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Effect of Slit Separation and Screen Distance on Double-Slit Interference and Calculated Monochromatic Wavelength

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TABLE OF CONTENTS

1. INTRODUCTION

Light is a physical phenomenon that plays a fundamental role in human life. It enables us to see, measure distances, communicate, and even utilize it in medical applications.[1] For centuries, the nature of the light remained a mystery. Early scientists thought that the distribution of light was like the distribution of particles.[2] However, the double-slit experiment performed by Thomas Young in the early 19th century provided strong evidence that light behaves like a wave.[3,4]

In his double-slit experiment, Thomas Young demonstrated that the interference pattern obtained by passing monochromatic (single-colored) light through two narrow slits in a dark environment is related to the principles of wave superposition of light.[3,5] Moreover, Young's conclusion in this experiment not only revolutionized optics but also played a fundamental role in the development of wave theory and eventually quantum mechanics. [5,6]

In this experiment, I investigate how the distance between the slits and the screen affects the interference pattern and how this pattern can be used to calculate the wavelength of light.[3] The experiment offers a useful measurement method for calculating wavelength, a fundamental attribute of light, in addition to reinforcing the core theoretical ideas of wave optics.[7] Finally, this study will discuss the simplicity and the richness of the double-slit experiment to reinstate the reason why it is the main point of physics teaching and theory even after over two hundred years.[2,6]

2. AIM

In the experiment, slit separation (d) and the slit-to-screen distance (L) are tested to determine their effect on the double-slit interference pattern. By varying d and L systematically and measuring fringe spacing, the wavelength of monochromatic light is calculated. The results are then used to evaluate the wave nature of light and the superposition principle.

3. RESEARCH QUESTION

How do variations in the distance between the slits and the distance from the slits to the screen affect the interference pattern and the calculated wavelength of monochromatic light in a double-slit experiment?

4. BACKGROUND INFORMATION

4.1 Nature of Light;

Light is an electromagnetic wave that consists of oscillating electric and magnetic fields that propagate perpendicularly to each other and to the direction of travel. According to Maxwell's electromagnetic theory, the speed of light in a vacuum is given by:

$$c = \frac{1}{\sqrt{\mu 0 \varepsilon 0}}$$

where;

- μ_0 is the magnetic permeability of free space
- ε_0 is the electric permittivity of free space
- c is the speed of light

The constant ε_0 represents how an electric field can exist and propagate in a vacuum, while μ_0 describes how a magnetic field interacts with the vacuum. Together, these constants determine how electric and magnetic fields influence one another and how electromagnetic waves travel through space. Their presence in Maxwell's equation shows that light is fundamentally an electromagnetic phenomenon.[11,12]

This theoretical derivation corresponds to the measured value of 3.00×10^8 m/s, confirming that light is an electromagnetic phenomenon.[11] The superposition of electromagnetic waves passing through the two slits produces alternating bright and dark fringes on the screen, allowing the wavelength of light to be determined from the observed fringe spacing. Therefore, Maxwell's theory provides the theoretical foundation for understanding the wave behavior that gives rise to the interference pattern analyzed in this investigation.[3,11,12]

4.1.1 Historical Context and Discovery

Before the 19th century, Isaac Newton proposed that light behaves similarly to particles, known as corpuscles.[2] This particle model successfully indicated phenomena such as reflection and refraction by dominating scientific thought for many years. However, with the double-slit experiment conducted by Thomas Young in 1801, it was discovered that light not only exhibits particle-like behavior but also has wave-like behavior.[3,4] Such patterns arise only from the superposition of waves rather than from the collision of particles. Young's findings provided groundbreaking evidence for the wave nature of light and laid the foundation for wave optics.[5,6]

Young's double-slit experiments provided decisive evidence for the wave nature of light and helped establish wave optics.[5,6] They also supported earlier wave-based ideas proposed by scientists such as Christiaan Huygens. The double-slit experiment remains one of the most important in physics because it reveals key properties of light that classical particle theory alone cannot explain.

4.1.2 Wave-Particle Duality

Later advancements in quantum mechanics exposed that light also exhibits particle-like behavior, with each photon carrying energy $E = hV$[5]. However, in interference phenomena, the wave nature dominates, even individual photos produce interference patterns when accumulated over time.[6,7]

Nonetheless, the interference pattern is governed by the wave behavior of light. Even when monochromatic photons are emitted one at a time, the pattern builds up gradually on the screen. This indicates wave-like propagation through space and particle-like, localized detection at the screen.

This two-sided action is referred to as the wave-particle duality, which is the fundamental fact of quantum physics. It emphasizes the drawbacks of classical models and indicates that a quantum mechanical model is needed to explain the behavior of light.[6,11] In this experiment, the detection of an interference pattern is direct evidence of the wave nature of light and the theoretical basis for analyzing fringe spacing and wavelength.

