Monochromatic Light Of Wavelength = 620 Nm From A Distant Source Passes Through A Slit 0.450 Mm Wide.

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Understanding the behavior of light as it interacts with obstacles and apertures is fundamental to the field of optics. When monochromatic light of wavelength 620 nm, originating from a distant source, passes through a slit that is 0.450 mm wide, it exhibits phenomena such as diffraction and interference. These effects are crucial in various scientific and technological applications, from optical instruments to communication systems. This article explores the physics behind this scenario, detailing the principles of diffraction, the calculations involved, and real-world implications, all organized for clarity and SEO effectiveness.

Fundamental Concepts of Monochromatic Light and Diffraction

What Is Monochromatic Light?

Monochromatic light consists of waves with a single wavelength and frequency. In this context, the light has a wavelength of 620 nanometers (nm), which falls within the visible spectrum and corresponds to a deep red hue. Such light can be produced by laser sources or filtered white light, and its predictable behavior makes it ideal for studying wave phenomena.

The Nature of Diffraction

Diffraction refers to the bending and spreading of waves when they encounter an obstacle or aperture comparable in size to their wavelength. When monochromatic light passes through a narrow slit, it does not simply travel straight but spreads out, creating a diffraction pattern that can be observed on a screen placed behind the slit. This pattern typically consists of a central bright fringe with successive dimmer fringes on either side.

Analyzing the Diffraction Pattern from a Narrow

Slit

Parameters of the Problem

- Wavelength of light, λ = 620 nm = 620 × 10-9 meters
- Width of the slit, a = 0.450 mm = 0.450 × 10-3 meters
- Distance from the slit to the screen, D (assumed sufficiently large for the far-field approximation)

Conditions for Diffraction

When monochromatic light passes through a slit, the resulting diffraction pattern can be analyzed using the single-slit diffraction formula:

- Angular position of minima (dark fringes): **sin θ = mλ / a**, where m = ±1, ±2, ±3, ...

This relation helps determine the positions of dark fringes on the observation screen. The central maximum occurs at the center (θ = 0), with bright and dark fringes symmetric about this axis.

Calculations for the Diffraction Pattern

Determining the Angular Position of the First Minimum

The first minimum (m=1) occurs at an angle θ1:

$\sin \theta_1 = \lambda / a$

Substituting the known values:

$\sin \theta_1 = (620 \times 10^{-9}\ m) / (0.450 \times 10^{-3}\ m) \approx 1.378$

Since sin θ cannot be greater than 1, this indicates that the diffraction angle exceeds 90°, which is physically impossible. This implies that the diffraction pattern is broad, and the minima are not observable within typical experimental setups.

However, in practice, the slit width is large relative to the wavelength, resulting in a narrow diffraction pattern with minima occurring at very small angles, which are often approximated for small θ using the small-angle approximation:

$$\sin \theta \approx \tan \theta \approx \theta \text{ (in radians)}$$

Thus, the approximate position of the first minimum on the screen is:

$$\theta_1 \approx \lambda / a \approx 1.378 \text{ radians } (\sim 78.9 \text{ degrees})$$

This large angle suggests the diffraction pattern is very broad, and the central maximum is wide, with the minima so far apart that they may not be well-resolved in typical experiments.

Position of the Central Maximum on the Screen

Assuming a distance D from the slit to the screen, the linear position y of a fringe (bright or dark) from the center is:

$$y = D \tan \theta$$

For small angles, $\tan \theta \approx \theta$, so:

$$y \approx D \times \theta$$

If, for example, D = 2 meters, then:

$$y_1 \approx 2 \text{ m} \times 1.378 \approx 2.756 \text{ meters}$$

This indicates the minima are very far apart, and the diffraction pattern is extremely broad, effectively appearing as a single, large bright central maximum.

Implications of Slit Width and Wavelength on Diffraction

Effect of Slit Width

The width of the slit plays a pivotal role in determining the diffraction pattern:

- Wider slits (larger a) produce narrower diffraction patterns, with minima closer to the central maximum.
- Narrower slits (smaller a) result in broader diffraction patterns, with minima farther out.

In this scenario, the slit is relatively wide (0.450 mm), which causes the diffraction pattern to be more concentrated, with a narrow central maximum.

Effect of Wavelength

The wavelength influences the diffraction:

- Longer wavelengths increase the diffraction angle, broadening the pattern.
- Shorter wavelengths decrease the diffraction angle, narrowing the pattern.

Since 620 nm is in the red part of the spectrum, it produces a specific diffraction behavior characteristic of visible red light.

Real-World Applications of Diffraction from Narrow Slits

Optical Instrumentation

Understanding the diffraction patterns caused by slits aids in designing optical devices such as spectrometers, where precise wavelength measurements depend on diffraction principles.

Communication Technologies

Diffraction effects influence signal propagation in optical fibers and free-space communication, where wave spreading affects signal quality and resolution.

