8. INTERFERENCE AND DIFFRACTION

Driving Question | Objective

How can the wave nature of light be used to determine the distance between two closely-spaced narrow parallel slits? Use a coherent light source and the principles associated with double-slit interference and diffraction to experimentally determine the spacing between the slits in a double-slit pattern provided by your instructor.

Materials and Equipment

- PASCO Diffraction Plate[1]
- Table clamp or large base (2)
- Support rod, 45-cm (2)
- Three-finger clamp (2)
- Stainless steel calipers

- Laser pointer with known wavelength
- White paper
- Pencil
- Ruler
- Tape
- Measuring tape

[1]www.pasco.com/ap33

PASCO Diffraction Plate

Background

Coherent light passing through a very narrow slit forms a distinct *diffraction* pattern, with clear areas of higher and lower intensity, on a screen. These areas are the result of conditional constructive and destructive interference between light waves at the viewing screen.

Single-slit diffraction pattern

Double-slit interference pattern

When coherent light passes through two very narrow, very closely spaced slits, the diffraction pattern includes many additional areas of bright and dark fringes compared to those from a single slit diffraction pattern.

The additional bright and dark fringes are the result of the interference of light emitted from each of the two slits. According to Huygens's Principle, when coherent light reaches two slits, each slit becomes an emission source for spherical light waves with the same wavelength as the original coherent light.

These light waves cross and interfere as they propagate, eventually reaching a screen where areas of constructive interference are seen as bright spots (maxima), and areas of destructive interference are seen as dark spots (minima).
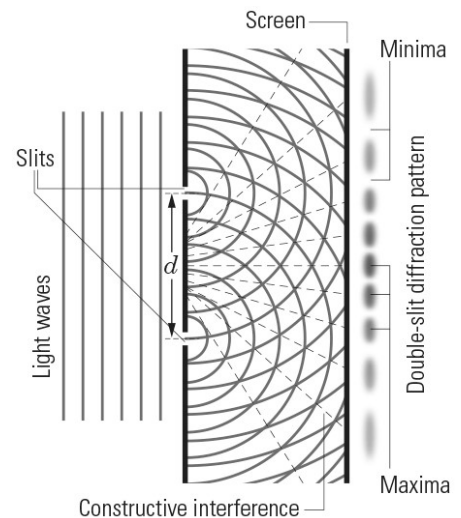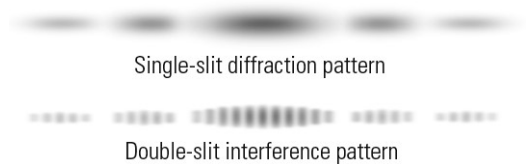
The mathematical expression describing the position (angle) of the maxima within this double-slit interference pattern is:

$$d \sin \theta = m\lambda \qquad (1)$$

Where m is the order number, an integer ± 1, ± 2, ± 3..., d is the distance between the slits, θ is the angle between each m order maxima in the interference pattern and the 0th-order (central brightest) maxima, and λ is the wavelength of the light source.
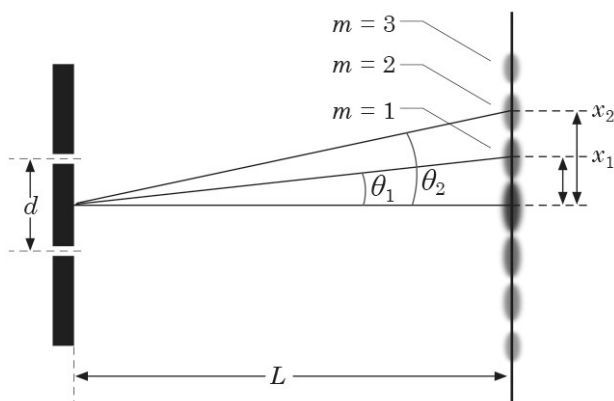
In practice, the angular position θ of each interference maxima is often expressed in terms of linear position x, where x_m is the linear distance between the 0th-order maxima and the mth-order maxima as observed in the interference pattern on a screen some distance L from the double-slit aperture. Going further, if the distance L between the slits and the screen on which you view the interference pattern is large compared to x_m, an approximation can be used to simplify Equation 1:

$$\text{If } L \gg x_m, \text{ then } \sin \theta \approx \tan \theta \approx \frac{x_m}{L} \text{ or, } \frac{dx_m}{L} \approx m\lambda$$

$$\text{Rearranging yields: } x_m \approx m\frac{\lambda L}{d} \qquad (2)$$

RELEVANT EQUATIONS

$$d \sin \theta = m\lambda \qquad (1)$$

$$x_m \approx m\frac{\lambda L}{d} \qquad (2)$$

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- A laser can cause serious damage to the human eye. Do not look directly at the beam and only turn the laser on when necessary for alignment or data collection.