4.2 Principle of Superposition and Interference:

4.2.1 Superposition of Waves

When two or more waves overlap, the resulting displacement at any point is the algebraic sum of the individual displacements produced by each wave. This action is referred to as the principle of superposition. This principle states that waves do not change each other since they travel through the same space. Rather, they simply combine, the effects to create a compound wave pattern.

This is the key to the concept of interference. A double-slit experiment is one in which the light waves that are produced by the two slits intersect and also overlay the screen. In places where the waves are in phase, the displacements of the waves combine constructively to form bright fringes, and at places where the waves are out of phase, the displacements of the waves cancel either partially or wholly to form dark fringes. Thus, the principle of superposition furnishes the physical explanation of the appearance of the alternate bright and dark interference wave in this experiment:

$y_1 = A\sin(\omega t)$

$y_2 = A\sin(\omega t+\phi)$.

Their superposition yields:

$$y = y_1 + y_2 = 2A\cos(2\phi)\,\sin(\omega t + 2\phi).$$

Since intensity is proportional to the square of amplitude, the total intensity becomes:

$$I = I_0 \cos^2(\frac{\phi}{2})$$

The variation of the strength with the difference in phases is given by this association.[8]

4.2.2. Constructive and Destructive Interference

Equation (1) illustrates that:

- **Constructive Interference:** Bright fringe occurs when $\phi = 2n\pi \Rightarrow I = I_0$
- **Destructive Interference:** Dark fringe occurs when $\phi = (2n + 1)\pi \Rightarrow I = 0.$

It is these alternate stripes of light that create the interference pattern that is observed in the Thomas Young double slit experiment.

4.2.3 Relation Between Phase and Path Difference

Phase difference (Δs) depends on the difference in the path (ϕ).

$$\phi = \frac{2\pi\Delta s}{\lambda}$$

Therefore, for constructive interference,

$$\Delta s = n\lambda,$$

and for destructive interference,

$$\Delta s = (n + \frac{1}{2})\lambda.$$

It is on the basis of this direct relationship that periodic bright and dark bonds are formed.[5,12]

The wave superposition principle does not only support the wave theory of light, it also serves to mathematically and conceptually explain complicated interactions of waves in optics, acoustics, and even in quantum mechanics. It is one of the most useful instruments in physics education because of its visual demonstration in the case of the double-slit experiment.[5,7]

4.3 Thomas Young's Double Slit Experiment:

4.3.1 Experimental Setup

In the layout of Thomas Young, there is a single-colored light that is passed through two slits, separated by a distance (d). Their amplitude is higher since the crests and troughs of the waves are aligned or are in phase. Consequently, the waves intersect, and an interference pattern is produced on a dark screen at a distance, L, of the barrier.[3,6]

4.3.2 Derivation of the Fringe Equation

From the geometry of the setup, the path difference between the waves reaching a point P on the screen is $d \times sin\theta$.

Constructive interference occurs when;

$$d \times sin\theta = n\lambda.$$

Under the small-angle approximation, the fringe location x_n for the n^{th} bright band is:

$$x_n = \frac{n\lambda L}{d}$$

The spacing between adjacent bright fringes is therefore

$$\Delta x = \frac{\lambda L}{d}$$

This relation shows that fringe spacing increases with screen distance L and wavelength λ\ but decreases as slit separation d increases.

4.3.3 Intensity Distribution

The distribution of intensity across the screen follows

$$I(\theta) = I_0 \cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$$

where;

- I(θ) represents the resultant intensity at an angle θ.
- I_0 indicates the maximum intensity.
- d is the slit separation
- λ is the wavelength of light

The equation illustrates the variation in brightness caused by interference. [9,12]

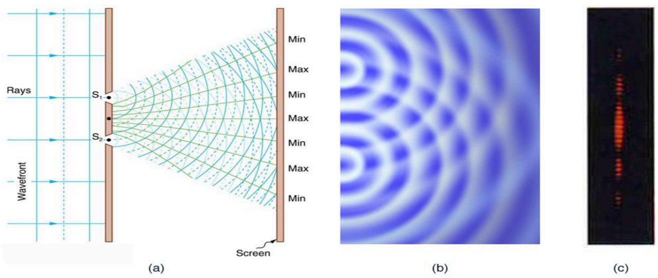


Figure 1: The formation of fringes on the screen

(*Young's Double Slit Experiment | Physics*, n.d.)

