Introduction
There are basically two modes to observe diffraction effects. In the (mathematically more complicated) near-field or Fresnel diffraction, the light on the side of incidence and/or on the side of the observation cannot be regarded as plane waves. In this mode, the shape of the diffraction pattern depends on the position of the light source and/or the position of the observation screen. The diffraction properties become much more simple in the far field or Fraunhofer mode of observation, in which plane-waves are used on both the light entrance and the observation side. Fraunhofer diffraction is achieved by observing the diffraction pattern on a screen, either far away from the diffracting object or placed in the focal plane of a convex lens. In the Fraunhofer diffraction, a change in the relative position of light source, object and screen does not change the shape but only the size of the pattern.

We will use in all our experiments this far-field or Fraunhofer diffraction.

With the laser at the left end of the bench, you can obtain a setup for the observation of Fraunhofer diffraction in two ways:
- a) By positioning the diffracting object close to the laser and observing the diffraction pattern on the screen at the far right end of the bench.
- b) By placing a convex lens behind the diffracting object and placing the observation screen in the focal plane of the lens.

Which method, a) or b), you use is often dictated by the size (and light intensity) of the pattern which you want to produce for best observation or recording.

How do you determine the angle $\Theta$ which appears in the formula of the Fraunhofer diffraction in the two cases, (a) and (b)?

VII.A Experiments with Observation on Screen (Report errors in measured quantities and do error propagation where indicated)

Experiment: Using method (a), observe the diffraction pattern produced by single slits of four different widths “a” (which are marked on the component).

- Observe and describe qualitatively (and think about!) how the size of the pattern changes with the slit width a.
- Measure the distance between several minima for the four slits, and determine the laser wavelength as accurately as you can (do error propagation for this part).
Experiment: Two diffracting screens are said to be *complementary* when the transparent regions on one exactly correspond to the opaque regions on the other and vice versa. The Fraunhofer diffraction patterns from complementary screens are identical (Babinet’s principle). Use this principle to measure the thickness of your hair (i.e., your hair is a complementary diffracting screen of a single slit). Pull one of your hairs, attach it (with tape) vertically into a component carrier, and place it – like you did with the slit before – into the laser beam.

☛ Observe the diffraction pattern and compare it to the one obtained by the single slit.

☛ Measure the distance between minima of pattern, and determine the thickness of your hair.

Experiment: Place component with *double-slits* into laser beam and observe diffraction pattern (you can do it for the double slits of narrow separation $d$, because only these are covered by the laser beam).

☛ Observe and describe the diffraction pattern. Explain why the double pattern is produced. (Shift the component slightly so that the laser beam covers only one of the double slits and observe the change.)

Experiment: Place component which contains (among others) two *circular apertures* (use the circular aperture of size 0.04mm and 0.08 mm. They are found on a slide called “Diffraction Patterns”. It is the slide that also contains a larger square and a larger round structure) into laser beam and observe their diffraction and how it changes with the aperture size.

☛ Measure the diameter of the first dark ring around the central disc. Determine the diameter of the circular apertures from the diffraction pattern and compare result with values given on the slide.

VII.B Experiments with Linear Translator, Photometer, Oscilloscope and “Data Studio” (*Report errors in measured quantities only*)

Experiment: Replace the screen with the linear translator (with a fiber optics probe attached). With the translator in a central position adjust the vertical position of the laser beam such that it hits the probe directly in the center.

Now place the photometer aperture slide on the translator’s holder (it must be very close to the fiber probe end) so that the laser beam hits the probe through the 0.1 mm slit. Set up your diffraction experiment by observing the single slit pattern in the focal plane of the lens ($f \approx 238$ mm); i.e., the distance between lens and the fiber probe has to be $f$. Optimize the pattern for a minimum of stray- and scattered-light and a maximum of clarity and contrast. Adjust everything properly so that the fiber probe will scan the pattern when it is driven by the linear translator. With this set up, only light incident on the small slit will be read by the photometer.

First scan the pattern using the manual dial and observing the ups and downs of the intensity with the photometer. Adjust the photometer such that the needle goes as high as possible at the maximum intensity without going beyond the scale.
Then scan the pattern with the translator (speed = 10 mm/min) symmetrically about the center of the pattern. Follow the intensity variation during scanning on the photometer. Try out the best method for obtaining a full scan of the diffraction pattern.

