EXPERIMENTAL STUDY OF FRAUNHOFER DIFFRACTION USING LASER LIGHT AND DETERMINATION OF MICROSCOPIC DIMENSIONS

PROJECT REPORT

Submitted by

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In the partial fulfillment of the requirements of award of Bachelor degree of Science in Physics.

ST. TERESA'S COLLAGE (AUTONOMOUS)

ERNAKULAM

2025-2026

ST. TERESA'S COLLEGE (AUTONOMOUS)
ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled "EXPERIMENTAL STUDY OF FRAUNHOFER DIFFRACTION USING LASER LIGHT AND DETERMINATION OF MICROSCOPIC DIMENSIONS "is an authentic work done by BHAVIKA SHINE St Teresa's College, Ernakulam, under my supervision at Department of Physics, St Teresa's college , Ernakulam, for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2025-26. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

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DATE: 16/04/26

EXAMINER:

ATHIRA PRAKASH

DECLARATION

I,**BHAVIKA SHINE** final year B.Sc Physics student, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project work entitled "EXPERIMENTAL STUDY OF FRAUNHOFER DIFFRACTION USING LASER LIGHT AND DETERMINATION OF MICROSCOPIC DIMENSIONS", has been originally carried out under the guidance and supervision of **Dr.SREEJA V G,** Assistant Professor, Department Of Physics,St. Teresa's College (Autonomous), Ernakulam, in partial fulfilment for the award of the degree of Bachelor of Physics. I further declare that this project is not partially or wholly submitted for any other purpose and the data included in the project is collected from various sources and are true to be the best of our knowledge.

PLACE: ERNAKULAM

DATE :

ACKNOWLEDGEMENT

First and foremost, I would like to thank God almighty for showering his blessing on me in this endeavour.

I wish to express our sincere gratitude to Dr.SREEJA V G , Department of Physics, St. Teresa's College (Autonomous), Ernakulam, for her guidance, timely help, expert advice, support and persistent encouragement given to me throughout the duration of my project work.

I express my deep sense of gratitude to the Department of Physics, St. Teresa's College (Autonomous), Ernakulam, for extending the facilities and co-operation required from time to time. I take this opportunity to thank once again Dr. MARY VINAYA, Head of the Department of Physics for generous concern and support.

Last but not the least i express our thanks to all teaching and non-teaching staff of the department of Physics, for their kind co-operation.

CONTENTS

ABSTRACT

This project aims to determine the diameter of a human hair and a sewing thread using the principle of laser diffraction. When monochromatic laser light falls on a thin obstacle such as a hair or thread, a diffraction pattern consisting of alternating bright and dark fringes is formed on a distant screen. According to Fraunhofer diffraction theory, the fringe width is directly proportional to the distance between the obstacle and the screen and inversely proportional to the diameter of the obstacle.

In this experiment, the distance between the hair (or thread) and the screen was varied, and the corresponding fringe widths were measured. A graph of fringe width (β) versus screen distance (D) was plotted, which produced a straight line, confirming the linear relationship predicted by theory. The slope of the graph was used to calculate the diameter of the hair and thread using the relation $\beta = (\lambda D)/a$.

The results obtained were in the expected range, demonstrating the wave nature of light and showing how diffraction can be used to measure extremely small dimensions accurately. This experiment highlights the practical application of wave optics in determining microscopic quantities using simple laboratory equipment.

CHAPTER 1
INTRODUCTION

Diffraction is a fundamental wave phenomenon that occurs when light encounters an obstacle or aperture whose dimensions are comparable to its wavelength. It provides strong experimental evidence for the wave nature of light and plays a crucial role in modern optics and measurement techniques.

Among the different types of diffraction, Fraunhofer diffraction refers to far-field diffraction where the incident wavefront is effectively plane and the source and screen are placed at sufficiently large distances. The diffraction pattern formed under such conditions can be mathematically analyzed and used to determine the dimensions of microscopic objects.

According to Babinet's principle, the diffraction pattern produced by an opaque obstacle is equivalent to that produced by a slit of the same width. Hence, a thin wire such as a human hair or sewing thread behaves like a single slit and produces a characteristic interference pattern when illuminated by monochromatic laser light.

In this project, Fraunhofer diffraction using a laser source is experimentally studied to determine the thickness of thin objects such as human hair and sewing thread. The variation of fringe width with distance is analyzed graphically, and the experimental results are compared with theoretical predictions. Error analysis is performed to evaluate the accuracy of the measurements.

This experiment demonstrates how optical diffraction techniques can be used as a simple yet powerful method for measuring microscopic dimensions.

