Fresnel Biprism Experiment

Under-Graduate Science Laboratory – BS 192 (Group - 7)

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1 Objective

The objective of this experiment is to determine the wavelength of sodium light using Fresnel's biprism, which is an essential method in optics to study the interference patterns of light. In this method, a biprism is used to divide a single beam of sodium light into two virtual coherent sources, which then overlap and form an interference pattern on a screen. By carefully measuring the distance between the interference fringes and using known distances in the setup, we can calculate the wavelength of the sodium light. This experiment helps us understand the wave nature of light and the phenomenon of interference in a straightforward and practical way.

2 Apparatus Description

- **Optical Bench**: A long, stable platform that holds all the apparatus components in place. It allows precise alignment and measurement of distances between different parts of the setup. .
- **Sodium Lamp**: A source of monochromatic light, which is ideal for creating clear interference patterns.
- **Uprights**: Adjustable stands that hold the slit, biprism, lens, and micrometer eyepiece securely on the optical bench. They help in positioning the components accurately along the bench.

- **Slit**: A narrow, adjustable opening through which the sodium light passes, forming a fine, coherent beam necessary for interference.
- **Biprism**: A prism with a very small refracting angle, which splits the single beam of light from the slit into two coherent virtual sources. These sources overlap and produce an interference pattern.
- **Convex Lens**: Used to focus the light and to determine the distance between the virtual sources.
- **Micrometer Eyepiece**: A measuring device with a fine-scale eyepiece used to measure the fringe width accurately on the screen formed by the interference pattern.

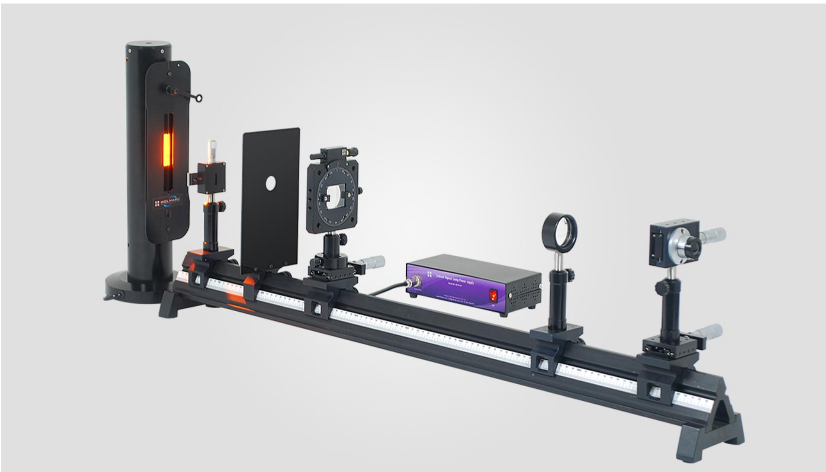

Figure 1: Apparatus for Fresnel Biprism experiment[1].

3 Theory

3.1 Historical Background[2]

The Fresnel biprism experiment, named after the French physicist Augustin-Jean Fresnel, was devised in the early 19th century to demonstrate the phenomenon of interference of light. Fresnel, a pioneer in wave optics, developed this experiment to support the wave theory of light, which was at the time competing with Newton's corpuscular theory. The experiment was first performed in 1819, a few years after Thomas Young's famous double-slit experiment, and served as further evidence for the wave nature of light. By using a biprism, a device consisting of two prisms placed base to base, Fresnel was able to split a single wavefront into two, creating two virtual coherent sources. This allowed him to observe interference fringes and further confirm the wave behavior of light, a crucial discovery in the field of optics.

3.2 Principle

Fresnel's biprism is an experiment used to demonstrate the interference of light. It consists of a biprism, which is basically two prisms with a small refracting angle (0.5–1°) joined at the base to form a sharp edge. Monochromatic light of wavelength λ falls on the biprism through a narrow slit S, resulting in two emergent waves that appear to originate from virtual sources S_1 and S_2. These sources are coherent as they are from the same source S, which allows them to interfere with each other, creating a pattern of bright and dark fringes. This can be observed by the eyepiece after the removal of the lateral shift.