☛ Record the diffraction patterns of a single slit (best results probably for 0.16mm slit width) and a double slit (good results for slit width 0.08mm and slit separation 0.5mm) separately.

Using the Oscilloscope to Initially Observe the Diffraction Patterns (Do this at your desk)

- Connect the output on the back of the photometer to the oscilloscope. Make sure that the ground connection of the oscilloscope is connected to the black output plug on the photometer. You can assure that by using a banana-to-BNC converter and a BNC cable; then make sure that the “GND” tab of the banana-to-BNC converter is on the side of the black output plug.
- Set the oscilloscope time scale (horizontal scale) to something long (5s or 10s per division).
- Once you are able to observe the desired pattern, you should record such a pattern using the computer using the Data Studio software at the front table.

Using Data Studio to Record the Photometer Output (Use the setup at the front table)

- Make sure the output of the photometer is connected to the RC Filter board, which is connected to the Science Workshop 750 interface (Pasco Scientific). The 750 interface is connected via USB port to the computer.
- Launch the “Data Studio” software and open the activity “Lab7.ds”.
- Start the motion of the Linear translator and click on the “Start” button in “Data Studio”.
- Click on the “Stop” button once you have recorded the diffraction pattern in “Data Studio” and stop the linear translator.

Processing the Recorded Data

(A) Single Slit Diffraction Pattern

Make a quantitative comparison of your recorded single slit diffraction pattern \( I(x) \) with the theoretically expected dependence \( I(\Theta) \). For the small angles \( \Theta \) used, your scanning abscissa \( x \) (counted from the position of the central 0th order maximum) is proportional to \( \Theta \), i.e., \( x = C \cdot \Theta \). Therefore, your measured intensity scan can be described mathematically as

\[
I(x) = I(0) \left( \frac{sin(Ax)}{Ax} \right)^2
\]

☛ Compare the theoretical and the measured values of the intensity pattern as described in detailed steps on the next page:
Select the desired data range in “Data Studio”: Click mouse button and hold it down while “drawing” a rectangle over the desired data range. The selected data will be highlighted.

- Copy the selected data (Ctrl-C).
- Open an empty MS Excel worksheet and paste the selected data into the spreadsheet (Ctrl-V).
- Save the spreadsheet using your name in the filename so you can easily identify it again.
- The pasted data contain two columns containing the time and voltage data.
- Identify the time \( t_c \) (c for “center”) at which the voltage has a maximum. This time corresponds to the time at which the center of the diffraction pattern was recorded.
- Create a third column called “Time-\( t_c \)” and put into this column the calculated values of Time-\( t_c \). For this column the modified “time” of value 0 corresponds now to the maximum voltage.
- Create a fourth column called “V-Voffset”. Identify the voltage offset \( V_{offset} \) (V at the edges of the diffraction pattern) and calculate V-Voffset into this column.
- Create a fifth column called “I(t)”. Calculate into this column the theoretical values of the diffraction pattern (compare to formula for single slit diffraction pattern above, realizing that \( x=vt \) with \( t \) being “Time-\( t_c \)” and that \( I(0) \) corresponds to the maximum voltage you recorded at the center of the pattern.

\[
I(t) = I(0) \left( \frac{\sin(Avt)}{Avt} \right)^2 , \text{where } A = \frac{\pi a}{D\lambda}
\]

- In Excel generate a graph that contains both a plot of “V-V offset” versus “Time-\( t_c \)” and a plot of “I(t)” versus “Time-\( t_c \)”. You now have both the measured pattern and the theoretical pattern on the same graph and you can compare them.
- Discuss any differences between the theoretical and measured values.

(B) Double Slit Diffraction Pattern

Convince yourself that the recorded double slit diffraction pattern is the superposition of a single slit diffraction pattern (like in 1) with a periodic modulation due to the double slit interference.

- Indicate in your measured scan (with different colors) these two parts of the pattern.
- Determine from the relative maxima and minima position the ratio between slit-width \( a \) and slit-distance \( d \). Compare the ratio to the experimentally used values of \( a \) and \( d \).