4.4 Diffraction Effects and Combined Pattern

Each slit causes diffraction, resulting in the superposition of two waves that creates an interference pattern. Because the interference pattern also occurred in this experiment, Thomas Young observed that light would exhibit wave-like behavior. Had light been composed of particles only, there would be no continuity of the pattern of interference, but two bright spots representing the slits.[2,4]

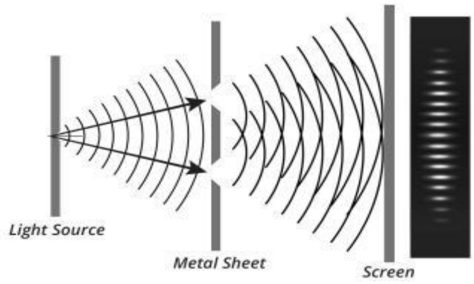


Figure 2: Mechanism of the Double Slit Experiment
(*Redirect Notice*, n.d.)

The combined effect is expressed as;

$$I(\theta) = I_0 \cos^2 \left(\frac{\pi d sin\theta}{\lambda}\right) \left[\frac{sin(\beta)}{\beta}\right]^2, \ \beta = \frac{\pi a \ sin(\vartheta)}{\lambda}$$

where:

- a is the slit width
- sin(β) ÷ β represents the single-slit diffraction envelope that determines fringe contrast.

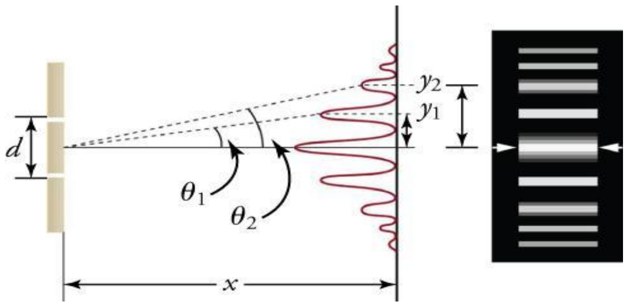


Figure 3: Combined interference and diffraction
(*17.1 Understanding Diffraction and Interference | Texas Gateway*, n.d.)

4.5. Monochromatic Light:

Monochromatic light is light that is made up of one wavelength and hence one colour of the visible spectrum. When applied to the wave theory, it is said to be a wave that has a constant frequency and wavelength. The word monochromatic literally means one color, and it is an important aspect in experiments, which include interference, like in the experiment of two slits done by Young.

The necessity of using monochromatic light is that it makes coherence and uniformity to achieve clear and measurable patterns of interference. When white light or multicoloured light was used, there would be overlapping waves of different frequencies, and this would lead to a blurred or washed-out interference pattern because of different fringe separations.[3,6]

The modern physics experiments normally employ lasers as sources of monochromatic light. They are highly temporally and spatially coherent sources of light, which allows them to be used in studying the effects of interference.[7]

In this experiment, a red laser will be employed because it is the most accessible, safe, and familiar wavelength that is easier to measure and compare with theoretical values.[3,6]

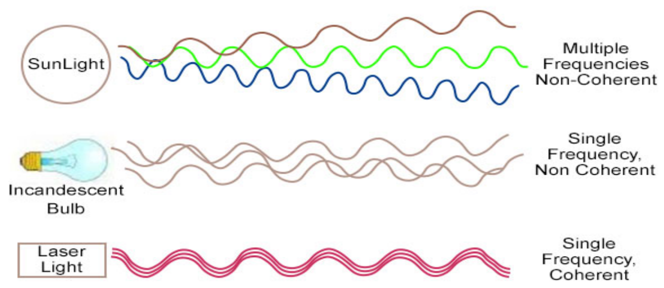


Figure 4: Monochromatic and Other Lights

(*What Is a Monochromatic Light? - GoPhotonics.com*, n.d.)

5. HYPOTHESIS

If the distance between the slits and the screen increases, then the fringe spacing in the interference pattern will also increase proportionally.[3] Similarly, if the distance between the two slits increases, the fringe spacing will decrease.[6] This is because, according to the equation

$$X = \frac{\lambda \cdot L}{d}$$

where x is the fringe spacing, L is the distance from the slits to the screen, d is the distance between the slits, and λ is the wavelength of the monochromatic light. X is directly proportional to L and inversely proportional to d.[3] Therefore, it is expected that increasing L will cause the interference fringes to spread further apart, while increasing d will cause them to become closer together.[3,6]

