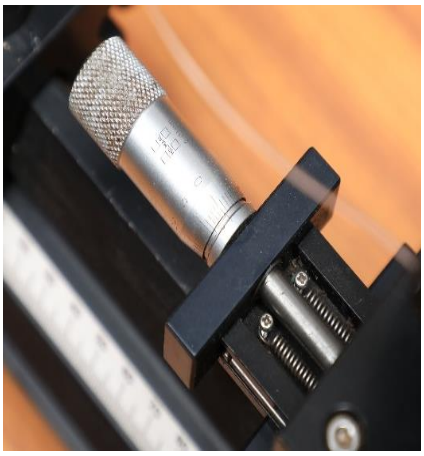


Fig.8

- After attaining the maximum output, manipulate the Z-micrometer by taking it through two full rotations. This will ensure a distance of 1 mm made between the detector and the fibre tip (Fig.9). In other words, Z = 1 mm. Throughout the experiment this Z value is to be kept fixed.

Fig.9

- Using the X-micrometre, move the detector to the right / left extreme position (where the output shows zero or minimum current) and move back the micrometre in the opposite direction, stopping at equal intervals (refer Figures 10 & 11). For each of those intervals note down the micrometre reading and the corresponding detector output current.

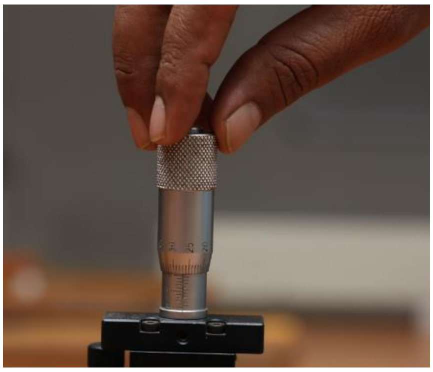


Fig.10

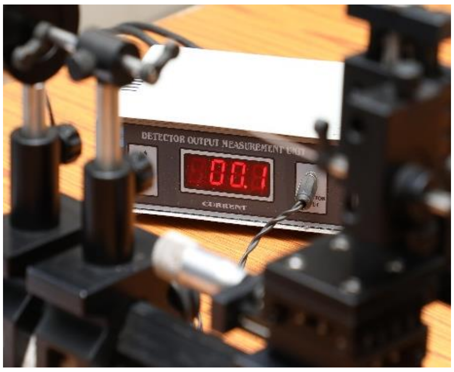


Fig.11

- The current output value will reach a maximum between the extreme positions, where the output currents are minimum.
- Plot a graph with the micrometre reading on X-axis and the corresponding output current on Y-axis. From the graph, evaluate 'D'. Calculate the acceptance angle from the obtained values, and eventually the numerical aperture (NA).

OBSERVATION TABLE:

Least count = 0.01mm

Z (mm)	Micrometer Reading (mm)			Output current (μA)	R= D/2 (mm)
	MSR	HSR	TR		

TR = MSR + HSR

HSR = HSC x LC

From the graph,

Beam radius corresponding to 5% of maximum attainable intensity = ………………..mm

Distance between detector and fibre optic end (Z) = ………………….. mm

Acceptance angle = ………………..

Numerical aperture = ………………….

RESULT:

The Numerical aperture (NA) of the given multimode fibre = …………..

INFERENCES/CONCLUSIONS:

- ………………………

- ....

PRECAUTIONS:

- Laser radiation predominantly causes injury via thermal effects; hence avoid looking directly into the laser beam.
- Diode laser source should be properly aligned with optical fibre cable.
- Ensure that the launch point of optical fibre cable is properly aligned and maximum amount of optical power is transferred to the cable.
- Keep the fibre optic cable straight to ensure minimum attenuation due to bending.

