

Interference and Diffraction

Goals of this lab

- investigate the interference and diffraction using various types of apertures
- calculate the wavelength of the laser light

Overview

The purpose of this experiment is to study the interference and/or diffraction patterns produced when collimated, monochromatic light (i.e. laser light) passes through various arrangements of apertures and is observed on a viewing screen. When the apertures are sufficiently small, the light intensity on the viewing screen exhibits variations (successive maxima and minima) which depend upon the wavelength of the light and the size and number of the apertures. The existence of the patterns is confirmation of the wave nature of light. While all optical phenomena (including the properties of lenses) can be understood on the basis of the wave theory, it is only when the light is monochromatic and well-collimated, as it is in a laser, and the apertures narrow, as it is in the slide you will use, that the wave properties are easily observed.

We will observe the following phenomena:

1 Single Slit Diffraction (Figure 1)

A single slit diffraction pattern results when the light passes through one aperture in an otherwise opaque surface. The light from the slit is equivalent to many in-phase, parallel pairs of point sources on either side of the center of the slit.

The light intensity on the viewing screen exhibits a bright central peak surrounded by subsidiary peaks. The difference in the distance that light from one edge of the slit travels compared to light from the center of the slit is called the path difference and equals $a \sin \theta_{\min}$.

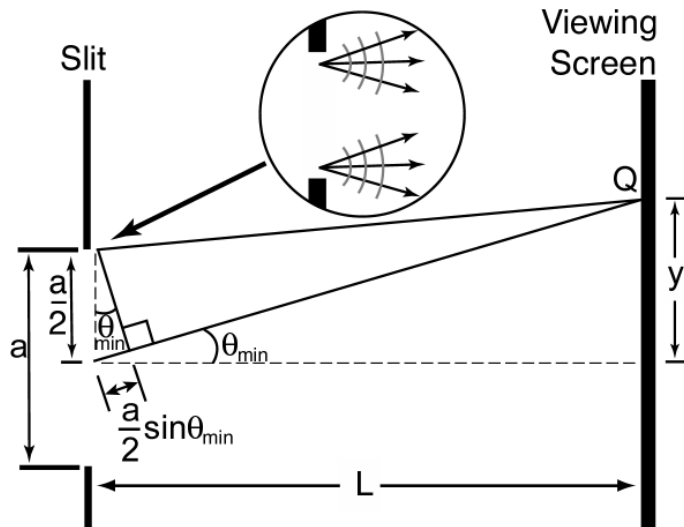


Figure 1: Single slit diffraction with a minimum at point Q.

When the path difference between light from one edge of the slit and light from the center of the slit is a multiple of half of the wavelength, the waves destructively interfere and there is a minimum in the pattern. Pairs of points on either side of the center of the slit differ in phase by half a wavelength. This explains the minimum at point Q.

The intensity minima occur at angular positions θ_{\min} with respect to the incident beam as follows:

$$\frac{a}{2} \sin \theta_{\min} = m \frac{\lambda}{2} \rightarrow a \sin \theta_{\min} = m \lambda \quad (1)$$

where a is the width of the single slit and $m = \pm 1, \pm 2$, etc. where m refers to the order of the minima (first, second, third, etc.). The viewing screen is located at a distance L from the aperture. A particular feature (e.g., an interference minimum) occurs a distance y from the center of the pattern at angle $\theta_{\min} = \tan^{-1}\left(\frac{y}{L}\right)$. The spatial intensity variation in a sample diffraction pattern is illustrated in **Figure 3a**, graphed as intensity vs. distance y .

Prelab Question 1: Light of wavelength 550 nm from a distant source passes through a slit 0.075 mm wide. The resulting diffraction pattern is seen on a screen 3.0 meters away. What is the distance between the two dark fringes on either side of the central bright line?

2 Interference (Figure 2)

The ideal two slit pattern, *Young's Experiment*, is produced by directing monochromatic light through two infinitesimally narrow slits in an otherwise opaque surface. In this lab we study *Fraunhofer diffraction*, the name for the diffraction effects seen on a screen which is some distance away from the slits. The path difference between the light from corresponding locations in the slits is $d \sin \theta_{\max}$, where d is the center to center distance between the slits.