6. VARIABLES

INDEPENDENT VARIABLES	***Distance between the slits (d):*** *This refers to the separation between the two narrow slits on the double-slit apparatus. By increasing or decreasing this distance, the amount of path difference between the two light waves changes, which directly affects the spacing of the interference fringes on the screen. According to the equation,* $X = \frac{\lambda \cdot L}{d}$ *the increasing d will decrease the fringe spacing x.* ***Distance between the slits and the screen (L):*** *This is the linear distance from the double-slit apparatus to the screen where the interference pattern is projected. The distance being altered influences the appearance of fringes as to their dispersion. The wider L is, the larger the width of fringes between them and the more easily can be measured.*

DEPENDENT VARIABLE	***Fringe Spacing (x):*** *The distance between the bright fringes that appear on the screen is the dependent variable in this experiment. The successive interference of light waves caused this spacing through the slits. The fringe separation depends on the spacing between the slits as well as the spacing to the screen which is explained by the formula:* $X = \frac{\lambda \cdot L}{d}$ *By measuring x for different values of d and L, one can analyze how the interference pattern responds to changes in slit and screen configuration, and even calculate the wavelength λ of the monochromatic light used.*

Table 2: The controlled variables, the method of controlling them, and the possible effects if they are not controlled.

CONTROLLED VARIABLES	***Method of Control***	***Possible Effect if Not Controlled***
Wavelength of the light source	*The same laser was used throughout all trials*	*Different wavelengths would affect fringe spacing*
Slit width and quality	*The same double-slit apparatus was used throughout*	*Irregular slits may cause an uneven or unclear interference pattern*

Room brightness	*The experiment was done in a darkened environment*	*Ambient light may reduce the visibility of interference fringes*
Air currents/vibrations	*Experiment performed in a stable, enclosed space*	*Movements can distort fringe patterns*
Alignment of the laser and the slits	*Ensured by careful setup and calibration*	*Misalignment would shift or blur the interference pattern*
Type and size of screen	*Same white screen used in all trials*	*Different surfaces may reflect light differently, altering visibility*

7. APPARATUS

Table 3: The material names, size, and quantity used in the investigation

Material Name	***Material Size***	***Quantity of Material***
monochromatic light (red laser)		*1*
Adjustable screen		*1*
Ruler	*precision 0.5 mm*	*1*
Optical bench		*1*
Slit holder		*1*
Black curtains		*-*
Notebook		*1*
Calculator		*1*
Phone		*1*

Board Marker		*1*

8. METHODOLOGY

This experiment aims at understanding the effects of the distance between the two slits and the distance between the slits (d) and the screen on the interference pattern and the wavelength (λ) of the monochromatic light that is calculated. The values of d and L that were used were selected to obtain interference fringes that were clearly visible and to test the predicted relationship.

$$\lambda = \frac{\chi d}{L}.$$

The effect of reducing d on reducing fringe spacing was studied with different slit separations, and the effect of reducing L on increasing fringe spacing was studied with different slit-screen distances. These options respond directly to the research question and will make the theoretical predictions experimentally testable.[7,11]

8.1 Preparation of the Experiment Environment

1. The curtains are fully closed to avoid the external light and minimize the lighting of the background.[7]

2. Test the position of the screen among a number of them. It is chosen by making the fringes as visible as possible.[3]

8.2 Setting up the Apparatus

1. A red laser pointer is firmly fixed on a clamp stand and given a horizontal direction to the location of the double slit.

2. The distance of the laser and the double slit card will be fixed to 20 cm and held constant in all the trials.

3. The screen, the laser, and the double slit slide are perfectly aligned on the same horizontal plane to have a symmetrical pattern, and the focus of the pattern is at the center of the screen.[3]

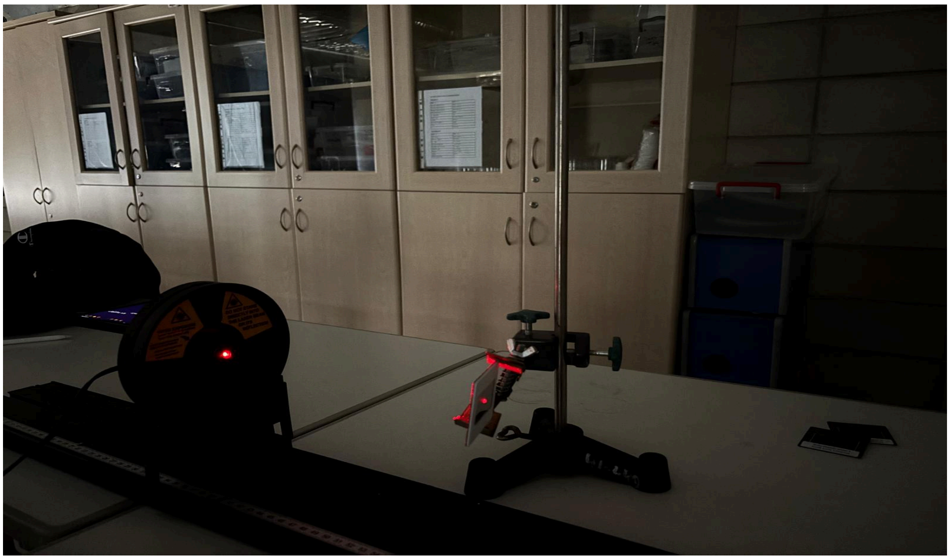


Figure 5: Apparatus alignment

8.3 Adjusting Variables

1. Modify the double-slit card to get various patterns. I have three different values, which are the manufacturer-labeled values of 1 cm, 0.5 cm and 0.1 cm.