1.1 THEORY OF DIFFRACTION

When monochromatic light of wavelength λ is incident on a single slit of width 'a', diffraction occurs due to interference of secondary wavelets originating from different points of the slit.

For Fraunhofer diffraction, the condition for minima is given by:

$$a\sin\theta = n\lambda$$

For small angles:

$$\mathrm{Sin}\theta \approx \tan\theta = y/D$$

Therefore:

$$a(y/D) = n\lambda$$

$$Y = n\lambda D/a$$

The fringe width (β) is the distance between successive bright or dark fringes:

$$\beta = \lambda D/a$$

This shows that fringe width is directly proportional to D and inversely proportional to the slit width (or diameter of the obstacle).

From the graph of β vs D:

$$\text{Slope} = \lambda/a$$

Thus,

$$a = \lambda/\text{slope}$$

1.2 FRESNEL DIFFRACTION

Fresnel diffraction is defined as a diffraction phenomenon that occurs in the intermediate field or Fresnel zone, where the binomial expansion of the distance function is applied, leading to a specific diffraction pattern described by the Fresnel diffraction formula. The near field can be specified by the Fresnel number (F) of the optical arrangement. When F << 1, the diffracted wave is considered to be in the Fraunhofer field. In general, Fresnel diffraction is valid if the Fresnel number is approximately 1.

The electric field diffraction pattern at a point (x, y, z) is given by:

$$E(x, y, z) = -(i/\lambda) \iint E(x', y', 0)\ (e\hat{}(ikr)/r)\ cos\theta\ dx'\ dy'$$

Where,

$$r = \sqrt{\{(x - x')^2 + (y - y')^2 + z^2\}},$$

i is the imaginary unit and,

$$\cos\theta = \frac{z}{r}$$

This is the Fresnel diffraction integral; it means that, if the Fresnel approximation is valid, the propagating field is a spherical wave, originating at the aperture and moving along z. The integral modulates the amplitude and phase of the spherical wave. Analytical solution of this expression is still only possible in rare cases. Unlike Fraunhofer diffraction, Fresnel diffraction accounts for the curvature of the wavefront, in order to correctly calculate the relative phase of interfering waves.

1.3 FRAUNHOFER DIFFRACTION

The Fraunhofer diffraction is a phenomenon that occurs when plane waves are incident on a diffracting object, and the diffraction pattern is viewed at a sufficiently long distance (a distance satisfying Fraunhofer condition) from the object (in the far-field region), and also when it is viewed at the focal plane of an imaging lens.

Fraunhofer diffraction occurs when the Fresnel number $F = \frac{W^2}{L\lambda} \ll 1$ (Fraunhofer condition)

where, W – The largest size of a diffracting aperture or slit,

λ - Wavelength,

L - The smaller of the two distances, one is between the diffracting aperture and the plane of observation and the other is between the diffracting plane and the point wave source.The Fraunhofer diffraction observed when a light passes through an aperture, produces an intensity $I(\theta)$ proportional to the square of the Fourier transform of the aperture function. For a single slit of width **a**, the intensity is

$$I(\theta) = I_0 \left(\frac{\sin\alpha}{\alpha}\right)^2$$

Where, $\alpha = \frac{\pi a \sin\theta}{\lambda}$

I_0 - Intensity at the center ($\theta = 0$),

a - Slit width,

θ - Diffraction Angle,

λ - Wavelength of light

Key Conditions include minima at **a sinθ = mλ** where **m** = ±1, ±2,... and the central maximum at $\theta = 0$

1.4 BABINET'S PRINCIPLE

Babinet's principle states that the sum of the scattered fields by an obstacle and its complementary aperture leads to the unobstructed incident wave. It was formulated in the 1800s by French physicist Jacques Babinet.