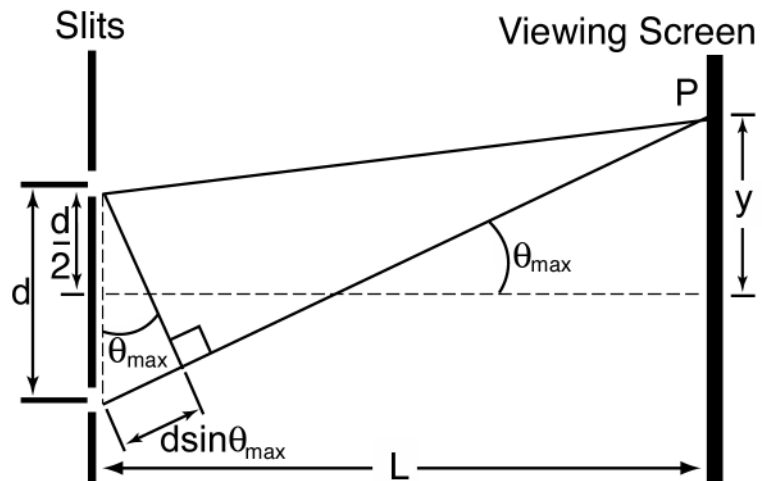


Figure 2: Double slit interference.

When the path difference between light from corresponding locations in the slits is a multiple of the wavelength of the light, the waves constructively interfere. This explains the maxima at point P . The intensity maxima, $M\lambda$, occur at angles θ_{\max} based on the following relation, where d is the distance between the slits and $M = \pm 1, \pm 2$, etc. where M refers to order of the maxima (first, second, third, etc.).

$$d \sin \theta_{\max} = M\lambda \quad (2)$$

The variation of intensity in the pattern formed on the screen is illustrated in **Figure 3** (on the next page) for $\lambda = 500 \text{ nm}$ and a slit spacing of 0.15 mm. (Neither the wavelength nor the slit spacing pertains to our apparatus). In practice, the slits are not infinitesimally wide, but rather have widths anywhere from 10 microns to about 200 microns. As a result, all observations of two-slit interference patterns are confounded by the diffraction effects.

Prelab Question 2: Consider the interference pattern produced by two parallel slits with width a and separation d . Let $d = 3a$.

- If we ignore the diffraction effects due to the width of each slit, at what angles θ from the central maximum will the next four maxima in the two slit interference pattern occur? (Give your answer in terms of d and λ , the wavelength of light)

- b. Now if you include the effects of single slit diffraction which of the figures 3 a, b, and c in the experiment write-up would best match your pattern?
- c. Sketch the intensity as a function of horizontal distance of the projected pattern. Indicate the order numbers in the sketch.

3 Interference and Diffraction (Figure 3c)

In any multiple slit experiment, the individual slits themselves produce a diffraction pattern. The diffraction pattern of the individual slits is superimposed on the interference pattern produced by the multiple slits. Accordingly, the intensity of the pattern observed on the screen is the product of the combined intensity of the individual slit diffraction patterns and the intensity of the multiple slit interference pattern. This can further complicate the observed pattern.

For example, an angular direction which satisfies Equation (2) for an interference maximum may in fact exhibit zero intensity because it coincides with a solution of Equation (1) for a diffraction minima. **Figure 3** shows graphs of intensity vs. angular position, where (a) shows the diffraction pattern for a single slit, (b) shows the ideal interference pattern for a double slit, and (c) shows the actual diffraction and interference pattern produced by a double slit.

For **Figure 3c** the slit separation distance is $d = 0.15$ mm and the slit width is $a = 0.05$ mm. The diffraction patterns of the individual slits, shown in **Figure 3b**, are superimposed on the interference pattern. The diffraction graph intensity forms an "envelope" for the interference pattern graph.

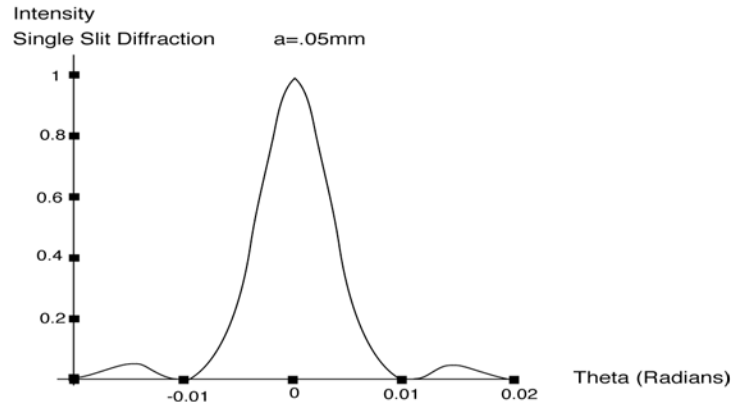


Fig. 3a: Single slit diffraction pattern.