QUESTIONS ON RELATED CONCEPTS:

1. What is the numerical aperture of an optical fibre?
2. How is the numerical aperture defined?
3. How can the numerical aperture be calculated from the refractive indices of the core and the cladding?
4. What is the significance of the numerical aperture?
5. What are the factors that affect the numerical aperture of an optical fibre?
6. How does the numerical aperture affect the performance of an optical fibre?
7. What is the difference between the numerical aperture of a single-mode and a multimode fibre?

REFERENCES:

3. https://drive.google.com/file/d/1IuaQgxz19OVqH2dzAqeHwoSXdLJTfcEv/view

4. John M. Senior. Optical Fibre Communications Principles and Practice, Third edition,2009,Pearson & prentice hall.

REFRACTIVE INDEX OF TRANSPARENT LIQUID

OBJECTIVE:

To determine the refractive index of the given transparent liquid using travelling microscope

APPARATUS TO BE USED:

- Travelling microscope
- Transparent liquid (Tap water)
- Glass beaker
- Magnifying glass
- Saw dust

BASIC THEORY:

The refractive index of a material is a dimensionless number that describes how light propagates through that medium. It is defined as the ratio between the speed of light in vacuum and speed of light in the medium. Further, from Snell's law, it can be defined as the ratio of sine of angle of incidence and sine of angle of refraction. Now, when light travels from rarer to denser medium, the light bends towards the normal to the surface of incidence; and it bends away from the normal when it is moving from denser to denser to rarer medium. The bending is governed by the Snell's law and this concept is necessary to understand the concept of apparent depth.

Real depth and apparent depth; and their relation with refractive index of the medium:

Real depth can be defined as the depth at which an object is placed in a medium, so that the observer and the object are in the same medium. Here, the important factor is that the light should propagate from the object to the observer and vice-versa and should be in the same medium.

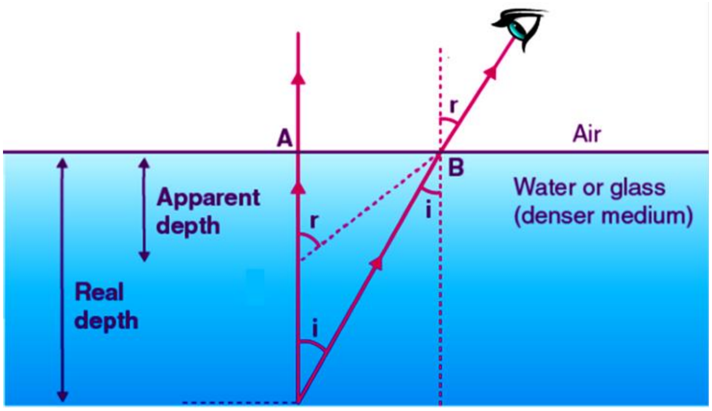


Figure.1 Real depth and apparent depth due to refraction of light

On the other hand, when an object is placed under water (or any other medium like glass), then observing it from outside the water (or medium), it appears to be raised up. This is defined as the apparent depth; wherein the depth of the object is measured by the observer when the object and the observer are in different medium. This is due to the effect of the refraction of light while propagating from one medium to the other medium.

The refractive index of a liquid can be defined as follows:

$$\mu = \frac{\text{Real depth of the liquid}}{\text{Apparent depth of the liquid}} \quad (1)$$

Travelling Microscope and refractive index of liquid

In simple terms, a travelling microscope is a compound microscope that is fitted with a vertical scale, which carries a main scale along with a vernier scale. Using this equipment, we can calculate the real and apparent depth as depicted in the figure below:

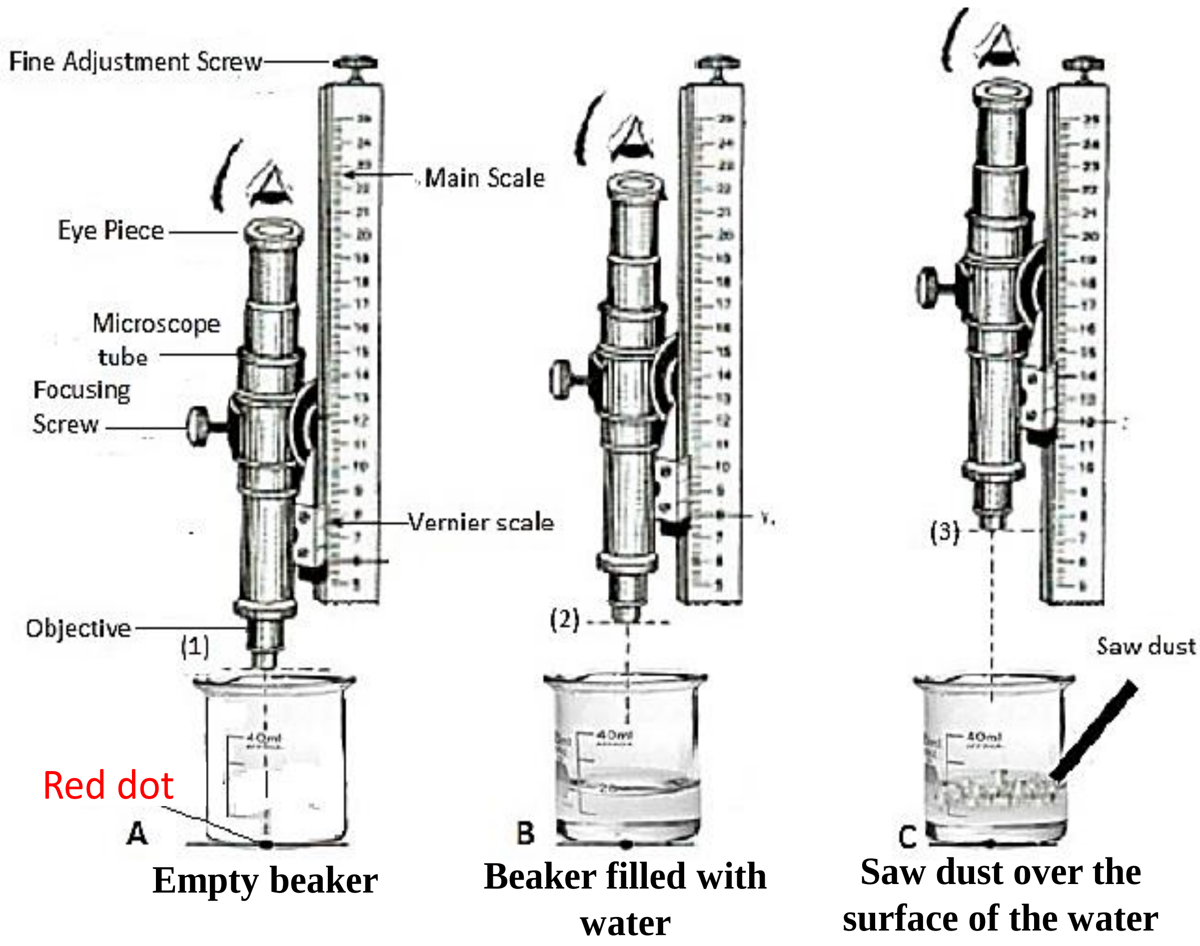


Figure.2 Steps in the measurement of refractive index using travelling microscope.

The refractive index can be calculated from the following equation:

$$\mu = \frac{C-A}{C-B} \quad (2)$$

where

A is the microscopic reading when the red dot is focused directly

B is the microscopic reading when the red dot is focused through the liquid

C is the microscopic reading when saw dust sprinkled on the surface of the liquid is Focused.