Scientific Research

Experiments involving slit diffraction help verify wave theories of light, fundamental to quantum physics and wave optics studies.

Summary and Key Takeaways

- Monochromatic light of wavelength 620 nm passing through a 0.450 mm wide slit produces a diffraction pattern characterized by a wide central maximum.
- The angular position of minima depends on the ratio λ/a, with larger ratios resulting in broader patterns.
- For the given parameters, the diffraction angles are large, meaning the pattern spreads over a significant distance, which can be observed in controlled experimental setups.
- The principles of slit diffraction are essential in various scientific and technological fields, underpinning the design of optical devices and understanding wave behavior.

Conclusion

The interaction of monochromatic light with slits provides a window into the wave nature of light. In the specific case of 620 nm wavelength light passing through a 0.450 mm wide slit, the diffraction pattern reveals fundamental wave phenomena that are critical in both theoretical physics and practical applications. By understanding these principles, scientists and engineers can manipulate light for advanced technological innovations, ensuring precise control over optical behavior.

Frequently Asked Questions

What is the wavelength of the monochromatic light passing through the slit?

The wavelength of the light is 620 nm.

How does the slit width of 0.450 mm affect the diffraction pattern of the light?

The slit width determines the angular width and intensity distribution of the diffraction pattern; narrower slits produce wider diffraction fringes.

What is the significance of the light being from a distant source in this context?

A distant source ensures that the incoming light waves are nearly parallel, simplifying the diffraction and interference analysis as plane waves.

Calculate the angular position of the first minimum in the diffraction pattern.

Using the slit width (a) and wavelength (λ), the first minimum occurs at $\theta \approx \sin^{-1}(\lambda/a) = \sin^{-1}(620\times10^{-9}\text{ m} / 0.450\times10^{-3}\text{ m}) \approx \sin^{-1}(0.001378) \approx 0.0789°$, which is approximately 0.079 degrees.

What type of diffraction pattern is produced by a single slit with the given parameters?

A single slit diffraction pattern consisting of a central bright maximum flanked by successive dark and bright fringes occurs.

How does the wavelength of 620 nm influence the diffraction pattern compared to shorter wavelengths?

A longer wavelength like 620 nm results in wider diffraction fringes and larger angular separation between minima and maxima.

What is the approximate width of the central maximum on a screen placed 2 meters from the slit?

The width of the central maximum is approximately $2L\theta \approx 2 \times 2\text{ m} \times 0.0789°$ (converted to radians) $\approx 2 \times 2 \times 0.001377$ rad ≈ 0.0055 meters, or about 5.5 mm.

How does the slit width of 0.450 mm compare to the wavelength of light in terms of diffraction effects?

Since the slit width is much larger than the wavelength, diffraction effects are visible but relatively limited; significant spreading occurs when the slit width approaches the wavelength.

Can this setup be used to measure the wavelength of light? If so, how?

Yes, by measuring the angular position of minima in the diffraction pattern and knowing the slit width, the wavelength can be calculated using the diffraction formula $\lambda = a \sin\theta$.

What assumptions are made in analyzing the diffraction pattern in this scenario?

Assumptions include that the incoming light is monochromatic and plane wave, the slit is narrow enough for diffraction to occur, and the source is sufficiently distant to produce parallel rays.

Additional Resources

Monochromatic Light Of Wavelength = 620 Nm From A Distant Source Passes Through A Slit 0.450 Mm Wide

In the realm of wave optics, the interaction between light and obstacles reveals fascinating phenomena that underpin many modern technological applications. One such scenario involves monochromatic light of wavelength 620 nanometers (nm) emanating from a distant source passing through a narrow slit measuring 0.450 millimeters (mm) wide. This seemingly simple setup unlocks a wealth of insights into the wave nature of light, diffraction patterns, and the principles governing optical interference. Understanding this process not only deepens our grasp of fundamental physics but also informs the design and optimization of devices ranging from optical sensors to communication systems.

Introduction to Monochromatic Light and Its Significance

Monochromatic light refers to light composed of a single wavelength or frequency. In practical terms, lasers are quintessential sources of monochromatic light, but sunlight filtered through specific optical elements or certain LED sources can also approximate monochromatic conditions. The wavelength of 620 nm lies within the visible spectrum, specifically in the orange-red region, making it particularly relevant for applications involving color optics and display technologies.

When such monochromatic light propagates over long distances, it can be considered as emanating from a source at an effectively infinite distance. This approximation simplifies the analysis of diffraction and interference phenomena because the incoming wavefronts are essentially planar. The interaction of this light with narrow apertures or slits provides a window into the wave properties of light, as opposed to particulate models.