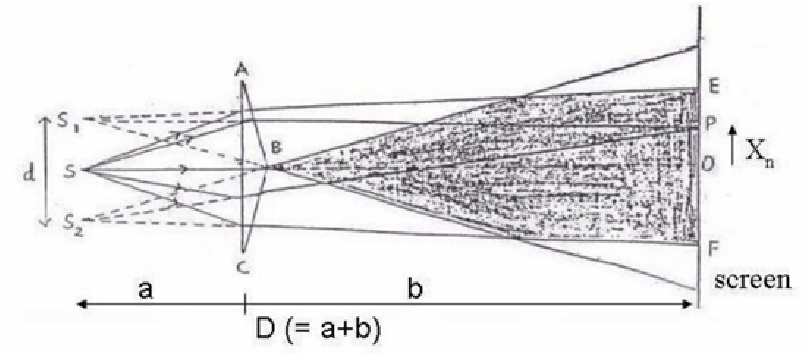

Figure 2: Illustration of Fresnel's biprism experiment[3].

Consider the point P, where light incidents form two virtual sources S_1 and S_2; their path difference at this point is given by S_2P - S_1P. It can be further calculated as follows:

$S_1S_2 = d$ and $SO = D$, D is the distance between the source and the screen

$$S_1P = D\left(1 + \frac{1}{2}\left(\frac{\frac{d}{2} + X_n}{D}\right)^2\right)$$

$$S_2P = D\left(1 + \frac{1}{2}\left(\frac{\frac{d}{2} - X_n}{D}\right)^2\right)$$

OP = $\mathrm{X_n}$, and it is assumed that $\frac{d}{2} \pm X_{\mathrm{n}}$ is very small compared to D. Therefore, the path difference is:

$$S_2P - S_1P \approx \frac{d}{D}X_{\mathrm{n}}$$

Let $\mathrm{X_n}$ be the position of the nth fringe; then the path difference is $n\lambda$.

$$\frac{d}{D}X_{\mathrm{n}} = n\lambda$$

Let x be the fringe width then:

$$x = (X_{\mathrm{n}} - X_{\mathrm{n\text{-}1}}) = \lambda\left(\frac{D}{d}\right)$$

From the above equation,

$$\lambda = \frac{dx}{D}$$

Using the above equation, we can solve for wavelength once we have the value for d. To obtain the d, we find $\mathrm{d_1}$ and $\mathrm{d_2}$ by using the conjugate foci method. For this, a convex lens is placed upright and moved between the biprism and the eyepiece to form magnified and diminished images of the virtual sources. This is only formed if the eyepiece is placed at a distance from the slit which is greater than four times the focal length (f) of the lens.

4 Experimental Procedure

1. **Initial Setup:**
   - Place all four uprights along the length of the optical bench: the slit, biprism, convex lens, and micrometer eyepiece holders.
   - Adjust the height of each upright so that the centers of the slit, biprism, lens holder, and eyepiece are aligned at the same height and perpendicular to the axis of the bench.

- Ensure that the slit is set to a 'just open' condition to produce a fine beam of light.

