Lab 8. Interference of Light

Goals

- To observe the interference patterns for laser light passing through a single narrow slit, through two closely spaced slits, and through multiple closely spaced slits, noting the similarities and differences.
- To determine by graphical techniques the wavelength of the laser light based on the observed interference patterns for single, double, and multiple slits.
- To compare the calculated values of wavelength with the accepted value for a red helium-neon laser.
- To "measure" the diameter of a human hair by observing and analyzing the interference pattern created when it is placed in the center of laser beam.

Introduction

Two waves that have the same frequency can "interfere" constructively when the peaks coincide or destructively when a peak of one wave coincides with a valley of the other. When speaking of peaks and valleys, water waves are a useful example. With sound waves the peaks and valleys correspond to regions of high and low pressure. With electromagnetic waves, such as light, the peaks and valleys correspond to regions of positive and negative electric and magnetic field vectors. Constructive interference of light rays produces regions of high intensity or brightness. Destructive interference produces regions of low intensity or darkness.

Double slit interference

Perhaps the simplest example of interference effects takes place after monochromatic light passes through two nearby, parallel slits (narrow openings for the light to come through). Laser light is nearly monochromatic (all of the same frequency and wavelength). The diagram in Figure 8.1 shows the path of a laser beam, traveling from right to left, incident on two slits at an incident angle of $0°$. This configuration assures that the phase of the waves at each of the slits is the same. In other words the peak of the wave in one slit is synchronized with the peak of the wave in the other slit. Let d be the center-to-center spacing between the slits. The light intensity is observed at a distance y from the center of the slit pattern. For constructive interference to take place at the point y, the difference in the distances from the point y to the individual slits, $r_2 - r_1$, must be equal to some integer multiple of the wavelength λ of the light. This can be expressed as

$$r_2 - r_1 = m\lambda \qquad \text{where } m \text{ is an integer } (...2, 1, 0, +1, +2, ...) \quad . \tag{8.1}$$

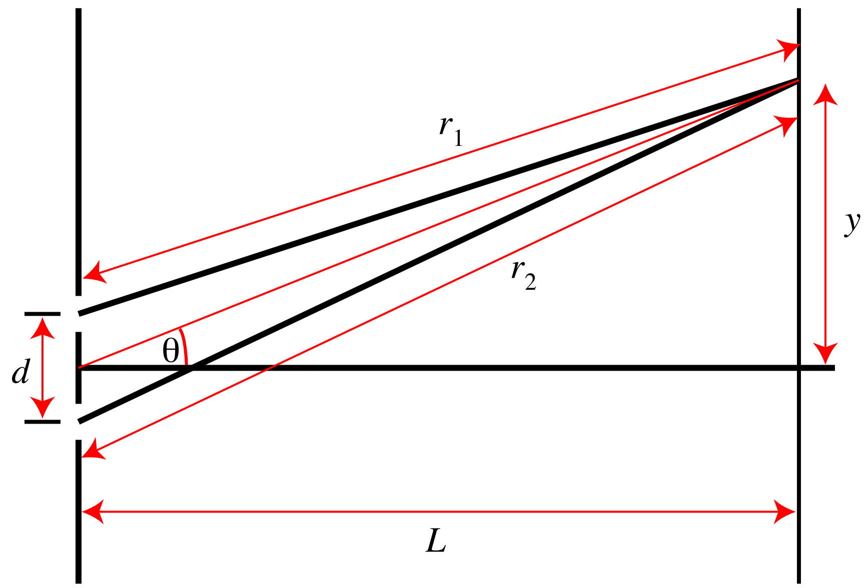

Figure 8.1. Geometry for determining the condition for constructive interference for a double slit.

In reality, the distance L from the viewing screen to the slits is much larger than the distance between the slits d. In this case the lines denoting the distances r_2 and r_1 are essentially parallel, like the edges of a very tall skinny triangle. For this limiting case the difference in the distances can be written to a good approximation as

This equation defines the angles for maximum intensity on the screen.

Interference patterns from double slits can be used to find the spacing between the two sources of light if the wavelength of the light being used is known. In other words, from the measured positions of the intensity maxima on the viewing screen, one can calculate the angles corresponding to the various values of m and determine the unknown d. On the other hand, if d is known, then the wavelength can be determined. Historically the wavelengths of light were difficult to measure until good quality slits became available about 100 years ago.

Single slit diffraction

Experimentally a narrow aperture such as a single slit will interact with a narrow beam of light such a way that some of the light appears to be "bent" from its original direction of travel. The term diffraction refers to this apparent change of direction. This behavior is due to interference between parts of the light wave that pass through the slit at different points within the slit. Thus diffraction can be thought of—not as some new phenomenon—but as another manifestation of the interference of waves. For a single slit of width a the relationship that describes the locations of the minima of intensity on the viewing screen is given by

$$a \sin \theta = n\lambda \tag{8.2}$$

where n is an integer excluding zero, that is, (... –2, –1, +1, +2, ...) Note that zero is missing from the list!

This expression looks a great deal like Equation 8.1, which describes intensity maxima for a double slit arrangement. Remember the important differences!

Multiple slit (more than two slits) interference

When more than two equally spaced slits are present, the explanation proceeds in exactly the same way as it does for the double slit arrangement. In fact the condition for making light from adjacent slits interfere constructively on the viewing screen is sufficient to ensure that the light from all of the slits will interfere constructively on the screen. Thus Equation 8.1 also prescribes the conditions to be met for intensity maxima when more than two equally spaced slits are present.

Determining the wavelength of light from a helium-neon laser

Never look directly into the beam or at reflections of the beam. Don't point the laser at anything other than the screen. Failure to follow these instructions may lead to a zero for the lab.