In equation (2):

(C-A): Real depth of the liquid

(C-B): Apparent depth of the liquid

PROCEDURE:

A. Procedure to calculate the refractive index of the transparent liquid

- Keep the travelling microscope near a light source.
- Find the least count of the travelling microscope; considering the vertical scale.
- Set the microscope with its axis vertical.
- Make sure that the base of the traveling microscope is horizontal. Adjust the screws at the base with a spirit label to make the base horizontal.
- Hold a white paper in front of the objective of the microscope and adjust the eyepiece so that the cross wires are seen clearly.
- Put an empty glass beaker with a red dot in the bottom under the microscope objective.
- Focus the microscope objective with the screws controlling the vertical movement of the microscope barrel to see clearly the red ink dot. Note down the T.S.R. (MSR + VSR) for this condition (**Reading A**)
- Pour 40 ml of water in the beaker slowly.
- Raise the microscope (without disturbing the focusing screw) so that the image of the red dot is in focus again. Note the corresponding microscope scale reading (**Reading B**)
- Sprinkle some saw dust over the surface of the water in the beaker.
- Raise the microscope (without disturbing the focusing screw) so that the saw dust particles are in focus. Note the corresponding microscope scale reading (**Reading C**).
- Repeat the above steps for 60 ml of water.
- Calculate the value of refractive index in each case of 40 ml and 60 ml and find the average.
- Calculate the percentage error, considering the standard refractive index (μ_0) of water 1.333.

B. Least count for traveling microscope

Least count = Value of 1 MSD/ Number of divisions in the Vernier

Value of 1 MSD = 0.05 cm; Number of divisions in the Vernier = 50

Least count = 0.05 cm / 50 = 0.001 cm

Total scale reading (TSR) = Main scale reading (MSR) + (Vernier scale division x least count)

OBSERVATION TABLE:

Least count of the vertical Vernier scale = ……cm

Volume of the water in the beaker	Clear image of the red dot through the empty beaker (**Reading A**)			Clear image of the red dot through water (**Reading B**)			Clear image of the saw dust over the surface of the water (**Reading C**)			(C-A) (cm)	(C-B) (cm)	μ
	MSR (cm)	VSR (cm)	TSR (cm)	MSR (cm)	VSR (cm)	TSR (cm)	MSR (cm)	VSR (cm)	TSR (cm)			
40 ml												
60 ml												

MSR- Main Scale Reading, VSR-Vernier Scale Reading, TSR: Total Scale Reading

VSR-Vernier Scale division x Least count (LC)

TSR = MSR + VSR

CALCULATIONS:

Calculate the value of (C-A) and (C-B), and obtain the refractive index for each of the volumes, 40 ml and 60 ml.

Error Calculations:

$$\% \, \text{error} = \left| \frac{\text{Experimental Value } (\mu) - \text{Standard Value } (\mu_0)}{\mu_0} \right| \times 100$$

RESULTS:

Average refractive of the water = Experimental value ± % error

INFERENCES/CONCLUSIONS:

1……………………………………………..

2……………………………………………..

PRECAUTIONS:

1. The parallax in the microscope should be removed properly.
2. To avoid backlash error, the microscope should be moved in only one direction.
3. Care should be taken so that the microscope is properly calibrated.
4. Once the microscope is focused for the first reading, the focusing arrangement in the lens system should not be changed/altered for subsequent readings.
5. Use magnifying glass to read the vernier scale to avoid error in finding vernier coinciding division.

QUESTIONS ON RELATED CONCEPTS:

1. Define refractive index of a medium.
2. Indicate the dependence of refractive index with the density of medium.
3. List two factors that affect the refractive index of the material.
4. What is apparent shift?
5. On what factors does the apparent depth depend?
6. Will a colourless slab be visible if immersed in a transparent liquid of the same refractive index as that of the slab? State the reason for it.

