

A Viewing Screen Is Separated From A Double Slit By 4.80 M. The Distance Between The Two Slits Is 0.030

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Understanding the fundamental principles of wave interference and diffraction is essential in optics, especially when analyzing experiments involving double slits. The setup described—a viewing screen placed 4.80 meters away from a double slit with a slit separation of 0.030 meters—serves as a classic demonstration of wave phenomena, highlighting how light behaves as a wave and how interference patterns form. In this article, we explore the physics behind this configuration, the calculations involved in analyzing the interference pattern, and the practical implications for optical experiments and applications.

Introduction to Double Slit Interference

The double slit experiment, first performed by Thomas Young in the early 19th century, provides crucial evidence for the wave nature of light. When coherent light passes through two closely spaced slits, the light waves emerging from each slit interfere with each other, creating a pattern of bright and dark fringes on a screen placed behind the slits.

Key Concepts:

- Interference: The phenomenon where two or more waves superimpose to form a new wave pattern.
- Diffraction: The bending and spreading of waves when they encounter an obstacle or aperture.
- Fringe Pattern: The series of bright and dark lines resulting from constructive and destructive interference.

The pattern's characteristics—such as fringe spacing and intensity—are determined by the slit separation, wavelength of light, and the distance to the viewing screen.

Setup and Parameters of the Experiment

Let's revisit the specific parameters provided:

- Distance from the double slit to the viewing screen: 4.80 meters
- Separation between the two slits: 0.030 meters

Additional parameters that are often relevant include:

- Wavelength of incident light: Typically in the visible spectrum (approximately 400-700 nm)
- Type of light source: Coherent sources like lasers are ideal
- Width of the slits: Not specified here but relevant in detailed analysis

Understanding these parameters allows us to calculate the interference fringe pattern.

Fundamental Equations Governing the Interference Pattern

The primary equation used to determine the position of bright fringes (constructive interference) on the screen is:

Position of Bright Fringes

$$y_m = \frac{m \lambda L}{d}$$

Where:

- y_m : Distance from the central maximum to the m -th bright fringe on the screen
- m : Fringe order (integer, e.g., 0, 1, 2, ...)
- λ : Wavelength of light
- L : Distance from the slits to the screen (4.80 m)
- d : Distance between the two slits (0.030 m)

This formula assumes the angles involved are small, which is valid for typical laboratory setups.

Calculating Fringe Spacing

Fringe spacing (Δy)—the distance between adjacent bright (or dark) fringes—is given by:

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

This value indicates how far apart the fringes are on the screen, which is crucial for experimental measurements.

Example Calculation:

Assuming a common wavelength of $\lambda = 650 \text{ nm} = 6.50 \times 10^{-7} \text{ m}$:

$$\Delta y = \frac{6.50 \times 10^{-7} \text{ m} \times 4.80 \text{ m}}{0.030 \text{ m}} =$$

$$\frac{3.12 \times 10^{-6} \text{ m}}{0.030 \text{ m}} \approx 1.04 \times 10^{-4} \text{ m}$$

or approximately 0.104 mm.

This indicates that each bright fringe is roughly 0.104 millimeters apart, an important consideration when designing experiments or analyzing data.

Implications of Fringe Spacing in Optical Experiments

Understanding the fringe spacing helps in:

- Designing experiments: Ensuring that the fringes are resolvable with available detection equipment.
- Measuring wavelength: Using the fringe pattern to determine the wavelength of light with high precision.
- Studying wave behavior: Confirming the wave nature of light through observed interference.

Measuring Wavelength Using Fringe Patterns

The fringe pattern provides a straightforward method for measuring the wavelength of light, especially when the slit separation and distance to the screen are known.

Method:

1. Measure the positions (y_m) of multiple fringes.
2. Use the fringe position formula to solve for (λ):

$$\lambda = \frac{d y_m}{m L}$$

3. Average the calculated wavelengths for multiple fringes to improve accuracy.

Example:

Suppose the first bright fringe ($m=1$) is observed at a distance ($y_1 = 1.04 \text{ mm}$):

$$\lambda = \frac{0.030 \text{ m} \times 1.04 \times 10^{-3} \text{ m}}{1 \times 4.80 \text{ m}} \approx 6.50 \times 10^{-7} \text{ m}$$

which aligns with typical visible light wavelengths.