- Avoid laser beam reflections that may cause eye damage. Be aware of the laser beam at all times; you might be producing unknown stray reflections.

Procedure

SET UP

1. Assemble your equipment and align the laser as shown:
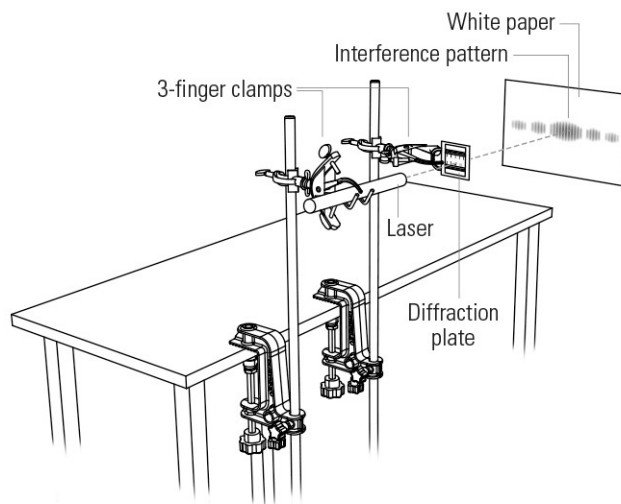
   a. Find an area on your lab table with enough space to align the components as in the illustration, with the laser aimed away from other lab groups, and toward a wall or other flat rigid surface on which you can attach the white paper.

   b. Use tape to hold the white paper in place against the wall or other surface.

   c. Lightly clamp the edge of the diffraction plate (the edge parallel to the slits on the plate) in the three-finger clamp. Be certain the double-slit patterns on the plate are vertical and the fingers of the clamp touch only the edge of the plate and not the plate film.

   NOTE: Over-tightening the clamp will damage the plate.

   d. Adjust the setup so that the laser beam is perpendicular to the diffraction plate, and the white paper and diffraction plate are parallel to each other.

   e. Have at least one meter of space between the diffraction plate and the paper. Use as large a distance as possible while ensuring visibility of the light on the paper.

2. Choose one of the three double-slit patterns on the diffraction plate, "D," "E," or "F," and adjust the laser so the beam shines on that pattern. A clear image of the interference pattern should appear on the white paper. Record which double-slit pattern you chose: "D," "E," or "F," in the space indicated at the top of the Data Analysis section.

   NOTE: Aim the laser slightly downward at the diffraction plate to prevent stray reflection of the laser beam traveling upward into a classmate's eyes. Also, you might want to place an object behind your setup (behind the laser) to catch any reflection of the laser beam from the diffraction plate.

3. Once aligned, tighten the setup components so the laser and diffraction plate do not move during data collection.

COLLECT DATA

4. With the interference pattern clearly shown, use the ruler and pencil to draw a horizontal line through the center of the interference pattern on the paper.
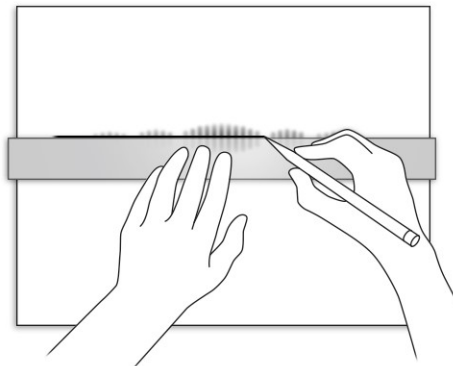
5. Make a small mark on the line you just drew at the center of the 0th-order (central brightest) maxima.
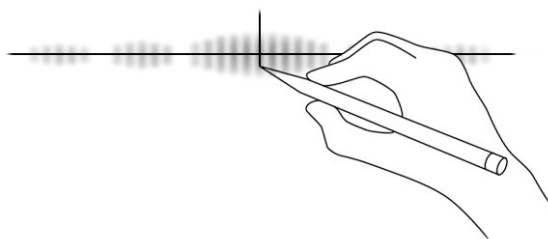
6. Continue to make small marks at the centers of the neighboring five maxima to the right or left of the 0th maxima.

7. Turn off the laser, and then record its wavelength λ in the Data Analysis section below.

   NOTE: The wavelength is usually printed on a sticker on the outside of the laser. If it is not printed on the laser, ask your instructor for this value.

8. Use the measuring tape to measure the distance L between the diffraction plate and the white paper. Record this value in the Data Analysis section.