2. **Mounting the Biprism::**
    - Fix the biprism holder on the second upright from the light source, ensuring the plane face of the biprism is facing the slit.
    - Position the biprism approximately 10 cm away from the slit. The refracting edge should be aligned with the slit's center using the side knob for lateral movement.
    - Rotate the biprism vertically about the horizontal axis using its holder and lock it in place with a tangent screw for fine adjustments.
3. **Positioning the Eyepiece:**
    - Place the micrometer eyepiece approximately 1 meter away from the biprism. Adjust its height to align with the optical path.
    - Remove the eyepiece to directly view the two virtual slit images through the biprism. If needed, adjust the biprism laterally using the base knob until the two virtual slits are clearly visible.
4. **Fringe Observation:**
    - Reinsert the micrometer eyepiece and observe the interference pattern of bright and dark fringes.
    - If fringes are not visible, adjust the biprism laterally or rotate it slightly for sharpness using the tangent screw. You may also fine-tune the slit width for better fringe clarity.
    - Set the distance between the slit and biprism to about 515 mm to optimize fringe visibility.
5. **Checking for Lateral Shift:**
    - Move the eyepiece closer to the biprism while observing the fringe pattern. If the fringes shift laterally with respect to the vertical crosswire in the eyepiece, adjust the biprism laterally in small steps until no shift is observed over a 1-meter eyepiece movement.
6. **Removal of Lateral Shift:**

- If the fringes shift to the left or right when moving the eyepiece backward, adjust the biprism laterally in the opposite direction. Repeat this process until the fringe pattern remains stationary.

7. **Fringe Measurement:**

   - Lock the eyepiece at approximately 1 meter from the slit. Align the vertical crosswire with the center of a bright fringe and record its position as x_o.
   - Move the micrometer screw to shift the crosswire to subsequent fringes (bright or dark) and record each position x_p. Repeat for several fringes to gather a series of readings.

8. **Measurement of Distance (D):**

   - Measure and record the positions of the slit and eyepiece along the bench to calculate the distance D between them. Ensure to account for any bench calibration errors.

9. **Measurement of Distance (d) Between Virtual Sources:**

   - Without disturbing the setup, use the conjugate foci method with the convex lens to measure the distance between the two virtual sources created by the biprism.
   - Take two sets of measurements, d_1 and d_2, at different positions of the lens. Calculate the actual distance d using the formula:

   $$d = \sqrt{d_1 \times d_2}$$

10. **Calculating the Wavelength (λ)**

    - Use the formula for fringe width:

    $$x = \frac{\lambda D}{d}$$

    Rearrange to calculate the wavelength λ by substituting the measured values of fringe width (x), distance between virtual sources (d), and the distance between the slit and eyepiece (D):

    $$\lambda = \frac{xd}{D}$$

5 Results and Discussion

Fresnel's biprism is a technique employed to determine the wavelength of light by analyzing the interference pattern resulting from diffraction. It is an advanced method for studying wave properties of light. The fringe width observed in the interference pattern allows for the calculation of the wavelength λ.

If x is the fringe width of the interference pattern, the wavelength λ is given by:

$$\lambda = \frac{xd}{D}$$

where:

- λ is the wavelength of the light,
- D is the distance between the light source and the screen (or eyepiece),
- d is the separation between the virtual (coherent) sources.

To measure the position of the bright fringes, a micrometer screw is used. The position X can be calculated as:

$$X = \text{M.S.R} + \text{C.S.R} \times \text{L.C} \tag{2}$$

where:

- M.S.R is the Main Scale Reading,
- C.S.R is the Circular Scale Reading,
- L.C is the Least Count of the micrometer screw.

Since the experiment relies on measuring differences in positions, zero error in the micrometer screw can be disregarded. The least count of the micrometer screw used in this experiment is 0.01 mm.

5.1 Calculation of Fringe Width

The fringe width can be determined using two methods. The first method involves calculating the difference in fringe positions (The positions of the bright fringes were calculated using Equation (2)) and dividing it by the difference in fringe numbers, Δm. The second method consists of plotting a graph of fringe positions against fringe numbers, where the slope of the resulting line corresponds to the fringe width.

Fringe Number	M.S.R	C.S.R	Position (in mm)
0	11	73	11.73
3	12	30	12.30
6	12	90	12.90
9	13	45	13.45
12	14	07	14.07
15	14	64	14.64
18	15	21	15.21
21	15	81	15.81
24	16	44	16.44
27	16	94	16.94
30	17	59	17.59

Table 1: Measured positions of bright fringes

5.1.1 Method 1

There are 15 possible values for the fringe width.

