DIFFRACTION IN A SINGLE SLIT **Exp-4**

Purpose

Observation of diffraction pattern from single slits with different widths by red laser beam.

Related topics

Huygens principle, interference, Fraunhofer and Fresnel-diffraction, coherence, laser.

Equipment

Laser, He-Ne 1.0 mw, 220 V AC
Lens, mounted, f +20 mm
Lens, mounted, f +100 mm
Universal measuring amplifier
Diaphragm, 3 single slits
Multi-range meter
Photocell

Theory and Evaluation

Diffraction of Light, light bending around an object

Diffraction may be envisioned as arising from the interaction of electromagnetic waves with some sort of physical obstruction. It is *the slight bending of light as it passes around the edge of an object* [3].

Diffraction effects are a consequence of the wave character of light. Even if the obstacle is not opaque but causes local variations in the amplitude or phase of the wavefront of the transmitted light, such effects are observed. Tiny bubbles or imperfections in a glass lens, for example, produce undesirable diffraction patterns when transmitting laser light. Because the edges of optical images are blurred by diffraction, the phenomenon leads to a fundamental limitation in instrument resolution. More often, though, the sharpness of optical images is more seriously degraded by optical aberrations due to the imaging components themselves.

Adequate agreement with experimental observations of diffraction of light is possible through an application of the *Huygens-Fresnel principle.* According to Huygens, every point of a given wavefront of light can be considered a source of secondary spherical wavelets. To this, Fresnel added the assumption that the actual field at any point beyond the wavefront is a superposition of all these wavelets, taking into account both their amplitudes and phases.

If both the source of light and observation screen are effectively far enough from the diffraction aperture so that wavefronts arriving at the aperture and observation screen may be considered plane, we speak of *Fraunhofer, or far-field diffraction*, when this is not the case and curvature of the wavefront must be taken into account, we speak of *fresnel, or near-field, diffraction.* In far-field approximation, the diffraction pattern changes uniformly in size only as the viewing screen is moved relative to the aperture. In the near-field approximation, the situation is more complicated: Both shape and size of the diffraction pattern depend on the distance between aperture and screen. As the screen is moved away from the aperture, the image of the aperture passes through the forms predicted in turn by geometrical optics, near-field diffraction and far-field diffraction [15].

Single Slit Diffraction

According to Huygens' principle, each portion of the slit acts as a source of light waves. Hence, light

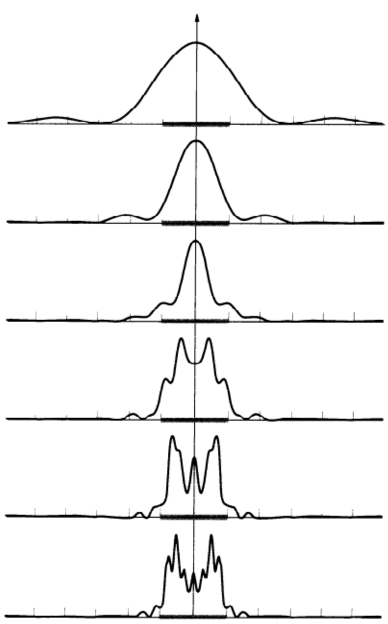

Figure 10: A succession of diffraction patterns at increasing distance from a single slit; Fresnel at the bottom(nearby), going toward Fraunhofer at the top(faraway) [10]

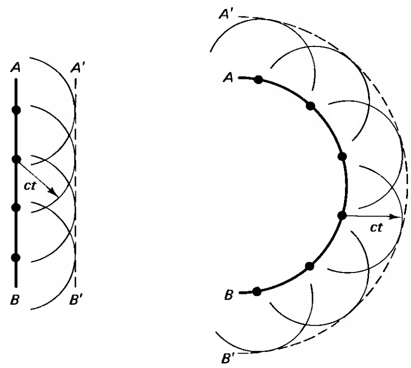

Figure 11: Illustration of Huygens' principle for plane and spherical waves [10]

from one portion of the slit can interfere with light from another portion, and the resultant light intensity on a viewing screen depends on the direction θ. Based on this analysis, we recognize that a diffraction pattern is actually an interference pattern in which the different sources of light are different portions of the single slit.