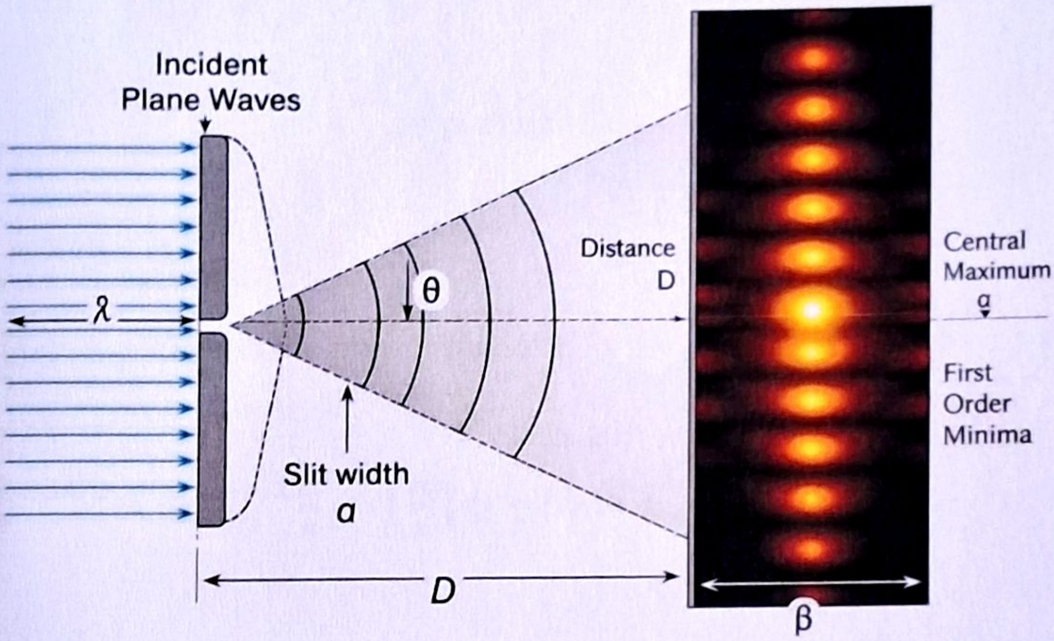
The principle is most often used in optics but it is also true for other forms of electromagnetic radiation and is, in fact, a general theorem of diffraction in wave mechanics. Babinet's principle finds most use in its ability to detect equivalence in size and shape.

Explanation of Babinet's Principle:

Assume **B** is the original diffracting body, and **B'** is its complement, i.e., a body that is transparent. The sum of the radiation patterns caused by **B** and **B'** must be the same as the radiation pattern of the unobstructed beam. In places where the undisturbed beam would not have reached, this means that the radiation patterns caused by **B** and **B'** must be opposite in phase, but equal in amplitude.

CHAPTER 2
MATHEMATICAL FORMULATION

2.1 Derivation of Diffraction Pattern



Single-Slit Fraunhofer Diffraction

Consider a monochromatic plane wave of wavelength incident on a single slit of width a. According to Huygens' principle, every point on the slit acts as a source of secondary wavelets. The interference of these wavelets produces a diffraction pattern on a screen placed at a distance D.

Let θ be the angle of diffraction.

Divide the slit into elements of width dx at position x (from −a/2 to a/2). Each element acts as a source with equal amplitude

$dA0 = A0\, dx/a$, where A0 is the total slit amplitude if in phase.

If the diffraction pattern is observed at an angle θ with respect to the central axis, the path difference for element at x relative to center is $x\sin\theta$.
Phase difference is

$$\delta = (2\pi/\lambda)x\sin\theta = (2\beta x)/a,$$

where

$$\beta=(\pi\ a\ \sin\theta)/\lambda.$$

Resultant Amplitude

The total amplitude is the phasor integral:

$$A = \int_{a/2}^{-a/2} \frac{A0}{a} e\hat{\ } i \left(\frac{2\beta}{a}\right) dx = A0/a \int_{-a/2}^{a/2} e\hat{\ } i \left(\frac{2\beta}{a}\right) d\,x$$

Evaluating gives:

$$A = A0(\sin\beta/\beta)\ ,$$

With

$$\beta= a\sin\theta/\ \lambda.$$

And A0 is the amplitude at $\theta = 0$.

This expression represents the amplitude distribution of the fraunhofer diffraction patter due to single slit. The amplitude varies with angle θ, leading to the characteristic diffraction pattern observed on the screen.

2.2 INTENSITY DISTRIBUTION EQUATION

In single-slit Fraunhofer diffraction, the intensity of light on the screen is not uniform. It varies with the angle of diffraction and forms a central bright maximum surrounded by alternating dark and bright fringes.

The intensity distribution is given by:

$$I = I_0 \left(\frac{\sin\alpha}{\alpha}\right)^2$$

Where, $\alpha = \pi a \mathrm{Sin}\theta/\lambda$

Here:

I_0 = maximum intensity at the center

a= slit width

λ = wavelength

θ = diffraction angle

The central maximum is the brightest and widest fringe. Its width is approximately twice that of the other bright fringes. As we move away from the center, the intensity of successive maxima decreases.

Minima occur when:

$$a\sin\theta = n\lambda$$

where n = ± 1 ,± 2 , ± 3,.....

This explains the formation of alternating bright and dark bands observed in the experiment.

