Exercise 11: single-slit and double-slit experiments

Purpose: to investigate double-slit interference and single-slit diffraction patterns.

Introduction

Double-slit interference

Under certain circumstances, light behaves exactly as if it were a wave. In two-slit interference, light falls on an opaque screen with two closely spaced, narrow slits. As Huygen's principle tells us, each slit acts as a new source. of light. Since the slits are illuminated by the same wave front, these sources are in phase. Where the wave fronts from the two sources overlap, an interference pattern is formed.

The essential geometry of the double-slit experiment is shown in Fig. 1(a). At the zeroth maxima, light rays from slits A and B have traveled the same distance from the slits to your eye, so they are in phase and interfere constructively on your retina. At the first order maxima (to the left of the viewer) light from slit B has traveled one wavelength further than light from slit A, so the rays are again in phase, and constructive interference occurs at this position as well.

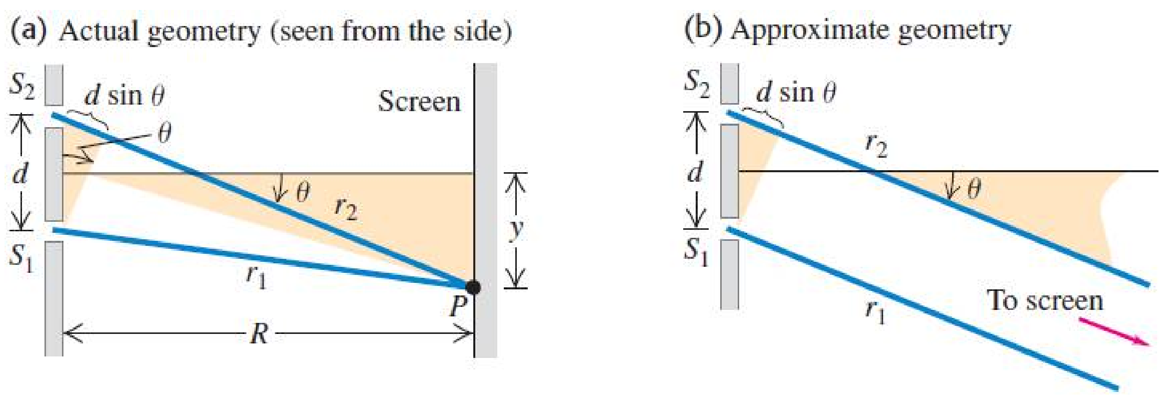

Fig. 1: (a) Double slit experiment and (b) the far-field approximation.

When viewed far away from the slit, the rays are approximately parallel as shown in Fig. 1(b). The resultant equation for the angles at which the constructive interference is at a maximum is given by

$$d \sin\theta_m = m\lambda \quad \text{where} \quad m = 0, \pm 1, \pm 2, \dots$$

When the angle between adjacent maxima is small, $\theta \ll 1$ radians, we may make the approximation $\theta \approx \sin\theta \approx \tan\theta$. By definition, $\tan\theta = \frac{y}{R}$, where y is the distance above or below the center maximum of the interference pattern on the viewing screen. Thus, the above approximation at small angles allows us to write

$$d\frac{y_m}{R} \approx m\lambda \quad \text{where} \quad m = 0, \pm 1, \pm 2, \dots$$

Single-slit diffraction

Unlike double-slit intereference, the intensity of the fringes varies in a single-slit experiment. This variation in intensity forms an interference pattern of its own that is independent of the number of slits or the separation between the slits. In fact, two slits are not required to see this pattern; it can be seen most clearly when light passes through a single, narrow slit.

The single slit pattern can be explained using Huygen's theory. When a plane wave front strikes the slit, each point on the slit acts as a point source of light as illustrated in Fig. 2(a). Because light from the above point travels a different distance than the light from the below point (except at an angle of $\theta = 0$), the light from different points across the slit interfer.

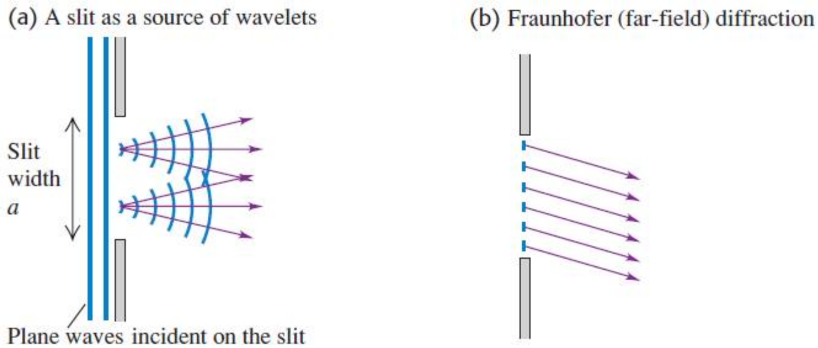

Fig. 2: (a) diffraction through a single slit and (b) the far-field approximation.