To analyze the diffraction pattern, let's divide the slit into two halves as shown in fig 12. Keeping in mind that all the waves are in phase as they leave the slit, consider rays 1 and 3. As these two rays travel toward a viewing screen far to the right of the figure, ray 1 travels farther than ray 3 by an amount equal to the path difference $(a/2)\sin\theta$, where a is the width of the slit. If this path difference is exactly half a wavelength (corresponding to a phase difference of 180°), the pairs of waves cancel each other and destructive interference results. So destructive interference condition become;

$$\begin{aligned} \frac{a}{2}\sin\theta &= \frac{\lambda}{2} \\ \sin\theta &= \frac{\lambda}{a} \end{aligned} \tag{10}$$

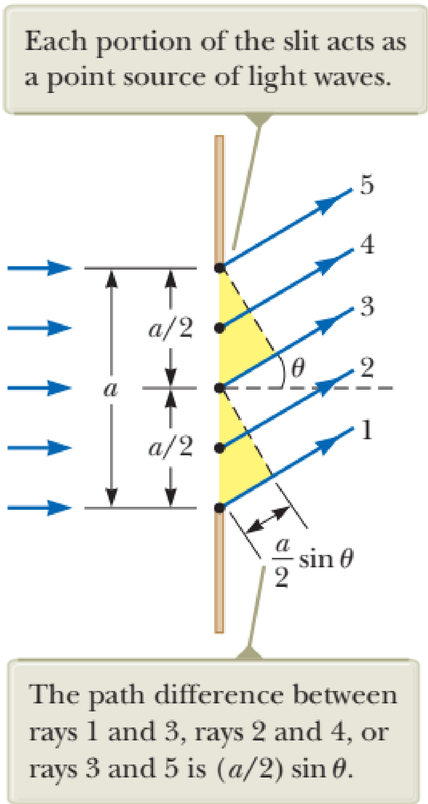

Figure 12: Paths of light rays that encounter a narrow slit of width a and diffract toward a screen in the direction described by angle θ [17]

if we consider waves at angle θ both above the dashed line in Figure 12 and below,

$$\sin\theta = \mp\frac{\lambda}{a} \tag{11}$$

Dividing the slit into four equal parts and using similar reasoning, we find that the viewing screen is also dark when

$$\sin\theta = \mp 2\frac{\lambda}{a} \tag{12}$$

Therefore, the general condition for destructive interference is [17];

$$\sin\theta_{dark} = m\frac{\lambda}{a}; \qquad m = \mp 1, \mp 2, \mp 3, \ldots \tag{13}$$

Babinet's principle

Babinet's principle is a basic theorem of classical optics, first formulated by the French scientist Jacques Babinet in 1837. It states that two complementary geometric objects, such as, for instance, a slit and a strip of the same size and shape (see Fig. a), produce identical diffraction intensities, except for the part of direct geometrical illumination. In the example of a slit in an opaque membrane and an opaque strip suspended in free space, it is obvious that the forward intensity must be far larger in the case of the strip than it is for the slit, because the slit limits the total transmitted flux. The intensities diffracted away from the geometrical ray direction are, however, identical according to Babinet's principle. As a result, Babinet's principle often allows for simplification of diffraction models [11].

The uncertainty principle

Imagine that you're holding one end of a very long rope, and you generate a wave by shaking it up and down rhythmically(fig 14) If someone asked you "Precisely where is that wave?" you think the wave isn't precisely anywhere, it's spread out over 50 feet. On the other hand, if he asked you what its wavelength is, you could give him a reasonable answer: about 6 feet. By contrast, if you gave the rope a sudden jerk (fig 15), you'd get a relatively narrow bump traveling down the line. This time the first question(where

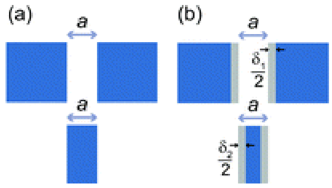

Figure 13: A slit and a strip of an identical physical width a [11].

Figure 14: A wave with a fairly well-defined wavelength, but an ill-defined position [9]

precisely is the wave?) is a sensible one, and the second (what is its wavelength?) seems nutty. it's hard to assign a wavelength to it. Of course, you can draw intermediate case, in which the wave is fairly well localized and the wavelength is fairly well defined, but there is an inescapable trade-off here: The more precise a wave's position is, the less precise is its wavelength, and vice versa. Our general observation now says that the more precisely determined a particle's position is, the less precisely its momentum is determined. Quantitatively,

$$\sigma_x \sigma_p \geq \frac{\hbar}{2} \tag{14}$$

where σ_x is the standard deviation in x, and σ_p is the standard deviation in p. This is Heisenberg's famous *uncertainty principle* [9].