9. Remove the white paper and place it on your lab table.

10. Use the calipers to accurately measure the distance from the 0th maxima mark ($m = 0$) to each higher order maxima ($m = 1, 2, 3, 4, 5$). Record each distance (x_m) in Table 1 in the Data Analysis section below.
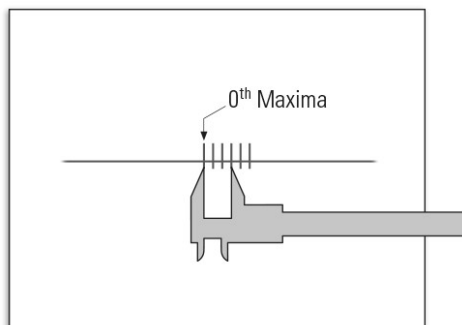
0th Maxima

Data Analysis

Double-slit pattern: _____

$\lambda =$ _____

$L =$ _____

Table 1: Measurements for determining the slit spacing

Integer Order Maxima m	Distance from 0th Maxima x_m (cm)
1	
2	
3	
4	
5	

1. Plot a graph of *distance of interference maxima from 0th maxima (x_m)* versus *integer order (m)* in the blank Graph 1 axes below. Be sure to label both axes with the correct scale and units.

Graph 1: Distance of interference maxima from 0th maxima versus integer order of double-slit interference maxima
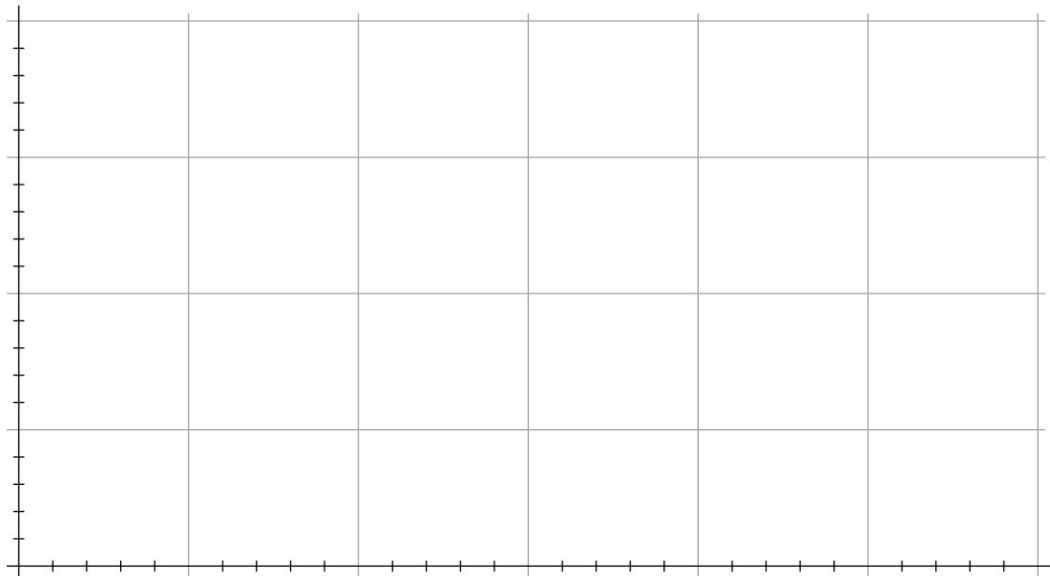
2. Draw a line of best fit through your data in Graph 1. Record the equation of the line here:

    Best fit line equation: _____

3. Use the slope from the best fit line to determine the spacing d between the parallel slits on the diffraction plate:

    $$\text{slope} = \frac{\lambda L}{d}$$

    Slit spacing d (cm): _____

Analysis Questions

❷ 1. What is your experimental value for the spacing between the double slits, and how did you determine this value from your data?

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❷ 2. What are factors that may have caused error in your experimental value of slit spacing? Explain how each factor you list could have been avoided or minimized.

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❷ 3. Ask your teacher for the actual slit spacing value, and then calculate the percent error between your experimental value and the actual value.

$$\text{Percent error} = \left| \frac{\text{Actual} - \text{Experimental}}{\text{Actual}} \right| \times 100$$

❷ 4. Explain how your data would differ if you had used slits spaced twice as far apart and half as far apart.

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❷ 5. Would the data in your experiment differ if the distance between your laser and the double-slit aperture had been much greater? Justify your answer.

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Synthesis Questions

❷ 1. A CO_2 gas laser ($\lambda = 1.06 \times 10^{-5}$ m) emits light incident on two very narrow, closely spaced slits that produce a diffraction and interference pattern on a screen 1.00 m away. If the slits are spaced 0.150 mm apart, how far from the central maxima is the 10th-order maxima?

❷ 2. Imagine you had a rigid sheet of metal foil with two extremely narrow, closely-spaced slits in it used as a particle shield in some advanced experiment. Before the shield can be used, you need to determine the spacing between the slits. Using a gamma ray gun ($\lambda = 1.00 \times 10^{-11}$ m) and a detector array 40.13 m away, you find that the diffraction pattern has a distance between the central maxima and the 1st-order maxima of 0.01332 m. What is the spacing between the slits?

❷ 3. When you observe a double-slit interference and diffraction pattern, the pattern is always symmetrical about a central bright point. In a few sentences, explain why a double-slit interference and diffraction pattern mirrors itself about this central bright point?

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