Lab #11: Diffraction

Goal:
Study Fraunhofer diffraction quantitatively; observe various diffraction phenomena…this experiment is under construction.

Equipment:
Optical bench, slits, thin wires, and some other stuff, we’ll see…

1 Fraunhofer diffraction from a slit and a thin wire

1.1 Physics: Fraunhofer diffraction
The limit where both, the light source and the screen are infinitely far away from the object that causes the diffraction, is called the ‘Fraunhofer regime’. The intensity distribution following a slit of width \( D \), is given by

\[
I(\beta) = I(\beta = 0) \left( \frac{\sin \beta}{\beta} \right)^2 \quad \text{with} \quad \beta = \frac{kD}{2} \sin \beta .
\]  

(1)

The zeros occur at angles

\[
\sin \beta_m = \frac{\lambda m}{D} .
\]  

(2)

Babinet’s principle: the diffraction pattern by a slit of width \( D \) is the same as that of a wire of diameter \( D \).

1.2 Measurements
Use a laser and a single slit of known width. Measure the positions of the zeros on both sides of the main peak on a screen located at a distance \( s \). Plot \( \sin \beta_m \) versus \( m \), and determine \( D \) (assuming that the wavelength of the laser is known).

Repeat this with one of your hairs, and determine the diameter of that hair (with an error, of course).

2 Fraunhofer diffraction from a circular hole

2.1 Physics
The radius of the hole shall be \( a \). The intensity distribution has circular symmetry, and is described by the first-order Bessel function, \( J_1 \). The angles from the central axis, at which the distribution goes to zero is given by the zeros \( q_m \) of the Bessel function,

\[
\sin \beta_m = \frac{\lambda q_m}{2\pi a} ,
\]  

(3)

Where \( q_1 = 3.83 \), \( q_2 = 5.14 \), and \( q_3 = 7.02 \), etc. (see table of special function for more values).
2.2 Measurement
Shine a laser at a small circular hole. Observe the pattern on a screen located at a known distance $R$ from the hole. Observe the large central maximum (called ‘Airy disk’). Determine the angle for as many minima as possible ($m = 1...M$), and plot versus $m$. Compare result with the known zeros of the Bessel function $J_1$.

3 Fresnel diffraction: Poisson’s spot
Poisson argued that, if Fresnel’s crazy wave theory were correct, there would have to be a bright spot in the center of the shadow of a spherical object, which is obviously not possible. Arago went home and looked, and Fresnel got his well-deserved first prize.
Use an $f = 18$ mm lens to expand a laser beam. Mount a ~ 4 mm diameter steel ball 10 to 30 cm downstream. Look at the shadow on a screen located at 0.5 – 3 m from the ball. Describe what you see, and how the picture changes as a function of screen distance.

4 Fresnel zone plate
Using two lenses, $f_1 = 18$ mm and $f_2 = 127$ mm, build a beam expander for a laser. Use the beam to illuminate the PASCO Fresnel Zone Plate (the radii of the zones are given in the figure on the right). View the intense, central spot as a function of the distance between the zone plate and the screen. Describe what you see. It is important that the incident beam is parallel (plane wave), so adjusting the distance between the expander lenses is something one wants to try.
Can you determine experimentally the focal length of the zone plate? Given the wavelength of the laser, what is the theoretical expectation of the focal length?