FURTHER READING:

1. https://drive.google.com/drive/folders/1-EzDHoG3sCKRn8-48qYuakPUG2Msrzcg
2. https://www.youtube.com/watch?v=6pNtRjGhwro

TO STUDY THE CHARACTERISTICS OF SOLAR CELL

OBJECTIVE:

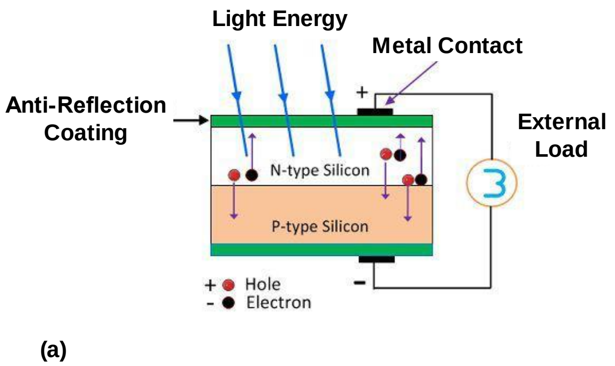
To determine the fill factor and efficiency of a solar cell.

APPARATUS TO BE USED:

Solar Cell, Light Source (100 Watt), Ammeter, Voltmeter, Variable Load Circuit, Connecting Wires

BASIC THEORY:

The Solar cell is a semiconductor device that converts solar energy into electrical energy. It is a specially designed PN junction diode that converts sunlight into electrical power by a three-step process: (i) Generation of carrier pairs (electron-hole pairs), (ii) Separation of electrons and holes, (iii) Collection of separated carriers. When the PN junction is exposed to light, electron-hole pairs are generated in the P and N regions. By diffusion in the material, the electron and holes reach the junction. The barrier field separates the positive and negative charge carriers at the junction. That is, under the action of the electric field, the electrons (minority carriers) from the P region are swept into the N region. Similarly, the holes from the N region are swept into the P region. The accumulation of charges on the two sides of the junction produces an emf (Voltage), called a photo-emf/Photo-voltage. The photo emf or voltage can be measured with a voltmeter, and this optical energy conversion is known as the photovoltaic effect. Therefore, a solar cell is also called a photovoltaic cell. When an external circuit (load) is connected across the solar cell terminals, the minority carriers return to their original sides through the external circuit, causing the current to flow through the circuit. Thus, the solar cell behaves as a battery with the N side as the negative terminal and the P side as the positive terminal.



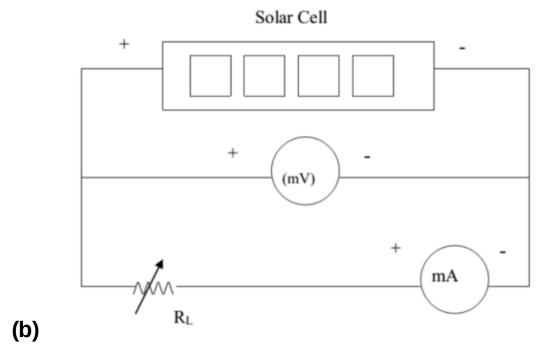


Figure1: (a) Solar cell working principle (b) Equivalent circuit diagram of Solar cell experiment

The emf is generated by the solar cell in the open circuit, i.e., when no current is drawn from it, and is denoted by V_{OC} (V-open circuit). This is the maximum value of voltage that can be generated by the solar cell. When an external (load of high resistance) is connected in the circuit, a small current flows through it, and the corresponding voltage decreases. The voltage goes on falling, and the current increases as the resistance in the external circuit is reduced. When the load resistance is reduced to zero, the current rises to its maximum value, known as short-circuit/saturation current, and is denoted as I_{SC}; the voltage becomes zero in this case. Figure 2 shows the I-V characteristic of a solar cell with its V_{OC} and I_{SC}.

