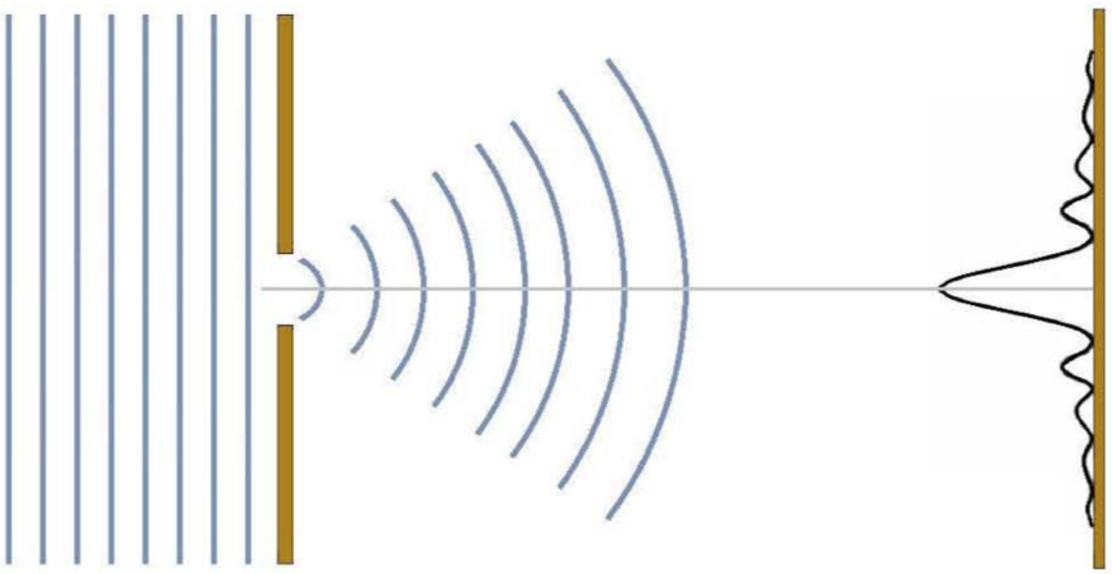
Lund University

O5: Diffraction and Interference

Optics and Waves



Introduction

The following lab has six parts, with limited work benches. The lab is complete when you are done with all six parts, and have suitable results in order to write your lab report, which should be no longer than 10 pages in length, and submitted 2 days after the completion of the lab.

The preparation questions should be either handed in before the lab, or submitted with your lab report as part of an appendix.

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Preparations

Read the textbook chapters 16.4 and 16.6, 35.2 and 35.3, and 36.1 through 36.5. Then solve the following problems and read through the entire instruction. Proper solutions are to be handed in before you start your lab.

1. At http://www.walter-fendt.de/html5/phen/singleslit_en.htm you will find an applet simulating light passing through a single slit. You can vary the wavelength of the light λ and the slit-width a.

a) Choose the largest wavelength and a slit-width that is half of the largest possible. At which angles do the light intensity become zero? Note that you can study both the diffraction pattern and the intensity profile, as well as change all parameters either via sliders or by entering values manually.

b) Select wavelength λ = 550 nm. How big should the slit-width a be, if the central maximum is to range from -45 ° to + 45 °?

c) Describe and explain what happens when you let the slit-width a approach zero (at λ = 550 nm).

2. The light from a mercury lamp passes a filter where all wavelengths except 546.1 nm are absorbed. The light passing the filter is made parallel using a lens and then sent through a single slit. The diffraction pattern is studied on a screen 7.00 m from the slit, see figure 1. Use the intensity profile to determine the width a of the slit as accurately as possible.