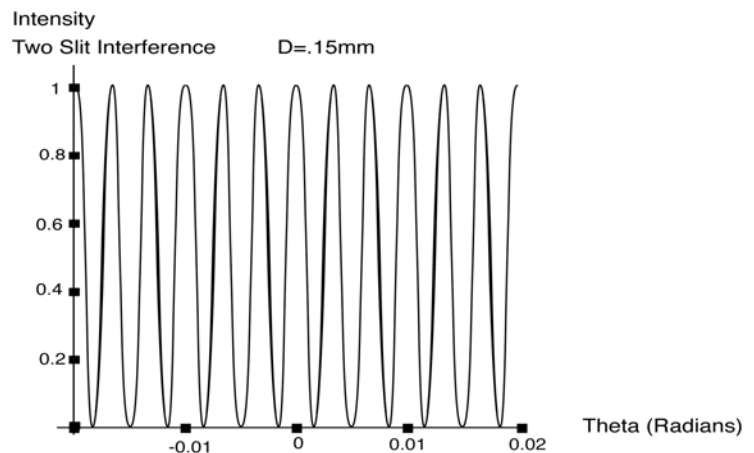


Fig. 3b: Double slit interference pattern.

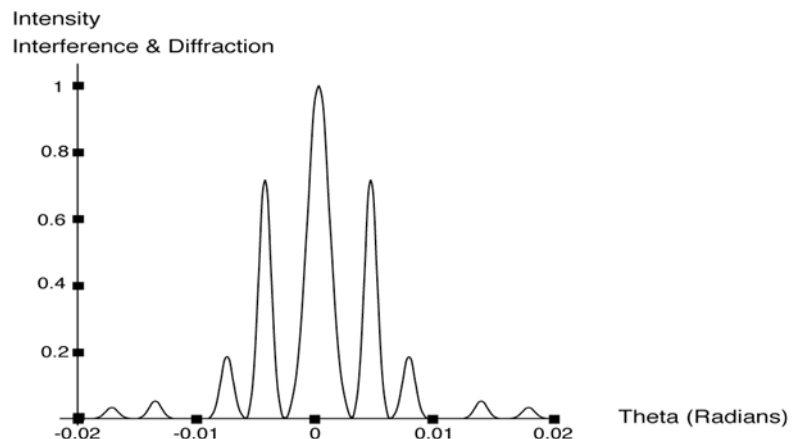


Fig.3c. Double slit interference-intensity pattern.

The Experimental Arrangement

We produce the interference and diffraction patterns by directing light from a laser onto a slit-pattern (single, double, or even multiple slits) on a 35mm slide. Note that for multiple-slit patterns the slit spacing (the quantity d in Equation (2)) is the center to center distance between the slits.

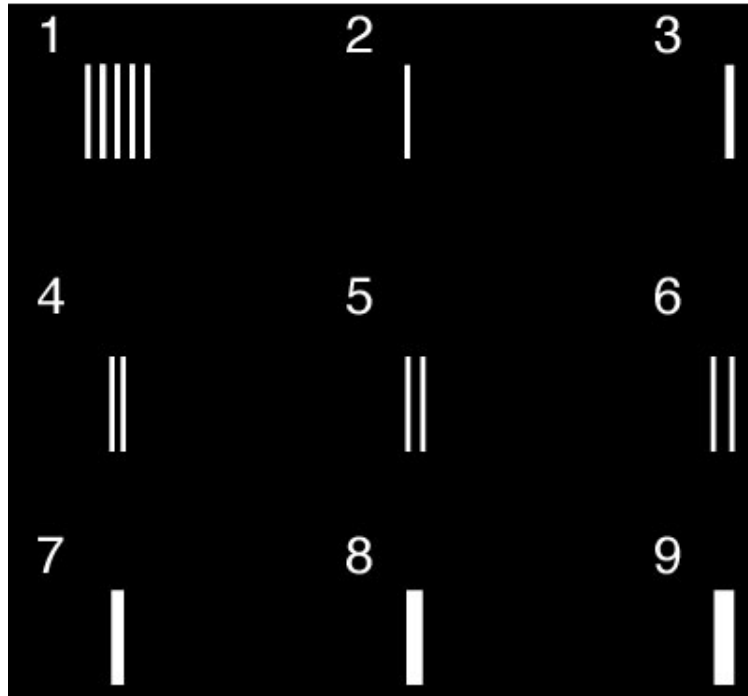


Figure 4. The fields with their apertures on the 35mm slide.