The average fringe width is:

$$x_{\text{avg}} = 0.31\,\text{mm}.$$

The standard deviation of the calculated fringe width values is:

$$\sigma = 0.0087\,\text{mm}.$$

The percentage error for this method is calculated as:

$$\%\,\text{error} = \frac{\sigma}{x_{\text{avg}}} = 2.8\%.$$

Thus, the final calculated fringe width is:

$$x = 0.31\,\text{mm} \pm 0.02\,\text{mm}.$$

5.1.2 Method 2 (Slope Method)

In the second method, the fringe width is determined by fitting a linear curve to the measured positions of the bright fringes versus their corresponding fringe numbers. This approach involves plotting the fringe positions as a function of fringe numbers and then using a linear regression to find the best-fit line. The slope of this line, obtained using polynomial fitting (specifically a first-degree polynomial), represents the fringe width. The slope is calculated using the least squares method, which minimizes the sum of the squares of the vertical distances of the points from the fitted line. This method provides an accurate measurement of the fringe width and offers a visual representation of the data, making it an effective technique for determining the wavelength of light in interference experiments.

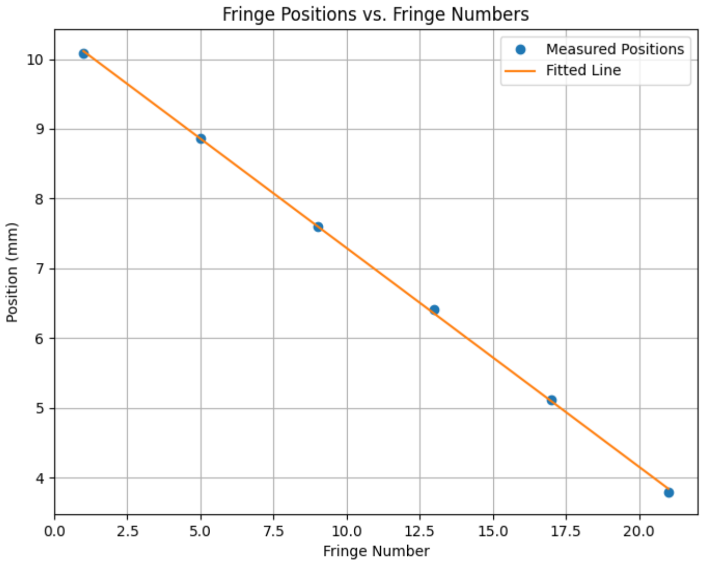

Figure 3: Fringe Position vs. Fringe Number.

The slope was found to be 0.3137, so the fringe width is approximately 0.31 after rounding.

5.2 Calculation of Distance between Virtual/Coherent Sources

To determine the distance between the virtual sources (d), we place a convex lens between the biprism and the eyepiece. The convex lens is adjusted until clear images of the two virtual sources are obtained, either enhanced or diminished. The distance between these two bands of light (virtual sources) is then measured.

Let d_1 and d_2 represent the separations between the images. These values are computed using:

$$d_i = (M \cdot S \cdot R + C \cdot S \cdot R \times L \cdot C) - (M \cdot S \cdot R' + C \cdot S \cdot R' \times L \cdot C)$$

where the least count (L.C) of the micrometer screw is 0.01 mm, and $i \in \{1, 2\}$. Since d_i is derived from the difference between two measurements with the micrometer screw, its least count is twice that of the micrometer screw, i.e., $\Delta d_i = 0.02$ mm, where $i \in \{1, 2\}$.