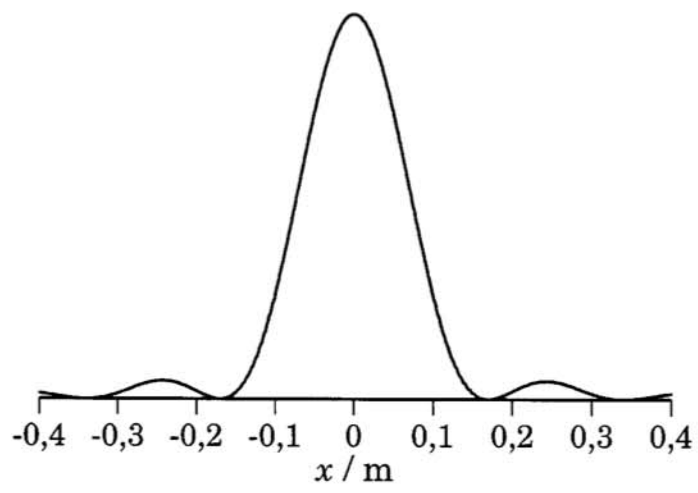


Figure 1. Light intensity distribution on a screen after diffraction in a slit.

3. Parallel light from a red He-Ne-laser ($\lambda = 632.8$ nm) is incident on a number of slits. All slits are of the same width and at the same distance apart. The intensity distribution on a screen 10.0 m away is shown in Figure 2.

a) How many slits are illuminated?

b) How big is the slit separation d?

c) What happens to the intensity distribution if one of the outer slits is covered? Sketch a figure similar to that below.

d) How much lower will the intensity of the central peak (of **c**)) be compared to the figure below?

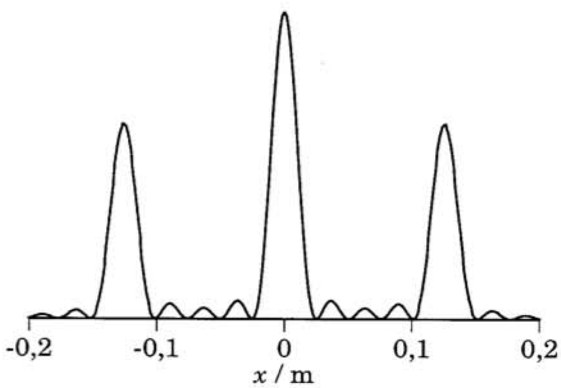


Figure 2 Intensity distribution when light from multiple slits interfere. Each slit also gives rise to a diffraction pattern, as shown in the figure.

During this lab-exercise you will study diffraction and interference phenomena of light and sound. These phenomena all belong to what we call wave-optics. Here the explanation model for light is built on wave-properties, unlike geometrical optics where wave properties are neglected.

1 Examination of Micrometer-Size Distances Using a He-Ne Laser

When small objects are illuminated with a laser, their size can be determined by studying the diffraction and interference patterns. In this experiment you use a He-Ne laser with a very well defined wavelength.

a) Illuminate a variable slit. Study the diffraction pattern on a screen a few meters away. Describe and explain what you see.

b) Determine the width a of a fixed slit. Then use the same method to determine the diameter of a hair. Describe the diffraction patterns in both cases. Can you explain why the slit and hair create a similar pattern of diffraction?

c) Determine the slit-distance d of a double slit by studying the interference-pattern.

Be sure to measure thoroughly! Make as much use of the screen as possible, and measure from min to min or max to max on each side of the central maximum.

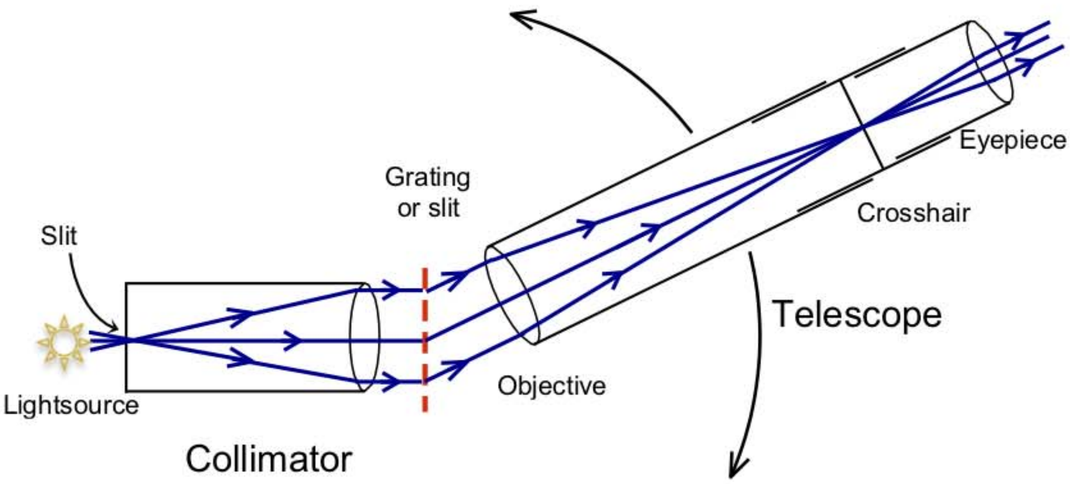
2 Determination of the Wavelength of a Diode Laser