2. Slit-screen distance is to be done at 186 cm, 166 cm, and 146 cm.

3. As the slit-screen distance is adjusted, adjust the double slit card and the laser to have a constant laser slit distance of 20 cm.

8.4 Measurement Procedure

1. Adjust the slit-screen distance by lining the screen to the necessary mark in a ruler.

2. Turn on the laser and make sure that the middle bright fringe is in the center of the screen.

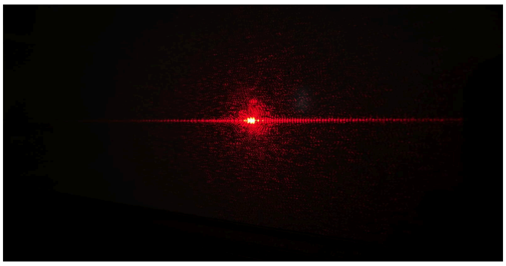
3. The overlapping of light waves will have a series of bright and dark dot-like lines.[7]

4. Indicate with a fine board marker a single bright dot line.

5. With the help of a ruler, indicate the lit area of the dotted pattern.

6. Note the slit separation ( ), slit -screen distance ( ), and the experimental length of bright-line ( ).[1]

Figure 6: Interference pattern captured on the screen



7. Photograph each interference pattern, ensuring the measured dot line is visible and labeled with its corresponding run ID.

8.5 Data Processing

1. Each separation between slits (d) has runs at all 3 distances between slit-screen (L = 186 cm → 166 cm → 146 cm).

2. Take the slit card and substitute it with the value 2 (c2) next, and do the same again with the next values in the same manner...

3. A minimum of two independent measurements of the length of the bright-line (ℓ) are to be taken per condition to reduce the effect of random error.

8.6. Records to Keep

1. Record all the variable values - *d* used, *L* set, fixed laser–slit distance (20 cm), raw dot-line markings, measured bright-line lengths (ℓ), and corresponding photographs.

2. Label all notebook entries clearly to match measurement data with each photograph.

9. SAFETY RISK ASSESSMENTS

1. Use a low-power red laser to minimize the risk of harmful effects to the eyes.

2. Reflecting items are avoided from the room to avoid reflections in the eyes.

3. Low-level background lighting was used to minimize interference with visibility of fringes, particularly when bumping into furniture or stands in a dark environment.

10. RAW DATA

Table 4: The measured fringe spaces for 186cm screen-slit distance

Double Slit Distance			
	0.1	*0.5*	*1.0*

Trial 1	*0.90*	*0.20*	*0.08*
Trial 2	*0.89*	*0.18*	*0.08*
Trial 3	*0.91*	*0.22*	*0.07*
Average Fringe Spacing Distance	*0.90*	*0.20*	*0.077*

Table 5: The measured fringe spaces for 166cm screen-slit distance

Double Slit Distance			
	0.1	*0.5*	*1.0*
Trial 1	*0.80*	*0.10*	*0.04*
Trial 2	*0.81*	*0.09*	*0.03*
Trial 3	*0.79*	*0.11*	*0.04*
Average Fringe Spacing Distance	*0.80*	*0.10*	*0.037*

Table 6: The measured fringe spaces for 146cm screen-slit distance

Double Slit Distance			
	0.1	*0.5*	*1.0*
Trial 1	*0.60*	*0.08*	*0.02*
Trial 2	*0.59*	*0.08*	*0.03*
Trial 3	*0.61*	*0.07*	*0.03*

Average Fringe Spacing Distance	*0.60*	*0.077*	*0.277*

11. DATA PROCESSING AND SAMPLE CALCULATIONS

11.1 Overview of Processing

The raw data collected in the experiment were processed to determine the wavelength of the monochromatic red laser used in the double-slit experiment. This is calculated based on the relationship between fringe spacing, slit separation, and slit-screen distance expressed as follows:

$$\lambda = \frac{\chi d}{L}$$

where;

- x is the mean spacing of fringes,
- d actually is the distance between the slits, and.
- L is the distance between the slits and the screen.