The distance between the virtual sources (d) is then calculated using:

$$d = \sqrt{d_1 \times d_2}$$

The values of d1 and d2 are calculated as:

$$d_1 = 0.58 \text{ mm} \quad \text{and} \quad d_2 = 5.45 \text{ mm}$$

To determine the least count of d, we first take the logarithm of both sides of the equation and differentiate:

$$\log(d) = \frac{1}{2} (\log(d_1) + \log(d_2))$$

$$\frac{\Delta d}{d} = \frac{1}{2} \left(\frac{\Delta d_1}{d_1} + \frac{\Delta d_2}{d_2} \right)$$

Substituting the values, we find the least count:

$$\Delta d = \frac{1.778 \times 0.02}{2} \left(\frac{1}{0.58} + \frac{1}{5.45} \right) = 0.034 \text{ mm}$$

Thus, the least count of d is $L.C = 0.034$ mm.
The calculated value of d is:

$$d = 1.778 \text{ mm} \pm 0.034 \text{ mm}$$

	P	P'	$P - P'$
d_1	10.88	11.46	0.58
d_2	8.21	13.66	5.45

Table 2: Measurements for d_1 and d_2

5.3 Calculation of Wavelength

Using the measured fringe width and the separation between the virtual sources, we can determine the wavelength of the incident light.

The distance between the source and the eyepiece (D) is measured to be $D = 1000$ mm, with a least count of $\Delta D = 2$ mm.

The fringe width was found to be 0.31 mm, with a least count of 0.02 mm.

To compute the least count of the wavelength (λ), we use the following formula:

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta x}{x} + \frac{\Delta d}{d} + \frac{\Delta D}{D}$$

where x, d, and D are substituted with their respective mean values. Substituting the values for d, D, and x into the wavelength equation:

$$\lambda = \frac{0.31 \times 1.778}{1000}$$

$$\lambda = 551.18 \text{ nm}$$

To determine the least count of λ, we use:

$$\Delta\lambda = 551.18 \times \left(\frac{0.02}{0.31} + \frac{0.034}{1.778} + \frac{2}{1000}\right)$$

$$\Delta\lambda = 47.18 \text{ nm}$$

Thus, the calculated wavelength of the incident light is:

$$\lambda = 551.18 \pm 47.18 \text{ nm}$$

Conclusion

The objective of this experiment was to measure the wavelength of sodium light using the Fresnel Biprism method. The findings are summarized as follows:

- The calculated fringe width was $0.31\,\text{mm} \pm 0.02\,\text{mm}$.
- The separation between the two virtual sources was measured to be $1.778\,\text{mm} \pm 0.034\,\text{mm}$.
- The wavelength of sodium light was found to be $\lambda = 551.18 \pm 47.18\,\text{nm}$.

- **Sources of Error:** Potential sources of error in this experiment include:
  - **Contamination:** Dust particles or imperfections on the biprism could affect the quality of the diffraction fringes, causing shifts in their observed positions.
  - **Human Error:** Deviations in measurements may also arise from human error, particularly in the manual reading of micrometer screws and alignment of optical components.
  - **Resolution Limitations:** The difficulty in resolving very fine fringes could contribute to inaccuracies in determining the fringe width and distances.
- Despite these potential sources of error, the experiment successfully measured the wavelength of sodium light. The results are consistent with the expected range, though attention to experimental conditions and precision can enhance measurement accuracy.

6 Author Contributions

- **Birudugadda Srivibhav**
  - Collected and recorded the experimental data.
  - Created and formatted the tables and figures used in the report.
  - Compiled the results section, including interpreting the data and comparing observed values with theoretical ones.
- **Vubbani Bharath Chandra**
  - Collected and recorded the experimental data.
  - Formatted and finalized the report.
- **Ankeshwar Ruthesha**
  - Collected and recorded the experimental data.
  - Wrote Objective, Apparatus description, Theory and Experimental Procedure
- **Kirtankumar Patel**
  - Generated plots using Python based on the experimental data.

7 References

1 Holmarc, "Difference Biprism," *Holmarc*. [Online]. Available: `https://holmarc.com/differ-biprism.php`. [Accessed: Sep. 9, 2024].

2 R. Robinson, "Fresnel Biprism Experiment," *Trinity College Dublin*, Oct. 2013. [Online].

3 J. A. Author, "Schematic of the Fresnel Biprism Interferometer Employing LED," *ResearchGate*, fig. 1, Sep. 2018. [Online].