Factors Affecting the Interference Pattern

Several factors can influence the clarity, position, and intensity of the fringes:

- **Wavelength dispersion:** Different wavelengths produce different fringe spacings, leading to fringe blurring if multiple wavelengths are present.
- **Slit imperfections:** Non-uniformity or misalignment can distort the pattern.
- **Coherence of light source:** Highly coherent sources like lasers produce sharp fringes, while incoherent sources result in washed-out patterns.
- **Environmental vibrations:** Movements can shift fringe positions, affecting measurements.
- **Slit width:** Wider slits introduce diffraction effects that can modify the pattern.

Applications of Double Slit Interference

The understanding of double slit interference extends beyond fundamental physics experiments into various technological and scientific applications:

1. Spectroscopy and Wavelength Measurement

- Precise determination of light wavelengths.
- Calibration of spectrometers using known fringe patterns.

2. Optical Instrumentation

- Designing interferometers for high-precision measurements.
- Enhancing resolution in microscopes.

3. Quantum Mechanics Experiments

- Demonstrating wave-particle duality.
- Investigating quantum coherence and entanglement.

4. Educational Demonstrations

- Visualizing wave interference.
- Teaching principles of wave physics and optics.

Real-World Challenges and Considerations

While the theoretical framework provides a clear method for analyzing interference patterns, practical challenges often arise:

- Achieving perfect coherence and monochromatic light.
- Maintaining precise slit alignment.
- Minimizing environmental disturbances.
- Dealing with diffraction effects from slit width.

Overcoming these challenges involves meticulous setup, calibration, and sometimes advanced equipment like stabilized laser sources and vibration-isolation tables.

Conclusion

The setup where a viewing screen is separated from a double slit by 4.80 meters and the slits are separated by 0.030 meters exemplifies fundamental wave interference phenomena. By understanding and applying the key equations, such as the fringe spacing formula, scientists and students can analyze the interference pattern to measure wavelengths, verify wave behavior, and explore quantum mechanics principles. As optics continues to evolve, the principles demonstrated in this classic experiment remain central to advancements in spectroscopy, quantum computing, and high-precision measurement technologies.

Further Reading and Resources

- "Optics" by Eugene Hecht – Comprehensive textbook on optical physics.
- Online simulations of double slit experiments for visual understanding.
- Research articles on advanced interferometry techniques.
- Laboratory kits and equipment for educational demonstrations of wave interference.

In summary, understanding how the separation of a viewing screen from a double slit influences the

interference pattern is fundamental in optics. Precise measurements of fringe spacing allow for accurate calculations of wavelengths and deepen our comprehension of wave phenomena. Whether in educational settings or cutting-edge research, the principles outlined here serve as a foundation for exploring the wave nature of light.

Frequently Asked Questions

What is the significance of the 4.80 m separation between the viewing screen and the double slit?

The 4.80 m separation determines the distance over which the interference pattern develops and is crucial for calculating fringe spacing in the double-slit experiment.

How does the distance between the two slits (0.030 m) affect the interference pattern observed on the screen?

The slit separation influences the fringe spacing; larger slit separation results in wider fringes, making the pattern more distinguishable.

What is the formula to calculate the fringe width in a double-slit experiment?

The fringe width (w) is given by $w = (\lambda L) / d$, where λ is the wavelength of light, L is the distance to the screen, and d is the slit separation.

If the wavelength of light used is 500 nm, what is the fringe width on the screen?

Using $w = (\lambda L) / d$: $w = (500 \times 10^{-9} \text{ m} \times 4.80 \text{ m}) / 0.030 \text{ m} = 8 \times 10^{-5} \text{ m}$ or 0.08 mm.

How does increasing the distance between the slits or the screen affect the interference pattern?

Increasing either the slit separation or the distance to the screen results in wider fringes, making the interference pattern more spread out.

What assumptions are typically made in calculating the interference pattern in a double-slit experiment?