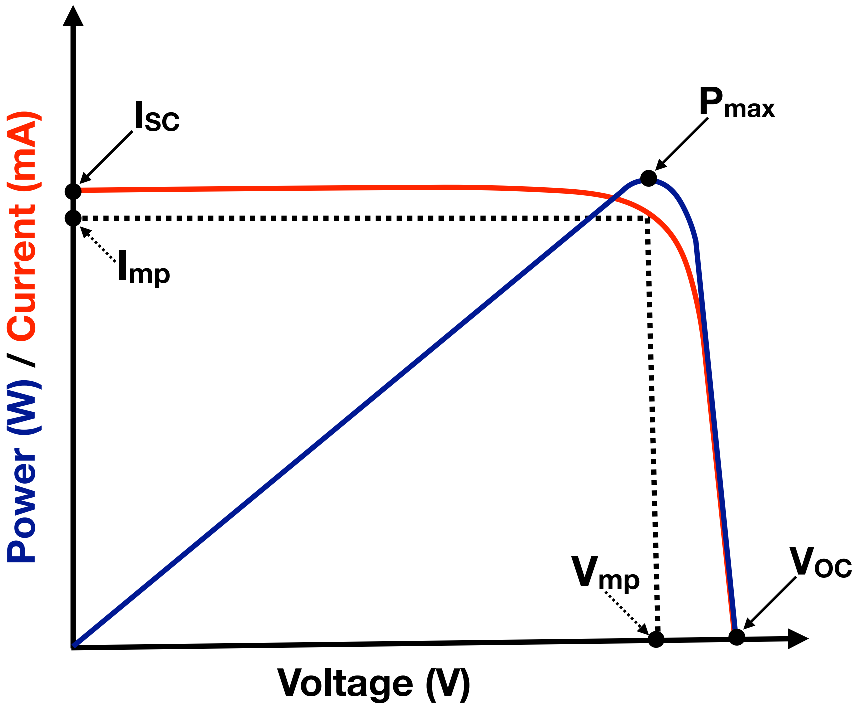


Figure2:Current-Voltage(I-V) and Power-Voltage (P-V) characteristics of Solar cell

The product of open circuit voltage V_{OC} and short circuit current I_{SC} is the (ideal) power that can be generated from a solar cell and it can be calculated as:

$$Power = V_{OC} \times I_{SC}$$

However, the maximum power (P_{max}) that can be harvested from the solar is the area of the largest rectangle that can be formed under the I-V curve (see Fig-2). It is calculated from the corresponding Current (I_{mp}) and Voltage (V_{mp}) at that condition as:

$$P_{max} = V_{mp} \times I_{mp}$$

The corresponding fill factor (FF) can be calculated by taking the ratio of the maximum power to the ideal power as:

$$FF = \frac{V_{mp} \times I_{mp}}{V_{OC} \times I_{Sc}}$$

If A_C is the area of the solar cell and Ω is the incident intensity, then the efficiency (η) of the solar cell is calculated as:

$$\eta = \frac{P_{max}}{A_C \Omega}$$

PROCEDURE:

Procedure for I-V characteristics of Solar cell:

1. Place the solar cell and the light source (100-watt lamp) opposite to each other.
2. Connect the circuit as shown by dotted lines on the circuit board (See Fig. 1) using connecting cables.

Load Resistance	**Distance (x) in mm: ----------------; Intensity of Light: --- -----------------**

3. Switch ON the lamp to expose the light onto the Solar Cell.
4. Set a suitable distance between the solar cell and the lamp as mentioned in the solar kit (Note: The gap between the solar panel edge to the tin-lamp box edge is the actual distance)
5. Break the circuit by plugging out any cable to measure the open circuit voltage V_{OC}
6. Set the load-resistance knob to Short-Circuit mode and measure the corresponding short-circuit current I_{SC}.
7. Vary the load resistance through the knob switch and note down the current and voltage corresponds to each load resistance in the observation Table 1
8. Repeat it for different distances to minimise the error in the experiment.
9. Plot a graph of current (I) versus Voltage (V). Plot a graph of Power (P) versus Voltage (V). From the plot, find the maximum power (P_{max}) and the corresponding Current (I_{mp}) and Voltage (V_{mp}).