2.3 CONDITION FOR MINIMA AND MAXIMA

From the Fraunhofer diffraction derivation for a single slit, the intensity distribution is:

$$I = I_\theta\left(\frac{\sin\beta}{\beta}\right)^2$$

where

$$\beta = \pi a \sin\theta / \lambda$$

a = width of slit (or thickness of hair by Babinet's principle)

λ = wavelength of laser

θ = diffraction angle

Condition for Minima (Dark Fringes)

Minima occur when:

$$\sin\beta = 0$$

$$\beta = m\pi$$

$$\pi\, a\sin\theta / \lambda = m\pi$$

$$a\sin\theta = m\lambda$$

Where, $m = \pm1, \pm2, \pm3, \ldots$

For small angles:

$$\sin\theta \approx \theta \approx y/D$$

$$a\,(y/D) = m\lambda$$

$$y = m\lambda D/a$$

Condition for Maxima (Bright Fringes)

- The central maximum occurs at $\theta = 0$.
- Secondary maxima occur between successive minima.
- Exact maxima positions are obtained by solving:

$$\tan\beta = \beta$$

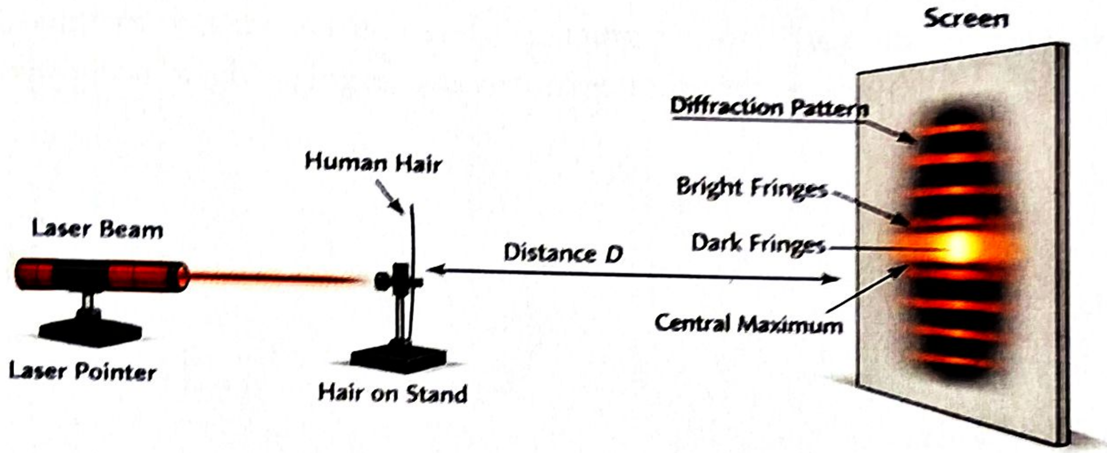
Width of Central Maximum

Distance between first minima:

$$\text{Width} = 2\lambda D/a$$

Chapter 3
EXPERIMENTAL METHODOLOGY

3.1 EXPERIMENTAL SETUP



The experiment was performed to study the Fraunhofer diffraction pattern produced by human hair and a sewing thread and to determine the slit width using diffraction principles.

According to Babinet's principle, diffraction pattern of an obstacle is equivalent to that of a slit of same width. Therefore hair and sewing thread behave like single slits.

A monochromatic light from a laser source was used to illuminate thin obstacles such as human hair or a sewing thread. The hair/thread was mounted vertically on an adjustable holder. The diffracted light emerging from the hair/thread was allowed to fall on a screen placed at a measurable distance from the slit.