Different measurements of fringe spacing were measured and averaged to minimize the influence of random errors in each of the experimental conditions. Mean values were then entered in the equation to obtain the corresponding wavelength of light. The averaged values were used to ensure that anomalous values did not have a substantial impact on the final calculated wavelength.[11]

The results obtained from the calculated wavelengths of various combinations of slit separation and screen distance were relatively consistent, indicating that the method was consistent and that the pattern of interference was acting as the wave theory predicted.[3,11]

11.2 Sample Calculation

The example values:

- Mean fringe spacing: x = 0.90 mm = 9.0×10^{-4} m

- Slit separation: d = 0.10 cm = 1.0 × 10^{-3} m
- Slit–screen distance: L = 186 cm =1.86 m

$$\lambda = \frac{\chi d}{L}$$

$\lambda = \frac{(9.0 \times 10{-}4\ m)(1.0 \times 10{-}3\ m)}{1.86\ m}$

$\lambda = \frac{9.0 \times 10{-}7\ m2}{1.86\ m}$

$\lambda = 4.84 \times 10^{-7}$ m

λ ≈ 484 nm

For another set of values taken from Table 5 (L = 166 cm):

Slit–screen distance:

L = 166 cm = 1.66 m

Slit separation:

d = 0.10 cm = 1.0 × 10^{-3} m

Average fringe spacing:

x = 0.80 mm = 8.0 × 10^{-4} m

Using the equation:

$$\lambda = \frac{\chi d}{L}$$

$\lambda = \frac{(8.0 \times 10{-}4\ m)(1.0 \times 10{-}3\ m)}{1.66\ m}$

$\lambda = \frac{8.0 \times 10{-}7\ m)}{1.66\ m}$

$\lambda = 4.82 \times 10^{-7}$ m

$\lambda = 482$ nm

For a third set of values taken from Table 6 (L = 146 cm):

Slit–screen distance:

L = 146 cm = 1.46 m

Slit separation:

$d = 0.10\ \text{cm} = 1.0 \times 10^{-3}\ \text{m}$

Average fringe spacing:

$x = 0.60\ \text{mm} = 6.0 \times 10^{-4}\ \text{m}$

Using the equation:

$$\lambda = \frac{\chi d}{L}$$

$$\lambda = \frac{(6.0 \times 10{-}4\ m)(1.0 \times 10{-}3\ m)}{1.46\ m}$$

$$\lambda = \frac{6.0 \times 10{-}7\ m2}{1.46\ m}$$

$$\lambda = 4.11 \times 10^{-7}\ \text{m}$$

$$\lambda = 411\ nm$$

11.3 Mean Wavelength Calculation

To obtain a more reliable estimate of the wavelength, the values calculated for different slit–screen distances were averaged:[3,11]

$$\lambda_{\text{mean}} = \frac{484 + 482 + 411}{3}\ \text{nm}$$

$$\lambda_{\text{mean}} = 459\ nm$$

This wavelength was estimated within the range of visible range and is of an order that can be expected of the red laser that was used. The experimental uncertainties, which might lead to small differences, are such that there is uncertainty in the measurement of fringe spacing, errors in the measurement of distance to the slit screen, and also in misalignment.[11,12]

12. ANALYSIS AND INTERPRETATION OF RESULTS

12.1 Consistency of Calculated Wavelength

The processed data demonstrate that the calculated wavelength values are roughly similar across various slit separations *(d)* and slit-screen distances *(L)*. This is in line with the wave theory, which asserts that the wavelength of a monochromatic source of light must not change, irrespective of the alterations in the geometry of the experiment.[3,11,12]

Even though the values found in the wavelength are not the same in all operations, the numbers are of equal magnitude and fall within the range of the visible areas of the electromagnetic spectrum. The fact that the value difference is rather minor indicates that the experimental approach is fairly valid and that the equation of the interference technique can be used to analyze the pattern of the interference created by the red laser.[3,5]

12.2 Relationship Between Fringe Spacing, Slit Separation, and Screen Distance

The theoretical relationship is supported by the results of the experiment.

$$\lambda = \frac{\chi d}{L}$$

as the model of Young suggests in his model of the double-slit interference.