If you need to locate the laser beam, insert a piece of paper into the beam path. Minimize reflections by positioning the slide with the slits close to the exit aperture of the laser, which directs the reflected beam back toward the laser. If a laser is powered up but the beam is not visible, make sure the aperture at the front of the laser is open.

Using double slit interference

On the viewing screen observe and mark the locations of the maxima or minima of intensity, as appropriate, for a double slit. The glass slide with the green tape on the edges contains the various slit arrangements. Use one of the double slits from Column 5, either (b) or (c). From this information calculate the wavelength of the laser light. Consider an appropriate graph. Most students will find Excel helpful. You should compare your calculated wavelength to the accepted value listed for He-Ne lasers in your textbook or a handbook. Does your calculated value agree with the accepted value within the limits of the expected uncertainties?

Using single slit diffraction

Use the single slit from Column 1, Row (e). (This slit has the same width of each of the double slits on your slide.) Again mark maxima or minima as appropriate and calculate the wavelength of the light from this data. Does your calculated value agree with the accepted value within the limits of error?

Using multiple slits

Choose a multiple slit from Column 3, either (b), (c), or (d), and calculate the wavelength from the resulting data. Does your calculated value agree with the accepted value within the limits of the expected uncertainties?

Measuring the diameter of a human hair with laser light

Mount a human hair so that it can be placed in front of the laser beam and look at the resulting light pattern. Does it most closely resemble the pattern of a single slit, a double slit, or multiple slits? Look at it carefully and note the pattern of bright and dark regions, particularly their spacing with respect to the center of the pattern. Then mark intensity maxima or minima as appropriate on the viewing screen. Using the textbook value for the wavelength of the laser light, calculate the diameter of the hair. Compare this value of the diameter to that obtained with a micrometer. Machinists use micrometers to make precise length measurements. Do the measurements agree within their expected uncertainties?

Before you leave the lab please:
    Straighten up your lab station.
    Report any problems or suggest improvements to your TA.

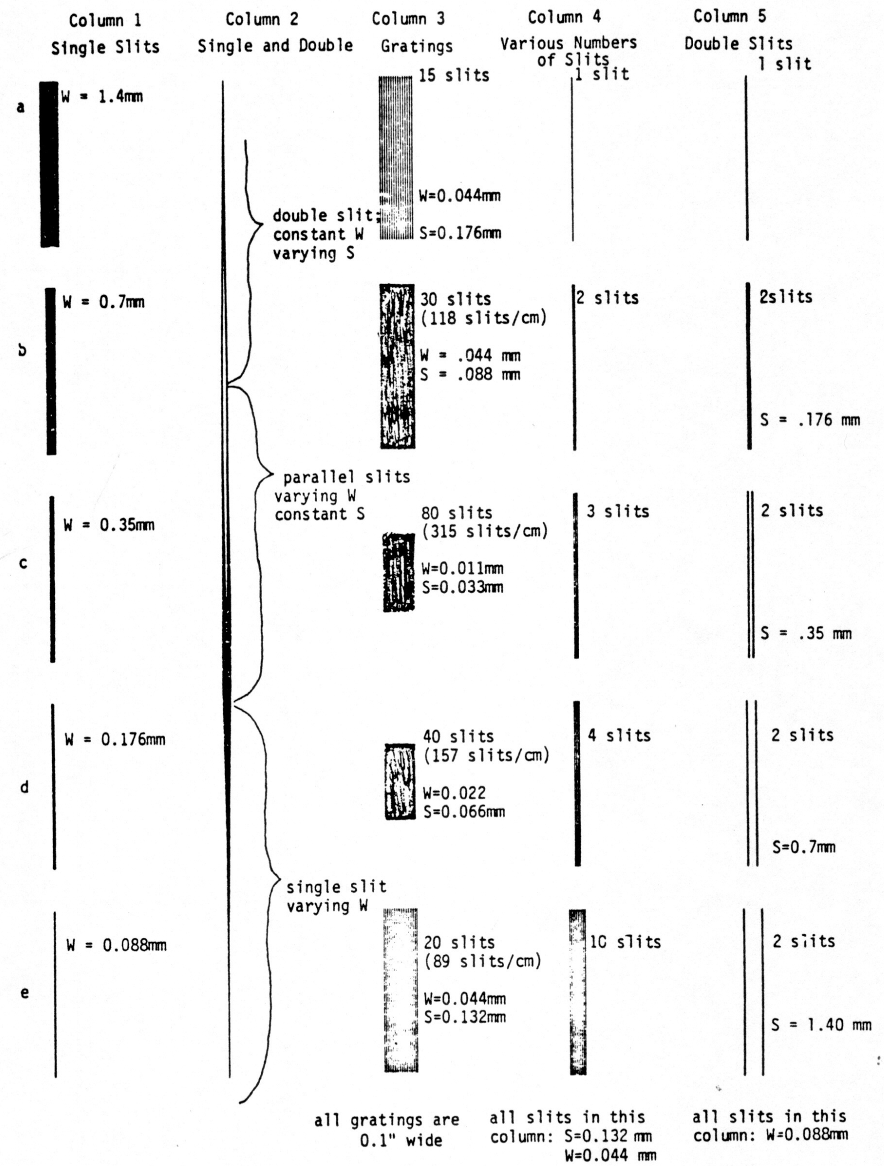

Fig. 2 Arrangement of slits and gratings on the green slide. The dark lines in the figure represent transparent regions on the slide.

W = width of an individual slit

S = spacing between centers of neighboring slits

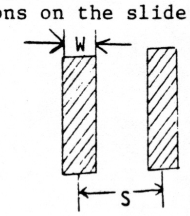

Figure 8.2. Arrangement of slits and gratings on black slide.