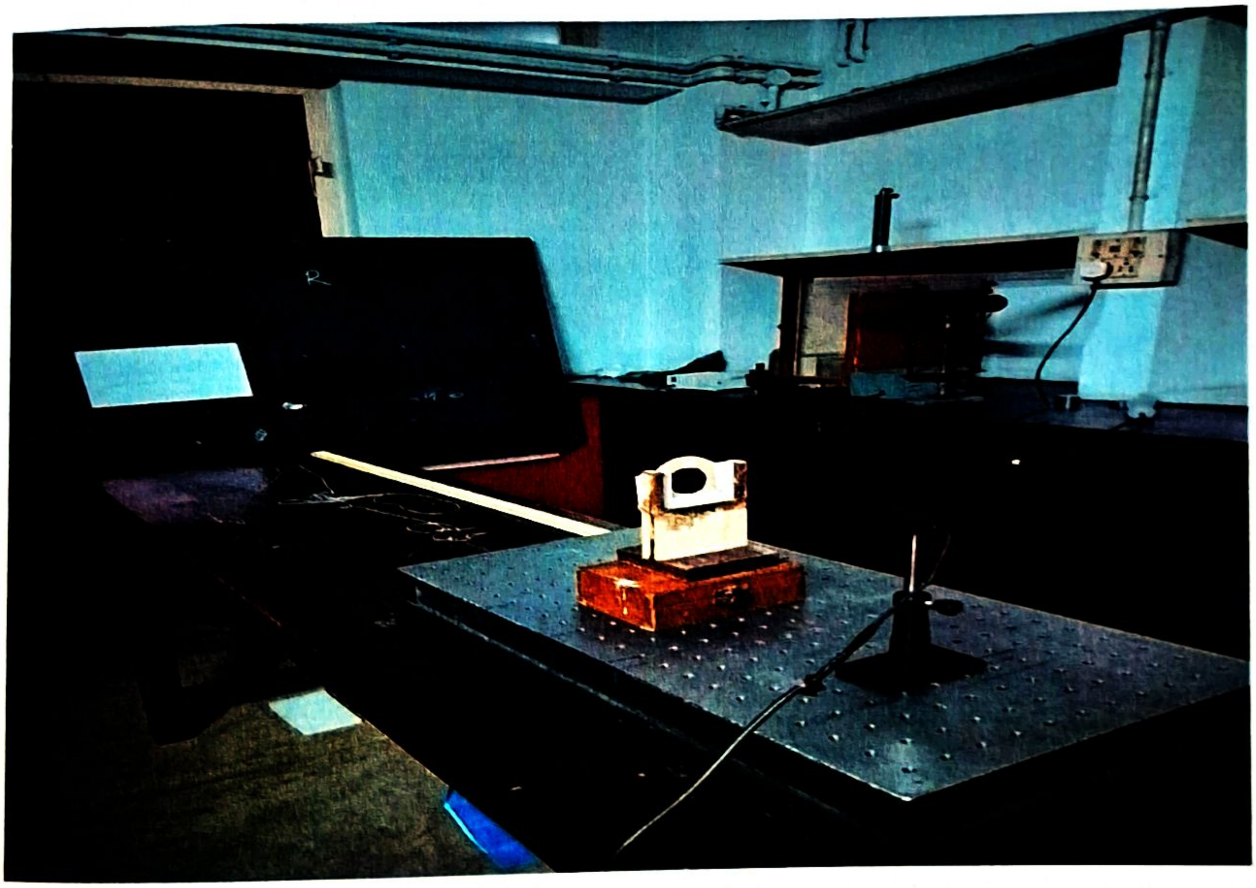
To ensure Fraunhofer diffraction conditions, the source and screen were placed sufficiently far from the hair/thread. The diffraction pattern consisting of a central bright maximum and alternating dark and bright fringes was observed on the screen.

The distance between successive maxima on either side of the central maximum was measured carefully using a scale. The distance between symmetric bright fringes was recorded to improve accuracy

3.2 APPARATUS USED

The following apparatus were used in the experiment:

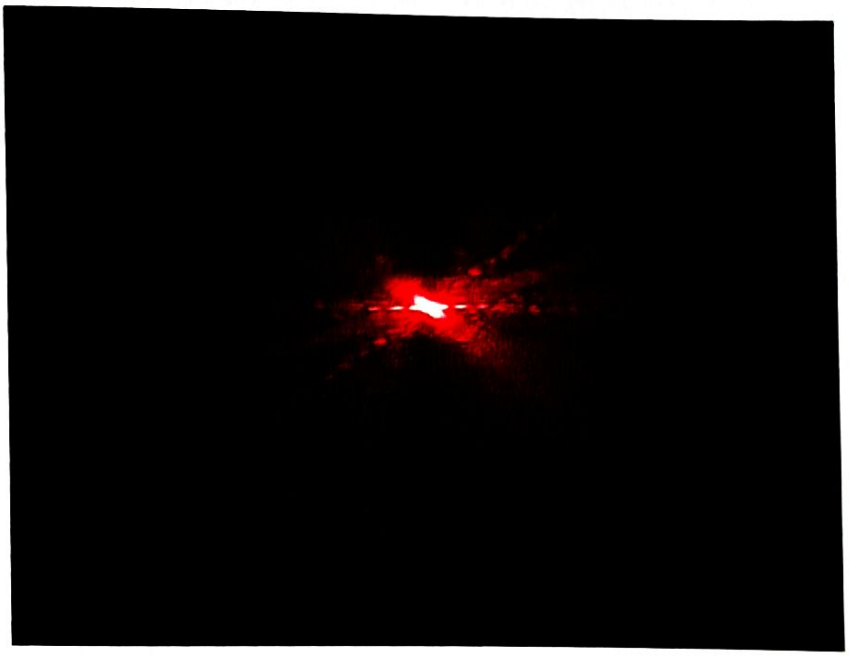
- Monochromatic light source (Laser)
- Human hair and sewing thread
- Optical bench
- Screen
- Meter scale
- Slit holder and stand