An increase in slit-screen distance 2 led to an increase in fringe spacing 2, which meant that the fringes became further apart and easier to measure. On the other hand, the more the separation between slits, the less the fringe spacing, resulting in the fringes becoming fainter. These behavioral tendencies were found to be consistent in all the trials and in accordance with the assumptions of the wave theory.[7,11]

The hypothesis that can be tested with the aid of this proportional relationship is that fringe spacing is proportional to the distance between the slit and the screen and inversely proportional to the distance between the slits. The correspondence of experimental tendencies and theoretical predictions speaks in favor of the validity of the experiment design and measurement process.[3,11]

12.3 Comparison with Expected Wavelength of Red Laser

The wavelength that is determined experimentally is in the visible spectrum of the electromagnetic spectrum and is similar to the wavelength that a red laser should have. This implies that the interference pattern observed was actually caused by monochromatic red light and that the experimental procedure was effective in capturing the wave nature of light.[1,7]

Even though there are certain discrepancies between the accepted value of wavelength, they are not too large when weighed against the experimental uncertainties. The variations may be explained by the inability to measure fringe spacing precisely, especially when it comes to establishing the distance between the slit and the screen, the imprecision of the slit-screen distance, and a minor misalignment of optical elements.[11,12]

12.4 Sources of Uncertainty and Their Effect on Results

A number of sources of experimental uncertainty exist that could have affected the calculated values of wavelengths.[12]

The fact that fringe spacing was measured with a ruler, which has limited precision, was one of the greatest sources of uncertainty. The slightest mistake in writing and reading the bright fringes might cause a significant deviation in the computed wavelength.

The other source of uncertainty was that it was hard to ensure perfect alignment between the laser, slits, and screen. Even minor variations in alignment would cause the interference pattern to be skewed or would cause the positions of the fringes to change, which would change the fringe spacing measured. For example, a lateral shift of about 2–3 mm across a 1.86 m slit–screen distance could change the measured fringe spacing by several percent, leading to noticeable variation in the calculated wavelength.[11,12]

Fringe spacing x was measured with a ruler of precision ±0.5 mm. Since the typical fringe separations were about 6-9 mM, this gives a relative uncertainty in x of 0.5/6 ≈ 8% to 0.5/9 ≈ 6%. This uncertainty propagates directly into the wavelength because $\lambda = \frac{xd}{L}$, so $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta x}{x}$. In addition, slight misalignment of the laser–slits–screen can shift the interference pattern laterally, making the identification of the same fringe positions less consistent and effectively increasing Δx. Using an optical bench with fixed mounts and an alignment jig would constrain the angular misalignment to a known bound (≈0.02∘), limiting lateral drift at L = 1.86 m to <1 mm and reducing the alignment contribution to the overall uncertainty in x.

Moreover, the lack of certainty in determining the slit distance to the screen and the vibrations that occurred in the experimental setup could have also been factors that led to the variation in the findings. All these uncertainties are the reason behind the small dispersion that is recorded in the calculated wavelength values.

12.5 Overall Interpretation

Overall, the results demonstrate that the double-slit interference pattern behaves as predicted by wave theory. The fact that the wavelength was computed to be nearly constant in various experimental conditions makes it possible to assume that the base of the light source was monochromatic.

The observed trends in fringe spacing with respect to slit separation and slit–screen distance confirm the theoretical model and validate the experimental method. Despite the presence of experimental uncertainties, the data are consistent with theoretical expectations and provide strong evidence for the wave nature of light, as originally demonstrated by Young's double-slit experiment.[2,3,6]

13. CONCLUSION:

This experiment examined the influence of the distance between the slits (d) and the distance between the slits and the screen (L) on the interference pattern, and the wavelength of monochromatic light in a two-slit experiment. Also, it is not the only way to observe the behavior of the interference fringes, but it can also be understood by measuring the wavelength of a red laser by using the observed patterns and the consistency of the experimental results with the theory of waves.[3,11]

The results indicate that the larger the distance of the slit-screen, the bigger the fringe spacing. Moreover, increasing the slit separation caused the fringes to become closer together. These trends are directly aligned with the theoretical relationship.

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

which predicts that fringe spacing is proportional to the slit slipping distance and the slit spacing. The consistency of these trends in all the tests is what warrants the suitability of the model of double-slit interference by Young and the fact that the interference pattern was behaving in accordance with the wave theory.

Moreover values of the calculated wavelength were almost in line with various combinations of slit separation and slit to screen distance. This aligns with the fact that the wavelength of the monochromatic light source is supposed to be constant, irrespective of the geometry of the experiment. The wavelength experimentally determined was in the visible part of the electromagnetic spectrum and was of the same magnitude as the anticipated wavelength of a red laser. This means that the method was able to measure the wave-like nature of light and that the interference pattern we were able to see was actually exhibited by the monochromatic red light.[1,3,7]

Even though there were some differences with the standard wavelength value, the differences can be attributed to errors in the experiment. The uncertainty of measuring the fringe spacing with a ruler of limited accuracy. Errors determine the distance between the slit and the screen, and even slight misalignment of the optical elements can cause variation in the calculated wavelength. There are other variables like ambient light and small vibrations, that could also have contributed to inaccurate results. Moreover, other assumptions included in the theoretical component, such as the small-angle approximation and ideal slit geometry, could have contributed to inaccurate results.