Assumptions include monochromatic light, coherent sources, negligible width of the slits, and no external disturbances affecting the pattern.

What are common sources of error in a double-slit interference experiment with these parameters?

Errors can arise from slit imperfections, environmental vibrations, imperfect monochromatic light, or measurement inaccuracies in slit separation and screen distance.

How can the experiment be modified to observe clearer interference fringes?

Using monochromatic, coherent light with a longer wavelength, increasing the slit separation, or increasing the distance to the screen can improve fringe visibility.

What real-world applications rely on principles demonstrated by this double-slit setup?

Applications include holography, optical interferometry, laser physics, and the development of high-precision measurement tools in scientific research.

Additional Resources

Double-Slit Interference and the Role of Observation Distance: An In-Depth Analysis

Introduction to Double-Slit Interference

The double-slit experiment is one of the most iconic demonstrations in physics, illustrating the wave-particle duality of light and matter. By passing a coherent light source through two narrowly spaced slits, an interference pattern emerges on a screen placed some distance away, revealing the wave nature of the particles involved.

This classic experiment not only supports the wave theory of light but also paves the way for understanding quantum phenomena. The precise arrangement, including the slit separation and the distance to the viewing screen, plays a crucial role in the observed interference pattern, affecting its fringe spacing, contrast, and clarity.

Understanding the Key Parameters

In analyzing this scenario, two critical parameters are provided:

- Separation between the viewing screen and the double slit (L): 4.80 meters
- Distance between the two slits (d): 0.030 meters (30 mm)

These parameters significantly influence the fringe pattern and the resolution with which interference fringes can be observed. To fully grasp their importance, it's essential to explore their roles individually and collectively.

Physical Principles Governing the Interference Pattern

Wave Nature and Path Difference

When monochromatic light passes through the two slits, each slit acts as a secondary source of waves. These waves interfere constructively or destructively depending on their phase difference, which is primarily determined by the path difference between the two waves reaching a point on the screen.

The fundamental condition for bright fringes (constructive interference) is:

$$\Delta r = d \sin \theta = m \lambda$$

where:

- Δr is the path difference,
- d is the slit separation,
- θ is the angle of the fringe relative to the central maximum,
- m is an integer (order of the fringe),
- λ is the wavelength of the light used.

For small angles (which is typical in these experiments), $\sin \theta \approx \tan \theta \approx y / L$, where y is the fringe position on the screen, and L is the distance from the slits to the screen.

Calculating Fringe Spacing

The fringe separation, or fringe width (Δy), is crucial for clarity and resolution. It is derived as:

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

This relation indicates that the fringe spacing increases with the wavelength (λ) and the distance to the screen (L), but decreases with increased slit separation (d).

Given the parameters:

- $(L = 4.80, \text{ m})$,
- $(d = 0.030, \text{ m})$,

and assuming a typical wavelength for visible light, say $(\lambda = 500, \text{ nm}) = 5.00 \times 10^{-7}, \text{ m})$.

The fringe spacing becomes:

$$\Delta y = \frac{(5.00 \times 10^{-7}, \text{ m}) \times 4.80, \text{ m}}{0.030, \text{ m}} = \frac{2.40 \times 10^{-6}, \text{ m}}{0.030} \approx 8.00 \times 10^{-5}, \text{ m} = 0.08, \text{ mm}$$

This fringe spacing of approximately 0.08 mm (80 micrometers) reflects a fine separation, emphasizing the importance of high-resolution detection equipment to observe the fringes clearly.

Impact of the Viewing Distance (L)

The 4.80-meter separation between the slit apparatus and the viewing screen is significant for several reasons:

1. Fringe Visibility and Resolution

- As the distance increases, the fringe separation (Δy) becomes larger, making the fringes easier to distinguish.
- Larger L reduces the angular spread (θ) , leading to more spread-out fringes.

2. Experimental Constraints and Practicality

- Longer distances demand more space and precise alignment.
- Environmental factors like air currents, temperature variations, and vibrations can distort the pattern over such distances.

