Diffraction Slits and Gratings

Fraunhofer, or far-field diffraction, occurs when collimated light passes through a diffracting aperture and the resulting pattern impinges on a screen which is far from the aperture. This lab explores the diffraction of laser light with the use of single, double, and multiple slits, as illustrated below. The Appendix summarizes the principles of Fraunhofer diffraction.

To record the diffraction patterns, attach a sheet of graph paper to a screen in the far field. Features can be indicated with a pen or pencil; several patterns can be recorded on a single sheet. Include the labeled graphs in your report. Note that the red He-Ne laser line occurs at 632.8 nm. Masks with multiple apertures should be placed in a mount on the optical axis. Each mask lists the nominal values of slit widths and spacings. Use these values in analyzing and comparing measurements.

Procedure:

A. Record the diffraction patterns for four different width single slits (nominally 0.02mm, 0.04mm, 0.08mm and 0.16mm).**Q1.** Based on Huygen's principle, explain why the central maximum gets wider as the width becomes narrower. From the positions of the minima and the distance to the screen, compute the slit widths. Compare the measured values to the nominal values marked on the masks.

B. Record the patterns for four different pairs of double slits (slit width 0.04 with spacings 0.25mm and 0.5mm, and slit width 0.08mm with slit spacings 0.25mm and 0.5mm). **Q2.** Develop empirical relations between various parts of these patterns and relate them to the slit spacings and separations. For example, isolate the contributions from slit spacing and from slit width.

C. Record the patterns resulting from four-slit and five-slit masks. **Q3.** From your measurements, compute the separation of the slits. Deduce the number of slits from the diffraction pattern. Explain how you are able to do this.

D. Use the mask labeled "circular apertures" and the mask with a square pattern. The latter is made up of smaller holes, as can be verified using a magnifying glass.

Record the resulting diffraction patterns. **Q4.** For the circular aperture, calculate its radius from diffraction theory (see Pedrotti Ch. 11-3). **Q5**. Relate the spacing from the square array to the Fourier Transform of a square lattice. What is the relation between real-space and the k-lattice spacing? (see Pedrotti 25-1).

E. Use the tick marks on a steel ruler as a diffraction grating in reflection mode. **Q6.** Use the spacing of the marks to calculate the wavelength of the laser light.

F. Observe the diffraction pattern from the mounted transmission grating (nominally 100 lines/mm). To see several spots, you may need to bring the screen closer. **Q7.** Calculate the line spacing and compare to the nominal value.

G. Replace the laser with white light from a halogen lamp. Shine the white light through the 1000 lines/mm card grating and photograph the diffraction pattern. Place a black cardboard mask with a 1 cm dia aperture just in front of the grating to block stray light. The screen should be about 10 cm behind the grating. In this case, a single diffraction order will result in a rainbow, since different wavelengths will have maxima at different angles. Mark the positions of the red and violet spectra. **Q8.** Calculate the angular positions of the red and violet maxima for a single order and calculate the ratio of wavelengths.

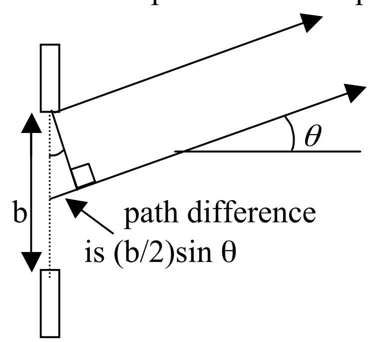
Indicate in your lab report which questions are being addressed (Q1, Q2, …).

The original graphs need only to be attached to one write-up per group. No need to make copies. Indicate which write-up has the data included.

Appendix: Diffraction Slits and Gratings

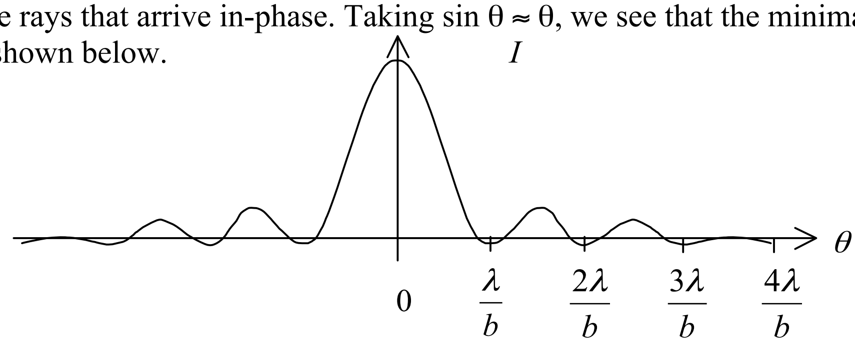
1. Diffraction from a single slit

Using Huygens' principle, we imagine the slit to be filled with a line of point sources. Consider two point sources separated by b/2, one at the edge and one at the center:



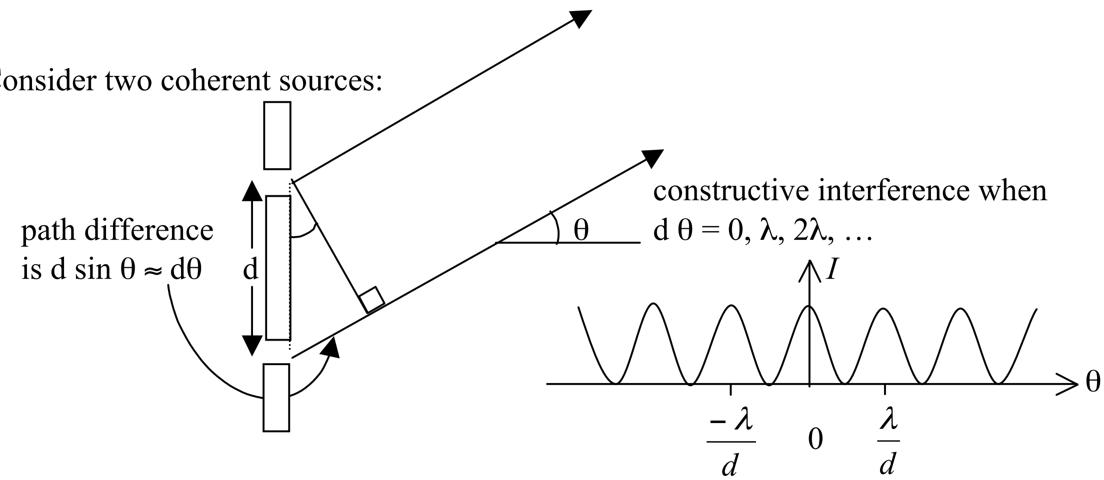
Destructive interference when
$(b/2)\sin\theta = \lambda/2, \lambda, 3\lambda/2, \ldots$

Now, each point source can be paired with one b/2 away. If one pair is out-of-phase, they will all be out-of-phase. Note that a minimum does not appear at $\sin\theta = 0$. The bright region arises from the undiffracted beam, i.e. the point sources away from the edges, which produce rays that arrive in-phase. Taking $\sin\theta \approx \theta$, we see that the minima occur at the angles shown below.

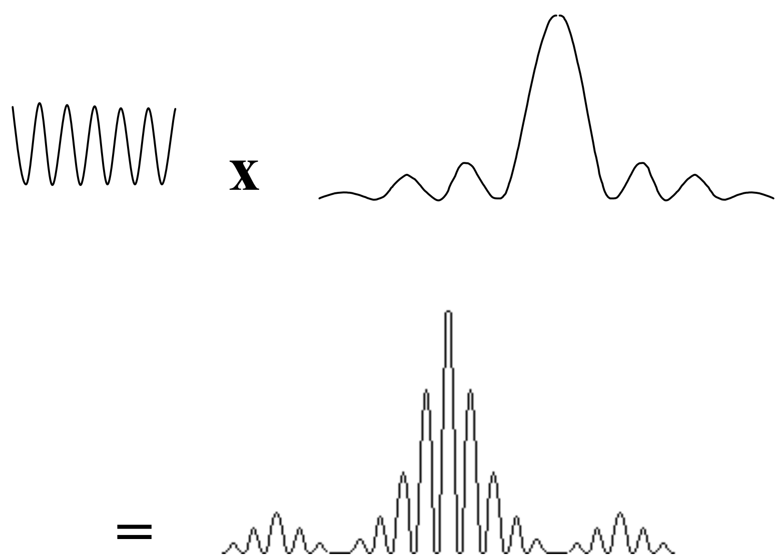


2. Diffraction from a double slit

Consider two coherent sources:



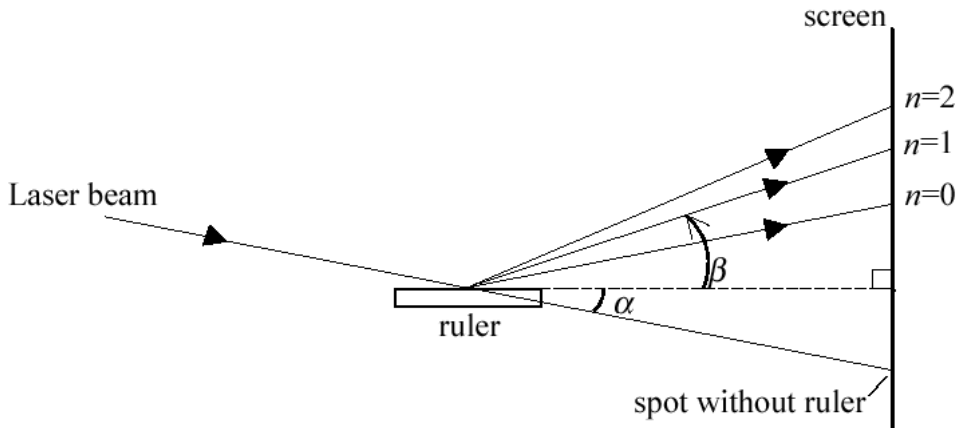
Now, let's consider that each slit has some non-zero width, b, which would result in a single-slit pattern if the slit were isolated. The resulting pattern is the product of two functions, shown schematically below::



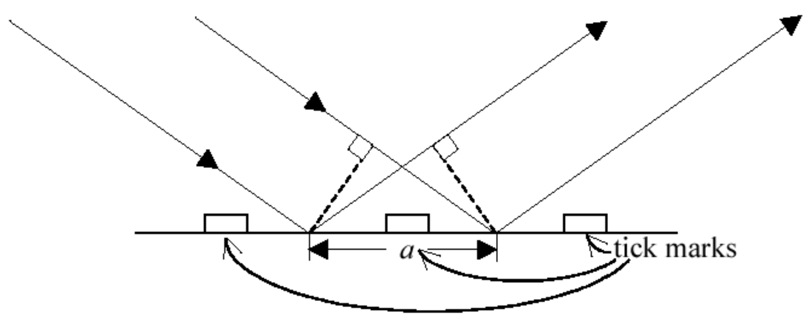
The pattern from multiple slits or a diffraction grating is calculated in a similar way.

3. Steel Ruler Diffraction Grating: Reflection Grating

Designate the angle of the incident beam α and the outgoing beam β:



Note: n= 0 corresponds to *specular* reflection, $\alpha = \beta$.



The condition for constructive interference: $a(\cos\alpha - \cos\beta) = 0, \lambda, 2\lambda, \ldots = n\lambda$