Notwithstanding these uncertainties, the general reliability of the obtained values of the wavelengths as well as their consistency with the theoretical results, proves that the experimental procedure was fairly consistent. The outcomes support the hypothesis that fringe spacing becomes larger with increasing slit–screen distance and smaller with increasing slit separation. Better still, the experiment offers good experimental support of the wave nature of light, which was initially proven by Thomas Young.[2,3,7]

To sum up, this experiment managed to provide the answer to the research question and prove the theoretical relationship governing the double-slit interference. Although experimental errors associated with the determination of the wavelength limited the accuracy of that determination, the results were in agreement with wave theory and confirmed the applicability of Young's double-slit equation to interpret the interference pattern. The experiment thus supports the basic principles of wave optics and also indicates the topicality of the experiment on the double-slit in the explanation of the nature of light.

14. EVALUATION:

Even though the results of the experiment were similar to the wave theory, various sources of uncertainty and limitations influenced the accuracy of the calculated values of the wavelengths. These uncertainties originated from both the measurement and the assumptions in the experimental model.

The uncertainty in measurements was one of the biggest, as fringe spacing was measured with a ruler having a precision of -0.5 mm. This was equivalent to a relative error of about 6%-8% in the value of x because the typical fringe spacings were of the order of 0.6-0.9 mm. Since the wavelength is directly proportional to the fringe spacing ($\lambda \alpha x$), this uncertainty was directly carried to the calculated wavelength, and it was a major contributor to the total error in the experiment.[11]

The other major source of uncertainty was alignment. Whether the slits and screen were in place and perpendicular at all times proved to be hard to make sure that the laser was on track. Even a little angular displacement will move the pattern laterally, by 0 = Ltan sin. At L=1.86 m, a deviation of 0.1 degree yields 65mm 2-14 = 3.2mm, a significant deviation to cause deviation in fringe marking and the spacing calculated. There was also uncertainty in slit-screen distance L which also affected the outcome. The distance was known by eye with a small error margin and since, $\lambda = xd/L$, any error in L was directly transferred to the final wavelength.

Besides measurement errors, environmental influences were also to have effects on the visibility of fringes and stability. Fringes were less visible due to ambient light, and fine vibration or air movement complicated the accurate locating of fringe markings. In addition, the theoretical model uses ideal slit geometry and the small-angle approximation, which can be the cause of part of the difference between experimental and accepted values of wavelength.

Despite these shortcomings, the computed wavelengths were quite consistent, and the tendencies observed corresponded to the relationship of the double-slit of Young: the spacing of the fringes was greater with the distance of the screen and smaller with the separation of the slits. This confirms the validity of the general experimental methodology.

A number of enhancements would make it more reliable. First, the ruler should be substituted by a travelling microscope or digital image analysis (CCD camera + software) so that the reading would be less ambiguous. Second, angular misalignment would be minimized by an optical bench that has fixed mounts or an alignment jig. Third, the fringe spans can be larger, and the repeats numbered to minimize the error due to randomness by averaging.

15. EXTENSION:

This study may be further developed by looking into other factors that affect the interference pattern, as well as increasing the accuracy of the determination of the wavelength.

It could be possible to extend the experiment with lasers of other wavelengths and maintain the slit separation and slit-screen distance. This would enable the relationship to be experimentally verified

$$\lambda = \frac{\chi d}{L}$$

by showing how fringe spacing varies with wavelength. Comparison of the determined wavelengths of the experiment with accepted values in the visible spectrum would also give a more thorough analysis of the accuracy and dependability of the method.

The other possible extension would be to examine the impact of slit width on the interference pattern. Through a series of slits of different sizes, with the distance between slits held constant, the contribution of diffraction to the overall pattern of interference-diffraction could be studied. This would enable a more realistic comparison with the idealized double-slit model and give an idea of the way real slits do not follow the theoretical assumptions.[14,15]

An extension to the experiment was possible by substituting the double slit with a diffraction grating. The sharper and stronger maxima of the interference would be created by a diffraction grating, and fringe spacing would be simpler to measure, and the fringe spacing would enhance the accuracy of wavelength determination. This would enable an experimental measurement of wavelength more accurately using the same theory.[9]

Lastly, a CCD camera and image analysis software to record and analyze the pattern of the interference digitally would also increase the accuracy of the measurements. Fringe positions would be automatically detected, and less human error would be introduced, more accurate data processing would be introduced, and more advanced statistical analysis of uncertainties would be possible.

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