3. Effects on Pattern Sharpness

- Over larger distances, diffraction and scattering can cause the fringes to blur, reducing contrast.
- Ensuring a stable environment and using collimated light improves pattern clarity at greater L.

Role of the Slit Separation ($d = 0.030 \text{ m}$)

The slit separation directly influences fringe spacing and pattern resolution:

1. Fringe Spacing and D

- Larger d results in smaller fringe spacing (Δy), making fringes more tightly packed.
- Smaller d produces wider fringes, easier to observe but may reduce fringe contrast depending on coherence and wavelength.

2. Resolution and Fringe Visibility

- As d increases, the interference fringes become more closely spaced, demanding higher precision in measurement.
- For $d = 0.030 \text{ m}$, the fringes are sufficiently spaced at $L = 4.80 \text{ m}$ to be observable with standard optical equipment, assuming the wavelength is in the visible range.

3. Practical Considerations in Manufacturing

- Creating slits with precise separation and narrow widths (often less than 0.1 mm) is crucial for clear interference patterns.
- The quality of the slits (edge sharpness, uniformity) affects fringe contrast.

Interference Pattern Characteristics at Given Parameters

Using the earlier calculation, the fringe spacing ($\Delta y \approx 0.08 \text{ mm}$) indicates very fine fringes that require sensitive detection equipment such as high-resolution cameras or microscopes.

- Number of fringes visible: The total number of fringes visible across the pattern depends on the size of the viewing screen and the maximum angle θ where fringes are observable.
- Max fringe order (m_{max}): Determined by the maximum θ where constructive interference occurs, which is constrained by the physical size of the apparatus.

Factors Affecting the Observation of the Interference Pattern

Several factors influence the clarity and stability of the interference fringes observed:

1. Coherence of the Light Source

- The light must be coherent (monochromatic and phase-stable) for well-defined fringes.
- Lasers are ideal sources; traditional sources like LEDs require spatial and temporal filtering.

2. Wavelength Stability

- Variations in wavelength (due to source instability or spectral spread) can blur the fringes.
- Narrow spectral linewidths improve fringe contrast.

3. Environmental Conditions

- Air currents, temperature gradients, and vibrations can distort the pattern.
- Conducting the experiment in a controlled environment enhances results.

4. Alignment Precision

- Precise alignment of the slits, light source, and screen ensures symmetric fringes.
- Misalignment can cause fringe shift or reduce visibility.

Applications and Broader Implications

Understanding the implications of the parameters (distance and slit separation) extends beyond a simple laboratory setup:

- Quantum Mechanics: Demonstrates wave-particle duality, especially when using electrons or other particles.
- Optical Instrument Design: Guides the development of high-resolution interferometers, spectrometers, and holography systems.
- Metrology: Fringe patterns are used for precise measurements of small distances and refractive indices.
- Educational Demonstrations: Visually illustrates fundamental physics concepts for students and enthusiasts.

Advancements and Modern Techniques

Modern optics leverage the principles discussed here, with improvements including:

- Use of Lasers: Providing highly coherent, monochromatic sources that produce clear, stable fringes.
- Digital Detection: CCD or CMOS cameras capture interference patterns for analysis.
- Computational Analysis: Image processing software enhances fringe visibility and allows precise measurement of fringe positions.
- Miniaturization: Microfabricated slits and integrated interferometers enable compact devices for scientific and industrial applications.

Conclusion

The scenario of a viewing screen separated from a double slit by 4.80 meters, with a slit separation of 0.030 meters, encapsulates fundamental concepts of wave interference and optical physics. The parameters directly influence the fringe pattern's size, visibility, and resolution, providing insights into the wave nature of light.

By carefully selecting the wavelength, maintaining coherence, and controlling environmental factors, a clear and observable interference pattern can be achieved. This setup exemplifies the delicate balance of variables necessary for precise optical experiments, demonstrating the elegance and complexity of wave phenomena and their practical applications across science and technology.

Understanding these principles enhances our appreciation of fundamental physics and informs the design of advanced optical systems, from spectrometers to quantum computing devices. The interplay of distance, slit separation, and wavelength underscores the intricate beauty of light and matter interactions, inspiring continued exploration and innovation in the field of optics.

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