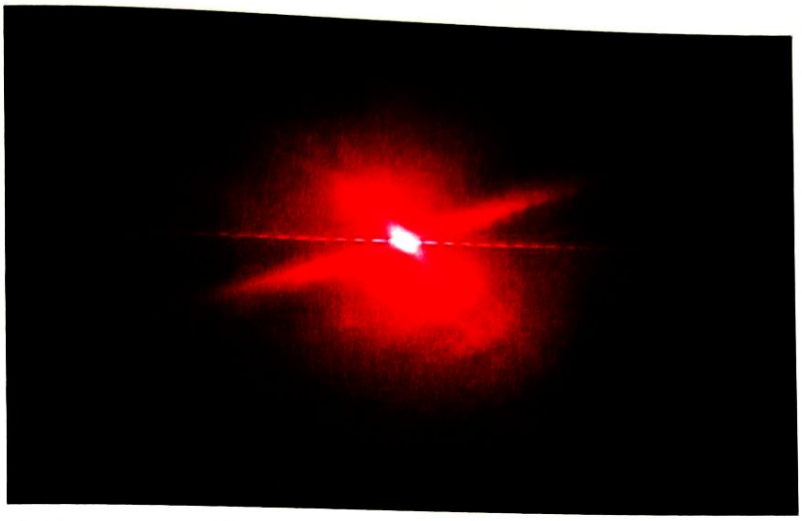
3.3 PROCEDURE

The experiment was performed in a dark room to obtain clear diffraction pattern. The laser source (λ≈ 650 nm)was placed on the optical bench and aligned properly. The human hair is stretched tightly and fixed vertically in front of the laser beam on a cardboard frame stand. The hair is placed in the path of the laser beam at a distance of about 17-20 cm from the laser. A white sheet of paper is placed as the screen at a measured distance *D* from the hair. The laser was switched on. The laser, the hair and screen are aligned so that the laser beam falls normally on the center of the hair and the diffraction pattern appears centrally on the screen the distance between the hair and the screen (D) is measured using a measuring tape. . The fringe number n is kept constant.

(DIFFRACTION PATTERN OF THREAD)



(DIFFRACTION PATTERN OF HAIR)



The central bright fringe was identified. The positions of successive bright fringes on both sides of the central maximum were marked. Mark the 3rd bright fringe on the left and 4th bright fringe on the right. Measure the total distance between these two points using a ruler.The distance between the nth order maxima on the left and right side was measured.

The fringe width β of the hair is calculated using:

$$\beta = \frac{\textit{Distance between symmetric fringes}}{2n}$$

Record the value of D and corresponding fringe width β in the observation table. The experiment is repeated using sewing thread instead of human hair and at different distances D = 120,140,160 etc.. between the hair and the and screen.

CHAPTER 4
OBSERVATION AND ANALYSIS

4.1 OBSERVATION TABLE

TO DETERMINE THE THICKNESS OF HUMAN HAIR

SL NO.	Distance between hair and screen (D) cm	No. of fringes (n)	Total width of 'n' fringes Cm	Fringe width β cm
1	100	6	4.5	0.35
2	120	6	5.6	0.46
3	140	6	6.7	0.55
4	160	6	7.9	0.65
5	180	6	9	0.75
6	200	6	10.3	0.85

No. of Fringes measured = 6

The distance between the 3rd bright fringe on the left and 3rd bright fringe on the right of the central maximum was measured.

The fringe width β of the hair is calculated using

$$\beta = \frac{Distance\ between\ symmetric\ fringes}{2n}$$

Distance between symmetric fringes = 4.5

$\beta = (4.5)/(2\text{x}6)$

$= 0.35$ cm

TO DETERMINE THE THICKNESS OF SEWING THREAD

SL NO.	Distance between screen and thread(D) Cm	No. of Fringes	Total width of n fringes Cm	Fringe width β
1	100	6	1.7	0.14
2	120	6	2.3	0.19
3	140	6	2.6	0.21
4	160	6	3.0	0.23
5	180	6	3.1	0.26
6	200	6	3.6	0.30

No. of Fringes measured = 6

The distance between the 3[rd] bright fringe on the left and 3[rd] bright fringe on the right of the central maximum was measured.