OBSERVATION TABLE:

Voltmeter reading for open circuit and Millimetre reading with zero resistance are

V_{OC}:-------------------------- ; I_{SC}:------------------- ;

	Voltage (V)	Current (mA)	Power (mW)

CALCULATIONS:

From the graph and observation table, the fill factor (FF) and the efficiency (η) can be calculated by using the values of V_{OC}, I_{SC}, V_{mp}, I_{mp} :

$$FF = \frac{V_{mp} \times I_{mp}}{V_{OC} \times I_{Sc}} \qquad \eta = \frac{P_{max}}{A_C \Omega}$$

Compare your calculated value of efficiency (η) to the standard value, η_0.

$$\% \text{ Difference} = \left| \frac{\eta - \eta_0}{\eta_0} \right| \times 100$$

RESULTS:

At a given distance, x=………. mm

1. The fill factor of the give solar cell is found to be, FF = ...
2. The efficiency of the give solar cell is found to be, η = ……………

INFERENCES/CONCLUSIONS:

1……………………………………………

2……………………………………………

3……………………………………………

PRECAUTIONS:

1. The solar cell should be exposed to light before using it in the experiment.
2. Light from the lamp should fall normally on the cell.
3. Distance should be appropriately measured using a scale
4. The load resistance should be used within a safe current limit.

QUESTIONS ON RELATED CONCEPTS:

1. What is the difference between a solar cell and a photodiode?
2. Why are solar cells known as photovoltaic cells?
3. What are the types of semiconductor materials used for solar cells?
4. What is Dark current?
5. What is the difference between solar photovoltaic and solar hot water systems?
6. What is the response time of a photocell?
7. What is the role of load resistance in solar cell experiment

ESTIMATING CRYSTALLITE SIZE FROM XRD PATTERN

Objective:

To determine the average crystallite size from the given X-ray diffraction (XRD) pattern of a polycrystalline material.

Tools Required:

- XRD pattern (uploaded in the course page)
- Peak fitting program (Open source/free software like fityk, gnuplot andqtiplotis preferable)

Basic Theory:

We will use Scherrer equation to calculate the crystallite size. This method gives qualitative results.

The Scherrer Equation is:

$$D = \frac{K\lambda}{\beta \cos\theta}$$

Here,

- Peak width (***β*** in radians)
- Crystallite size (***D***)
- Scherrer constant (***K***)
- X ray wavelength (***λ***)
- Peak position (***θ***)

There are several reasons for X- ray diffraction peak to get broadened: instrumental peak profile, crystallite size, micro strain, solid solution in-homogeneity and temperature factors. In this exercise we assume that in the given X- ray diffraction pattern the peaks are broadened only due to crystallite size and instrumental peak profile.

When the size of the crystallite becomes small, small number of lattice planes only available for diffraction. Because of this the Bragg condition of diffraction will get satisfied at lower angles and extends to the higher angles on both the sides of original Bragg peak position. This will broaden the diffraction peak.

Procedure:

1. Fit the given diffraction data with Voigt or pseudo-Voigt peak profile function.
2. Note down the peak center and "full-width at half-maximum" (FWHM) of thediffraction peaks in the tabular column given. (Should be converted into radian)
3. Subtract the given instrumental broadening from the FWHM of all the peaks.
4. FWHM will be in 2θ, one has to make it as θ.
5. Make the required conversions in units.
6. Use the given formula and calculate the crystallite size.

Observations:

Instrumental broadening: 0.01^o Wavelength

of the X- ray used: 1.546 Å

Scherrer constant: 0.94 (assuming that crystallites are spherical in shape)

Table

Peak Center 2θ (deg)	**θ (deg)**	**FWHM**	**FWHM (rad)**	**Average crystallite size (nm)**

Results: The average crystallite size is ------------------------