When viewed from a distance far greater than the slit width a as shown in Fig. 2(b), the diffraction pattern minima are at the angles θ_n, given by the equation

$$a \sin \theta_n = n\lambda \quad \text{where} \quad n = \pm 1, \pm 2, \pm 3, \dots$$

Note that there is no minimum at the center, and therefore $n \neq 0$.For small angles, we may make the same approximation as we did with the double-slit experiment, which results in the approximate relationship

$$a \frac{y_n}{R} \approx n\lambda \quad \text{where} \quad n = \pm 1, \pm 2, \pm 3, \dots$$

Laboratory assignment

I. Double-slit experiment

1. Setup the experiment as shown in Fig. 3 using double-slit patterns.

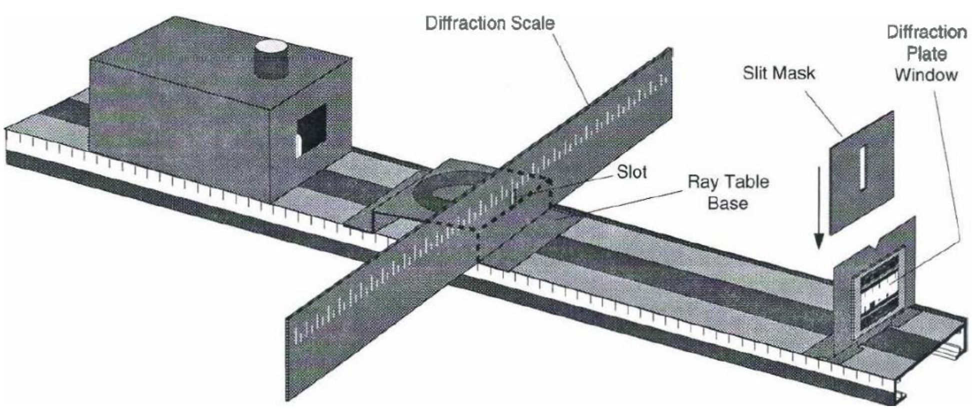

Fig. 3: Diagram for double-slit and single slit experiments.

2. While looking through the Slit Mask, adjust the position of the diffraction scale so you can see the filament of the light source through the slot in the diffraction scale.
3. Attach the diffraction plate to the other side of the component holder.
4. Center pattern D, with the slits vertical, in the aperture of the slit mask. Look through the slits. By centering your eye so that you look through both the slits and the window of the diffraction plate, you should be able to see clearly both the interference pattern and the illuminated scale on the diffraction scale.

5. In this experiment, you look through the narrow slits at the light source, and the diffraction pattern is formed directly on the retina of your eye. You then see this diffraction pattern superimposed on your view of the illuminated diffraction scale. The geometry is therefore slightly more complicated than it would be if the pattern were projected onto a screen, as in most textbook examples.
6. Start by using the red color filter. Record the locations y_m of the first two maxima on either side of the center maximum.
7. Repeat the above step for the green and blue color filters.
8. Make a table similar to Table I.

Table I: *maxima locations for different colors of light using pattern D.*

(y_m)	y_{-2}	y_{-1}	y_0	y_1	y_2
Red filter					
Green filter					
Blue filter					

9. How does the spacing between fringes vary with the color of the light source?
10. Suppose the space between the slits was smaller than the wavelength of light you were trying to measure. How many orders of maxima would you expect to see?

II. Single-slit experiment

1. Set up the experiment the same as in Fig. 3, but this time use single slit patterns.
2. Examine each of the three diffraction patterns of all slits without the color filters. Explain what you see.
3. Now place the red color filter over diffraction pattern A. Record the locations y_n of the first three minima on either side of the center maximum.
4. Repeat the above step for diffraction patterns B and C.
5. Make a table similar to Table II.

Table II: *minima locations for different diffraction patterns using red light.*

(y_n)	y_{-3}	y_{-2}	y_{-1}	y_1	y_2	y_3
Pattern A						
Pattern B						
Pattern C						

6. Now place the green color filter over diffraction pattern A. Record the locations y_n of the first three minima on either side of the center maximum.
7. Repeat the above step for the blue color filter.
8. Make a table similar to Table III.

Table III: *minima locations for different colors of light using pattern A.*

(y_n)	y_{-3}	y_{-2}	y_{-1}	y_1	y_2	y_3
Red filter						
Green filter						
Blue filter						

9. How does the spacing between fringes vary with the width of the slit?
10. How does the spacing between fringes vary with the color of the light source?
11. How does a double-slit interference pattern differ from a single-slit pattern?

Equipment list: Pasco optics kit.