The fringe width β of the hair is calculated using

$$\beta = \frac{Distance\ between\ symmetric\ fringes}{2n}$$

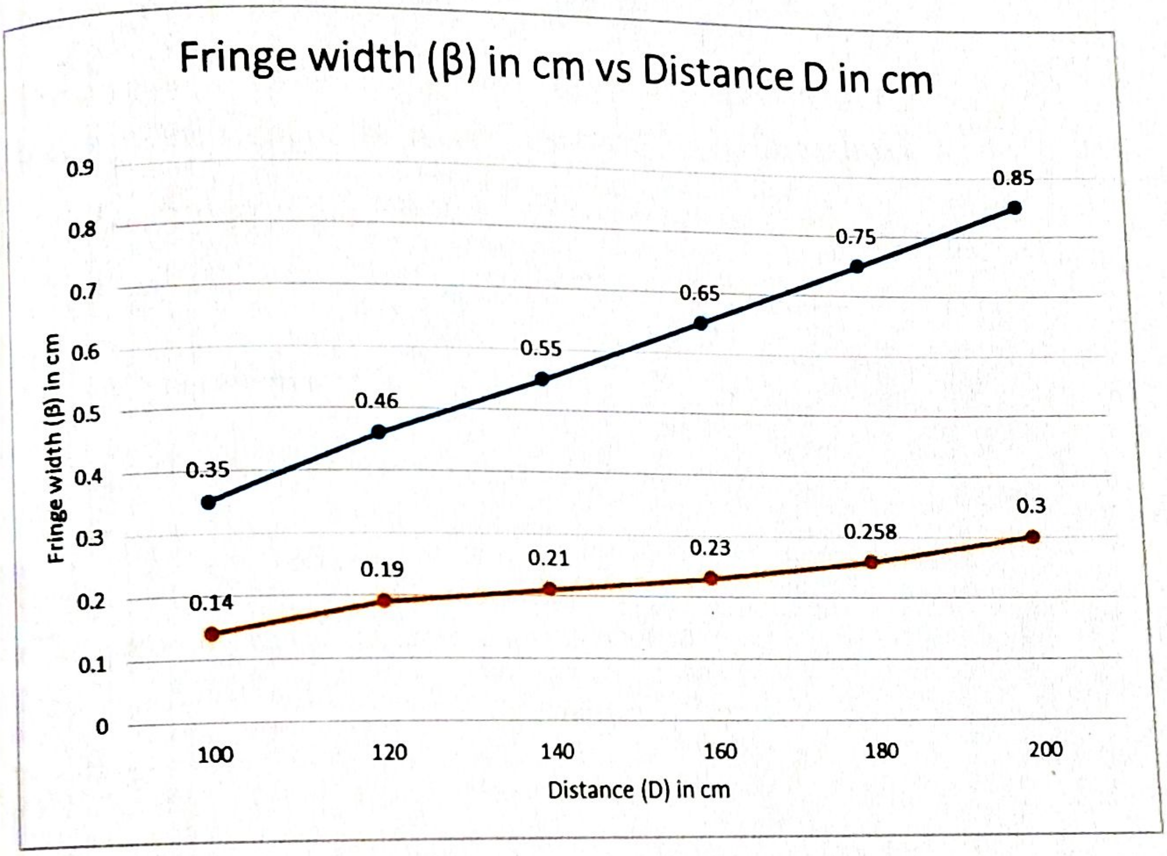
Distance between symmetric fringes = 3.1

β =(3.1)/(2x6)

= 0.26 cm

4.2 GRAPH

Graph showing variation of fringe width (β) with distance (D)



■ - Human hair

■ - Sewing thread

4.3 CALCULATION

- **TO DETERMINE THE THICKNESS OF HUMAN HAIR**

No. of Fringes measured = 6

The distance between the 3rd bright fringe on the left and 3rd bright fringe on the right of the central maximum was measured.