Use the light from a He-Ne laser (with a well-known wavelength) to determine the number of lines per millimeter of an unknown grating.

Then use this grating to determine the unknown wavelength of a diode laser.

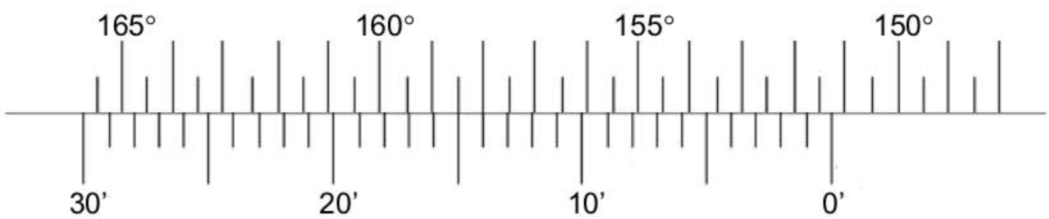
3 Examination of Micrometer-Size Distances Using a Spectrometer

A spectrometer consists essentially of two parts; a fixed collimator and a moving telescope. The collimator is equipped with a variable slit and a positive lens imaging the slit at "infinity", i.e. parallel light out from the collimator. This parallel light then illuminates an "object", in our case a grating or a slit system. The light from the grating is then entering the telescope, consisting of an objective and an eyepiece. In the joint focal plane of the eyepiece and objective, an illuminated so-called crosshair is located.



Illuminate the collimator slit with the sodium-lamp. Place a fixed slit on the spectrometer table so that the light hits the slit at an angle of 90°. Make sure the collimator slit is relatively small. Describe what you see and determine the slit-width of your fixed slit by determining the angles for which you have light minima.

Readings of angle θ are made by means of a so-called Vernier scale, the lower scale in the picture below. The main scale, the upper, is graded in half degrees and the reading of the main scale is done at 0 on the Vernier scale. You can see that in the figure below, 0 is at just over 151°. The Vernier scale is then used in the following way: look up the graduation mark on the Vernier scale, which is just in front of a graduation mark on the main scale. In this case, 15', i.e. 15 minutes. The spectrometer is thus set at the angle 151 full degrees, plus 15'. 15' is 15/60 of a degree, i.e. 0.25 degrees. All in all, 151.25 °.



Measure the slit width using a microscope and a micrometer scale. Do your measurements agree?

Examine the diffraction patterns created when different slit-systems are illuminated. For each slit-system, change the size of the collimator slit to make the diffraction pattern sharp. Describe what you see and try to qualitatively illustrate how the light intensity varies for the different slit-systems. Particularly note the number of secondary maxima.

4 Examination of a Grating

Illuminate the collimator slit with a cadmium lamp and use a grating with e.g. 2000 LPI (Lines Per Inch), i.e. about 80 lines per mm. Look at the colourful image and try to explain how it occurs. Why are we talking about spectral **lines** and not e.g. spectral **circles** or other forms? Note that there is one spectrum on each side of the normal to the grating surface, i.e. on each side of the zeroth order ($m = 0$). Why don't you see any spectrum in the zeroth order? Also note that for large angles there is an overlap between light from different orders. In which order does this overlapoccur?

Quantitative wavelength determinations are made using the grating formula which states that the maximum for a given wavelength (λ) and order (m) occurs at an angle (θ) where:

$$d \cdot \sin\theta = m \cdot \lambda$$

Here, d is the distance between two adjacent lines in the grating. In our case, we only know d approximately. However, we can utilize the green cadmium line, with the well-known wavelength of 508.58 nm, to determine a better value of d by measuring the angle in which the green line occurs. Do so, and compare with the number of LPIs specified. Use the new value of d and determine the wavelengths of the other lines in the Cd-spectrum. Compare your measured wavelengths with tablevalues.