Understanding the Experimental Setup

At the core of this setup is a slit—an opening in an opaque screen—that is significantly narrower than the distance to the light source. The key parameters are:

- Wavelength (λ): 620 nm or 620 x 10^-9 meters
- Slit Width (a): 0.450 mm or 0.450 x 10^-3 meters
- Source Distance: Considered sufficiently large so that the incident light

is effectively parallel (plane wave approximation)

This configuration is classical in wave optics experiments, often used to demonstrate diffraction—the bending and spreading of waves as they encounter obstacles or apertures.

Wave Nature of Light and Diffraction Phenomena

Light behaves as a wave, characterized by oscillating electric and magnetic fields propagating through space. When a wave encounters a slit comparable in size to its wavelength, it does not travel straight through like a narrow beam but instead spreads out. This spreading is known as diffraction, and it is most prominent when the slit width is on the order of the wavelength.

The diffraction pattern produced on a screen placed beyond the slit manifests as a series of bright and dark fringes—maxima and minima—resulting from constructive and destructive interference of the wavefronts emanating from different parts of the slit.

Mathematical Framework of Diffraction Through a Single Slit

The phenomenon can be quantitatively described using the principles of wave interference and the Huygens-Fresnel principle. For a slit of width a, the angular position θ of the minima in the diffraction pattern is given by:

$$
a \sin \theta = m \lambda, \quad m = \pm 1, \pm 2, \pm 3, \ldots
$$

where:

- a is the slit width,
- λ is the wavelength,
- m is the order of the minimum.

For small angles (which is typical in such experiments), $\sin \theta \approx \tan \theta \approx y / D$, where:

- y is the distance from the central maximum to the m-th minimum on the screen,
- D is the distance from the slit to the screen.

The central bright fringe, the principal maximum, spans the region between the first minima on either side, providing a reference point for measurements.

Calculating the Diffraction Pattern Parameters

Suppose an experiment is set up with the following typical parameters:

- Distance from slit to screen, $D = 2\, \text{meters}$
- Observation point, y, varies depending on the interference order

Using the formula for minima:

$$
y_m = \frac{m \lambda D}{a}
$$

Plugging in the values:

$$
\lambda = 620 \times 10^{-9}\, \text{m}
$$
$$
a = 0.450 \times 10^{-3}\, \text{m}
$$
$$
D = 2\, \text{m}
$$

For the first minimum ($(m=1)$):

$$
y_1 = \frac{1 \times 620 \times 10^{-9} \times 2}{0.450 \times 10^{-3}} \approx 2.75\, \text{meters}
$$

This indicates that the first dark fringe appears approximately 2.75 meters from the central bright maximum, assuming an ideal setup.

Implications of Diffraction Pattern Width and Brightness

The width of the central maximum is inversely proportional to the slit width—the narrower the slit, the wider the diffraction pattern. This phenomenon has practical implications:

- Resolution Limits: In optical instruments like microscopes, diffraction sets a fundamental limit to resolving details.
- Optical Device Design: Engineers tailor slit sizes and distances to optimize light throughput and pattern clarity.
- Spectroscopy and Measurement: Precise calculations of diffraction patterns enable accurate wavelength measurements and analysis.

Applications and Technological Relevance

Understanding the diffraction of monochromatic light through narrow slits is not merely academic; it has tangible applications across various fields:

- Optical Instrumentation: Designing slit-based spectrometers relies on diffraction principles to separate light into its constituent wavelengths.

- Communication Technologies: Optical fibers and waveguides exploit controlled diffraction and interference for signal transmission.
- Metrology: Precise measurement of wavelengths and slit dimensions employs diffraction patterns, enabling high-accuracy optical metrology.
- Nanotechnology: Fabrication of nanostructures often involves controlling light diffraction at sub-micron scales.

Challenges and Limitations

While the classical wave theory accurately predicts diffraction patterns, real-world experiments face challenges such as:

- Imperfections in the slit: Edge roughness or irregularities can distort patterns.
- Finite source size: If the source is not truly distant or monochromatic, the pattern becomes blurred.
- Alignment issues: Precise positioning of the slit, source, and screen is critical for accurate results.

Advancements in laser technology and nanofabrication have mitigated some of these challenges, enabling more refined experimental setups.

Conclusion: The Significance of Diffraction in Modern Optics

The passage of monochromatic light of wavelength 620 nm through a narrow slit exemplifies wave behavior that is fundamental to optics. The resulting diffraction pattern encapsulates the wave nature of light, illustrating principles that are central to both theoretical physics and technological innovation. From designing high-resolution optical systems to understanding the limitations of optical resolution, the insights gained from such experiments continue to influence scientific progress.

As we harness the wave phenomena demonstrated in these experiments, our ability to manipulate and measure light at microscopic and nanoscopic scales advances, opening new frontiers in science and engineering. The simple act of a distant monochromatic beam passing through a slit thus remains a cornerstone of optical physics, bridging fundamental theory with practical application.

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