This applies, of course, to any wave phenomenon, in diffraction experiments, passage through the slit screen represents a position measurement that establishes the state of the system in coordinate space. The quantum mechanical interpretation of diffraction is that the physical property recorded at the detection screen is the momentum distribution of the diffracted particle. The uncertainty principle is clearly revealed the narrow slit produces a broader momentum distribution. In other words, localization in coordinate space leads to delocalization in momentum space.

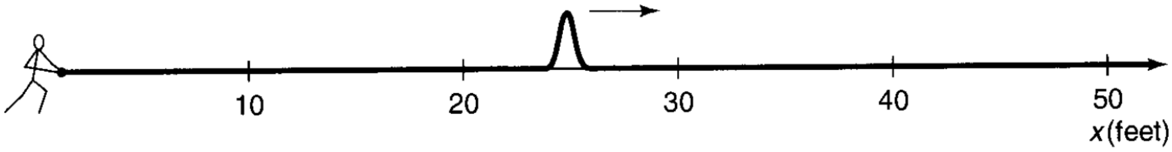

Figure 15: A wave with a fairly well-defined position, but an ill-defined wavelength [9]

Set-up, Procedure

Caution: Never look directly into a non attenuated laser beam

1. The experimental set-up is shown in Fig. 16. A broadened and parallel laser beam obtained with the lenses f = 20 mm and f = 100 mm.

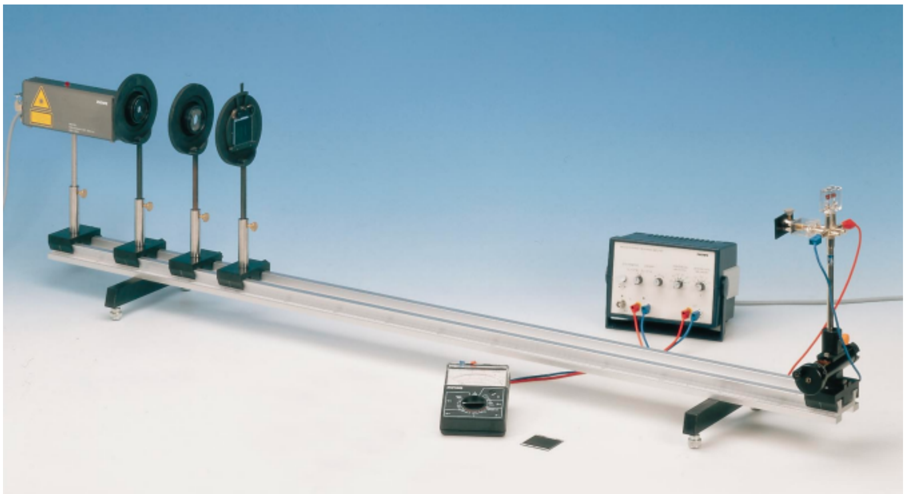

Figure 16: Experimental set-up for the investigation of the diffraction intensity of slits. (Component locations on the optical bench: laser = 2.5 cm; lens f/20 mm = 14 cm; lens f/100 mm = 27 cm; slits = 32.5 cm; slide mount lateral adjustm, calibr. = 139.5 cm) [7]

2. Make sure that laser beam impinge centrally on the photocell. The photocell is situated at the centre of its shifting range. The slit diaphragm is then set onto the photocell.
3. Set diaphragm with a simple slit which is to be investigated into diaphragm support. It must be made sure that the slit is placed centred and perpendicularly to the beam.
4. Plug in the power supply for the laser. Turn on the laser. The laser and the measurement amplifier should be warmed up for about 15 minutes before work starts, so as to avoid bothersome intensity fluctuations during measurements.
5. By using screw of zero adjustment of amplifier, make sure that zero is readed by multimeter with covered photodiode.
6. Change the position of the photocell by 0.5mm and record the responding intesity values from the multimetre. Record your value in Table below.
7. Repeat step 6 for the other diaphragms.
8. Measure the L, difference between slit and screen, record your value in Table below.
9. Record the wavelength of laser source.