5 Determination of the Speed of Sound Using Kundt's Tube

We will now take a closer look at the standing wave created when two oppositely directed sound waves interfere. A loudspeaker creates the sound wave, and directs it into a tube called Kundt's tube, see Figure 3 below. The sound wave propagates in the tube and is reflected at the end of the tube. The lid at the end can be removed so that it is possible to study the sound wave's reflection against both the lid and air.

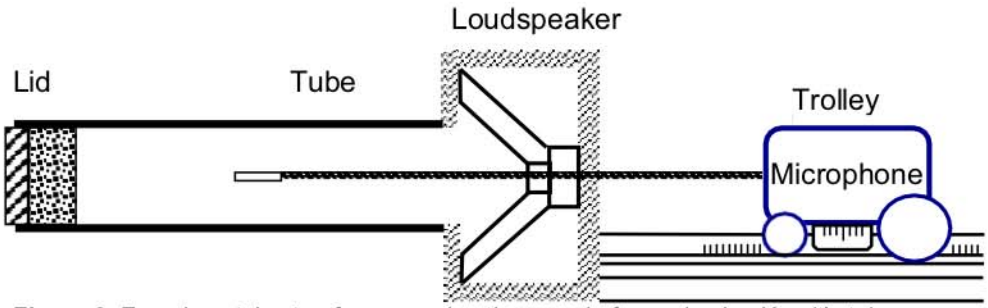


Figure 3. Experimental setup for measuring the speed of sound using Kundt's tube.

The microphone, which is mounted in the "trolley", records sound pressure, which is converted into a voltage read on a voltmeter.

Adjust the speaker frequency to a resonance frequency between 400 Hz and 800 Hz. Carefully measure the sound pressure along the tube. Then plot the sound intensity, i.e. the reading of the voltmeter, as a function of the microphone's position and determine the speed of sound.

6 Phase Difference Between Sound Waves

By studying phase differences between the signal put into a loudspeaker and the signal recorded by a microphone at different distances from the speaker, one can determine the speed of sound.

Put a 3.0 kHz signal from the frequency generator on to the *x*-channel of an oscilloscope. The oscilloscope should show a sinusoidal function. Then connect the frequency generator to the amplifier and on to the speaker. The microphone registers the sound from the speaker, and the signal from the microphone should enter the *y*-channel of the oscilloscope. The oscilloscope image shows the sum of the two sine functions;

$x = A_x \sin \omega t$ and $y = A_y \sin(\omega t + \phi)$

where A_x and A_y are the amplitudes of the signals. Convince yourself that the sum will be a straight line on the screen when $\phi = 0°$ or $180°$. What does the sum look like when $\phi = 90°$?

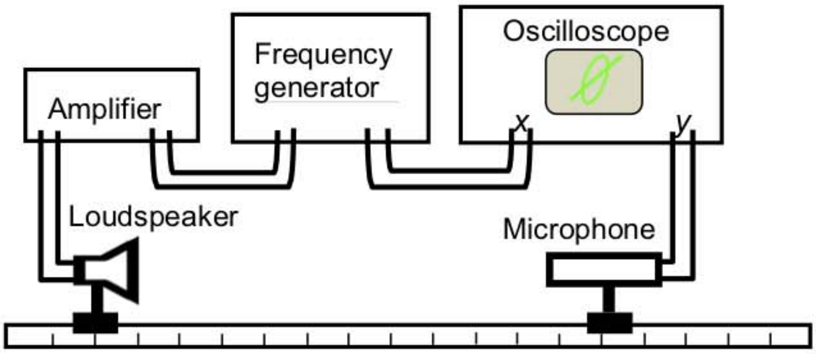


Figure 4. Setup for measuring the speed of sound using phase differences.

Slowly move the microphone from a position near the speaker and away. Record the microphone position each time the shape becomes a straight line - try to find 10 such positions. Use this to calculate the speed of sound.