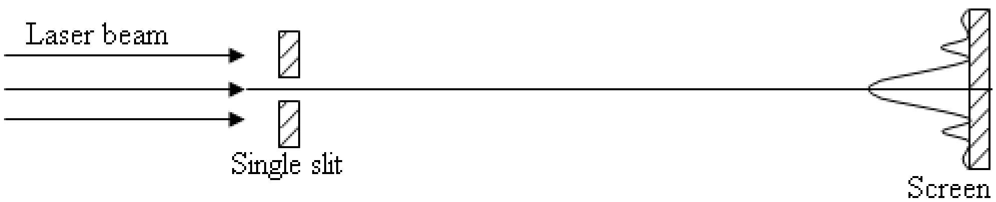
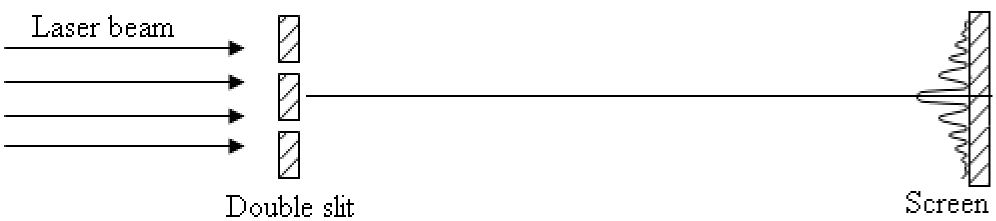
Experiment 8: Diffraction Slits and Gratings PHY 431

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 when the light is incident on 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 region. Features can be marked with a pen or pencil and several patterns can be recorded in rows on a single sheet. Include the labeled graphs in your report. For the red and green diode lasers that you will use for illumination, the manufacturers claim the wavelengths of 651 and 532 nm, respectively. Masks with multiple apertures should be placed in a mount on the optical axis. Each mask lists the nominal values of slit widths and slit separations. Use these values in analyzing and comparing measurements.





Procedure:

A. Record the diffraction patterns for light incident on a <u>single</u> slit for four cases of slit widths (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 gets 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 <u>double</u> slits (slit width 0.04mm with slit separation of 0.25mm and 0.5mm, and slit width 0.08mm with slit separation of 0.25mm and 0.5mm). **Q2.** Develop empirical relations between various characteristics of the observed patterns and relate them to the slit widths and separations.

C. Record the patterns resulting from <u>four-slit</u> and <u>five-slit</u> masks. **Q3.** From your measurements on the screen, 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 in 3^{rd} Ed.). **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 Ch. 21-1 in 3^{rd} Ed.).

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 narrow slit cut out 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 should 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 representative wavelengths.

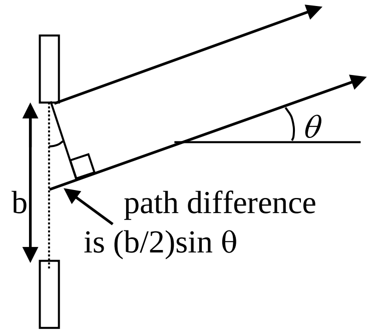
Indicate in your lab report which questions are being addressed (Q1, Q2, …).

The original graphs need only to be attached to only one report per team. I.e. there is no need to make copies for the sake of reporting. Indicate which report has the original data included.

Appendix: Diffraction Slits and Gratings

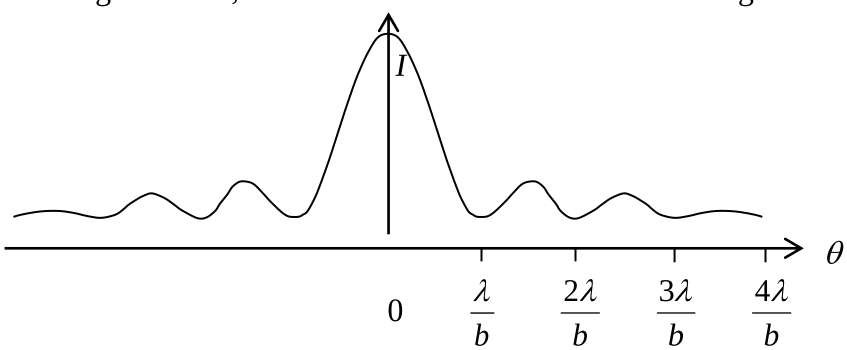
1. Diffraction from a single slit

Following the Huygens' principle we can 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:



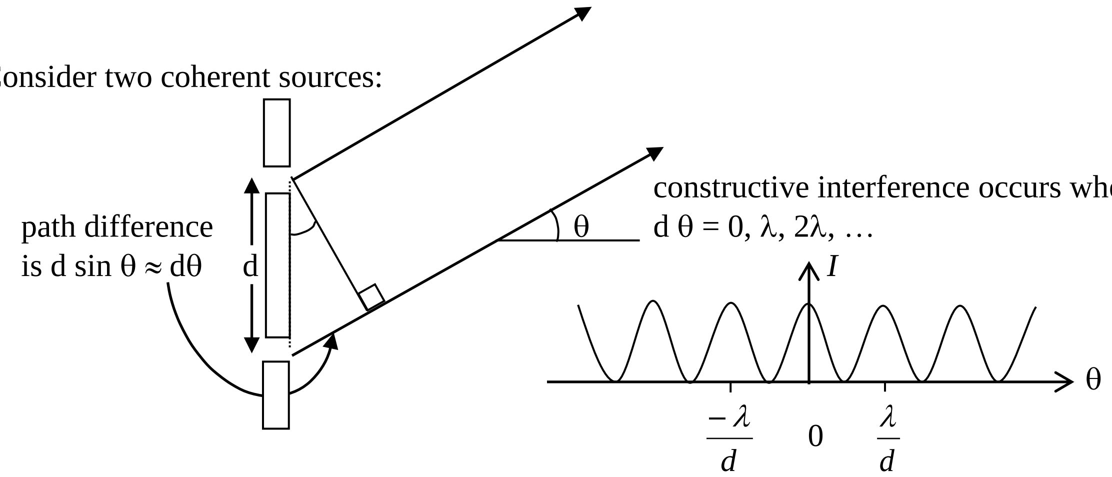
Destructive interference occurs when
$(b/2)\sin\theta = \lambda/2, \lambda, 3\lambda/2, \ldots$

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.

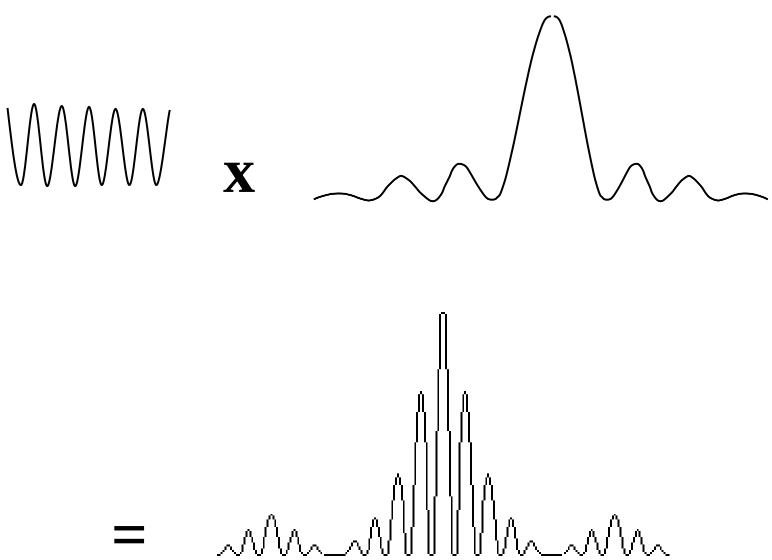


2. Diffraction from a double slit

Consider two coherent sources:



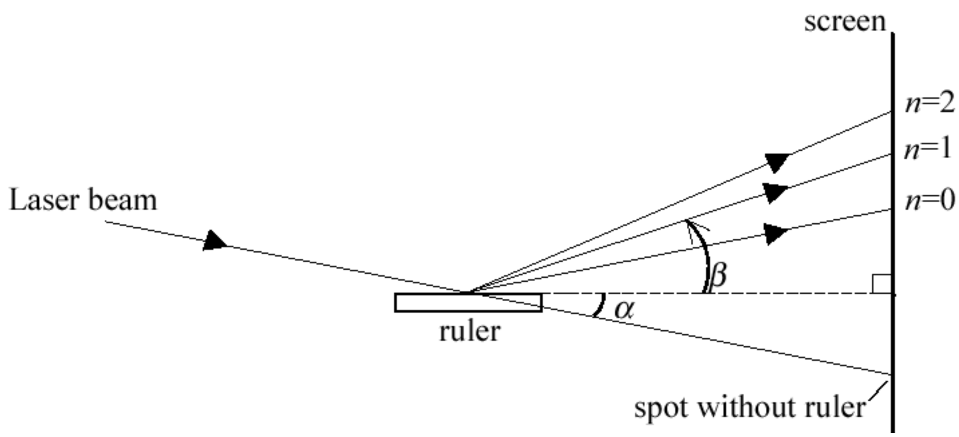
Now, let’s consider that each slit has some non-zero width, b, which would result in a single-slit pattern, if the slit were isolated. The resulting pattern for slit superposition is the product of two functions, shown schematically below::



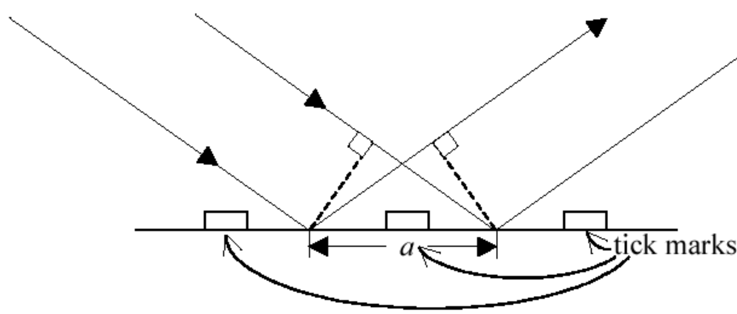
The pattern from multiple slits or a diffraction grating is calculated in a similar way.

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: $a(\cos\alpha - \cos\beta) = 0, \lambda, 2\lambda, \ldots = n\lambda$