The aperture patterns on the slide are arranged in nine fields as follows; however, the actual slit widths and separations will be different for each slide.

- 1** Multiple slits
- 2 & 3** Single slits of different widths
- 4, 5, & 6** Double slits with different spacings (slit widths much smaller than the spacing)
- 7, 8 & 9** Single slits (slit widths approximately equal to the spacing of the double slits directly above them on the slide)

The interference or diffraction patterns are observed by passing the laser beam through the desired slit or slits and measuring the locations of the maxima and minima on the viewing screen. The best way to determine the angles is to measure the linear distance between corresponding features.

For example, you would measure the second interference maxima on the left and right sides of the center of the pattern, as shown in **Figure 5**. For a *single slit* y represents the location of the *minima*. For a *double slit* y represents the *distance between two features* of the same order on the left and the right of the center of the pattern.

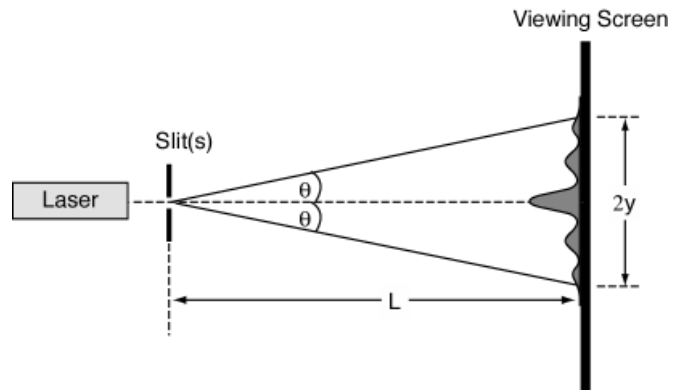


Figure 5: Measuring the diffraction/interference patterns on a screen.

Since it is difficult to be sure exactly where the center of the pattern is located, we measure the distance between equivalent features on the two sides of the pattern and call this distance $2y$.

Then we find $\tan \theta = \frac{y}{L}$, or, equivalently, $\theta = \tan^{-1}\left(\frac{y}{L}\right)$.

Questions:

1. How is the single slit pattern affected by the width of the slit?
2. How do you explain the locations of the missing *maxima* in the double slit pattern?
3. Compare the intensity pattern of one of the double slits with the sample pattern shown in **Figure 3b**.
4. Why does equation (2) for the double slit interference pattern apply to the multiple slit interference pattern?
5. Even though formulae (1) and (2) *look* alike they mean entirely different things. Explain how they are similar and how they are different.

Advanced Questions:

1. Now that you have studied the relationship between slit spacing and dimension and the projected intensity pattern on the screen, work backwards and find the slit separation distance and slit width for one of the double slit patterns from the intensity pattern on the screen. Compare your values for a and d with the reference values that your TA has.
2. Find the number of slits in the multi-slit pattern in field #1

Suggested Measurements

- 1) Ask your instructor for the dimensions of the slit patterns in the 9 fields for your particular slide.
- 2) Tape a large piece of paper to the viewing screen. Measure the distance, L , between the slide and the viewing screen. Prop the triangle on the horizontal meter stick and use that to help locate and mark the locations of the minima or maxima.
- 3) Study the diffraction patterns produced by the single slits in fields #2 and #3. Sketch the light intensity as a function of position on the screen for one of the single slit fields.
- 4) Measure the distances between corresponding pattern features to the left and right of the pattern center. Determine the angles corresponding to six intensity *minima*.
- 5) Plot $a \sin \theta_{min}$ as a function of the order, m (± 1 , ± 2 , etc.), of the minima. Include the appropriate error bars. Find the slope of each plot and its uncertainty.
- 6) Study the interference patterns produced by the double slits in fields #4, #5, and #6. Sketch the light intensity as a function of position on the screen for the one of the double slit fields. Show the maxima, minima and the half-fringes.
- 7) Measure the distances between corresponding pattern features to the left and right of the pattern center. Determine the angles corresponding to six intensity *maxima*.
- 8) Plot $d \sin \theta_{Max}$ as a function of the order, M (± 1 , ± 2 , etc.), of the maxima. Include the appropriate error bars. Find the slope of each plot and its uncertainty.
- 9) Compare the intensity variations produced by the double slits related to the single slits: #4 & #7, #5 & #8, and #6 & #9.
- 10) Study the interference patterns produced by the multiple apertures in field #1. Describe the difference between the intensity pattern on the screen produced by many, as opposed to just two, slits of the same slit spacing.
- 11) Compare your calculated values for the wavelength of the laser light to the accepted value.