The fringe width β of the hair is calculated using

$$\beta = \frac{Distance\ between\ symmetric\ fringes}{2n}$$

Distance between symmetric fringes = 4.5

$$\beta = \frac{(4.5)}{(2*6)}$$

$= 0.35$ cm

The wavelength of the laser used is 650nm

$$\lambda = 650 \text{x} 10^{-7} cm$$

$$= 6.5 \text{x} 10^{-5} cm$$

From the graph

The thickness of human hair, $a = \frac{\lambda}{\text{slope}}$

$D_1 = 100$cm $\quad\quad D_2 = 200$

$\beta_1 = 0.35$cm $\quad\quad \beta_2 = 0.85$

$$\text{Slope} = \frac{\beta 2 - \beta 1}{D2 - D1}$$

$$= \frac{0.85 - 0.35}{200 - 100}$$

$$= \frac{0.5}{100}$$

slope = $5x10^{-3}$

therefore the thickness, $a = \frac{\lambda}{\text{slope}}$

$$= \frac{6.5x10-5}{5x10-3} = 0.013\text{mm}$$

- **TO DETERMINE THE THICKNESS OF SEWING THREAD**

No. of Fringes measured = 6

The distance between the 3rd bright fringe on the left and 3rd bright fringe on the right of the central maximum was measured.

The fringe width β of the hair is calculated using

$$\beta = \frac{\text{Distance between symmetric fringes}}{2n}$$

Distance between symmetric fringes = 1.7

$$\beta = \frac{(1.7)}{(2*6)}$$

= 0.14 cm

The wavelength of the laser used is 650nm

$\lambda = 650x10^{-7}\,cm$

$= 6.5x10^{-5}\,cm$

From the graph

The thickness of the sewing thread, $a = \frac{\lambda}{\text{slope}}$

D_1 =100cm D_2 = 200cm

$\beta_1 = 0.14cm$ $\beta_2 = 0.30cm$

$$\text{Slope} = \frac{\beta 2-\beta 1}{D2-D1}$$

$$= \frac{0.30-0.14}{200-100}$$

$$= \frac{0.16}{100}$$

$$\text{slope} = 1.6x10^{-3}$$

therefore the thickness, $a = \frac{\lambda}{\text{slope}}$

$$= \frac{6.5x10-5}{1.6x10-3} = 0.04062mm$$

4.4 ERROR ANALYSIS

- **Instrumental Error**

Least count of measuring scale = 0.1cm

Since fringe distance is measured using a ruler, the maximum possible error in measurement is ± 1

- **Percentage Error in Thickness**

Percentage error is calculated using:

$$\%Error = \frac{estimated\ error}{measured\ value} \text{x}100$$

If measured thickness, a = 0.041mm
Assume uncertainty in β measurement produces an estimated error of $\pm 0.002mm$
then,

$$\%\text{Error} = \frac{0.002}{0.041} \text{x } 100$$

$$= 4.87$$

- **Source of error**

- Hair/ thread may not be perfectly vertical.
- Laser beam may not be exactly perpendicular to the hair.
- Difficulty in locating exact position of bright fringes.
- Parallax error while measuring fringe distance.

- Slight divergence of laser beam.
- Human reaction error in marking fringes.

- **Methods to Reduce Error**
    - Measure multiple fringes instead of one.
    - Use symmetrical fringes (left and right).
    - Perform experiment in dark room.
    - Repeat readings and take average.
    - Ensure proper alignment of laser and hair.

CHAPTER 5
RESULT AND APPLICATIONS

RESULT:

From the graph plotted between fringe width (β) and distance (D), a straight line was obtained.

Using the slope of the graph and the relation:

$$a = \frac{\lambda}{SLOPE}$$

The thickness of the given thread was calculated.

The diameter of the given thread is found to be:

Thickness of Human hair:

$a = 0.013$mm

Thickness of sewing thread:

$a = 0.0406$mm ≈ 0.041mm

Hence, the experimental value of the thickness of the given thread using laser diffraction method is 0.041mm and for hair 0.013mm.

APPLICATIONS:

- Used to determine thickness of very thin objects like hair, thread, or fine wires.

- Principle of diffraction is used in optical instruments such as spectrometers.

- Used in measuring wavelength of laser light.

- Applied in quality testing of thin fibres in textile industries.

- Important in wave optics to study diffraction and interference phenomena.

- Used in research laboratories for precise microscopic measurements.

CONCLUSION

The diffraction patterns produced by laser light due to obstruction by a hair and a thread were observed and measured carefully. A graph was plotted between fringe width (β) and distance (D), which resulted in a straight line. This verified that fringe width is directly proportional to the distance between the obstacle and the screen.

Using the slope of the graph and the diffraction formula,

$$a = \frac{\lambda}{SLOPE}$$

the thickness of both the hair and the thread was calculated.

The diameter of the hair was found to be approximately:

$a_{\text{hair}} = 0.013$ mm

The diameter of the thread was found to be:

$a_{\text{thread}} = 0.041$mm

Thus, the experiment successfully demonstrated the principle of Fraunhofer diffraction and showed that laser diffraction can be used to measure extremely small thicknesses accurately.

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