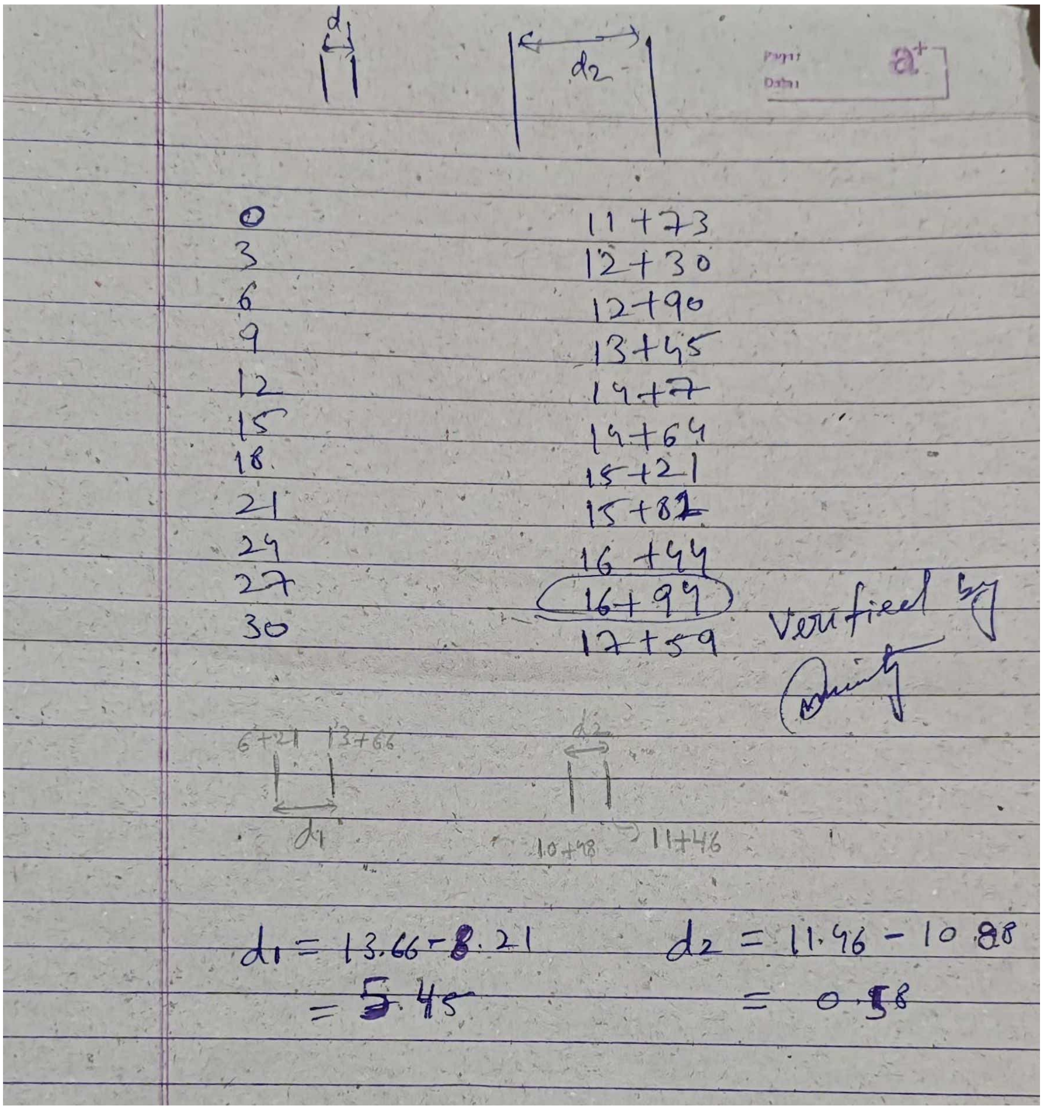

Figure 4: Lab Recordings