Diffraction at a single slit and double slit
Measurement of the diameter of a hair
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BACKGROUND
Parallel light rays which pass through a small aperture begin to diverge and interfere with one another. This becomes more significant as the size of the aperture decreases relative to the wavelength of light passing through, but occurs to some extent for any size of aperture or concentrated light source.

Since the divergent rays now travel different distances, some move out of phase and begin to interfere with each other—adding in some places and partially or completely canceling out in others. This interference produces a diffraction pattern with peak light intensities where the amplitude of the light waves add, and less light where they cancel out. If one were to measure the intensity of light reaching each position on a line, the data would appear as bands similar to those shown below.
Objects of the experiments

- Investigating diffraction at a slit at different slit widths.
- Determining the diameter of hair.
- Investigating diffraction at a double slit and measuring the wavelength of the laser.
- Compare the diffraction patterns of a single-slit and a double slit.

Principles

Diffraction experiments provide evidence of the wave character of light. Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

When diffraction phenomena are studied, two types of experimental procedure are distinguished:

In the case of Fraunhofer diffraction, parallel wave fronts of the light are studied in front of the diffraction object and behind it. This corresponds to a light source which is at infinite distance from the diffraction object on one side and, on the other side, the screen which, too, is at infinite distance from the diffraction object.

In the case of Fresnel diffraction, the light source and the screen are at a finite distance from the diffraction object. With increasing distances, the Fresnel diffraction patterns are increasingly similar to the Fraunhofer patterns. Calculating the diffraction patterns in easier in the case of Fraunhofer diffraction. Therefore the experiments described here are based on Fraunhofer’s point of view.

Single slit:

Diffraction phenomena can be clearly demonstrated by means of the intensive and coherent light of a laser. Diffraction of the incoming parallel light at the slit aperture causes the light to propagate also in the geometrical shadow of the slit diaphragm. Moreover, a pattern of bright and dark fringes is observed on the screen. This cannot be explained by the laws of geometrical optics.
An explanation is only possible if wave properties are attributed to the light and if the diffraction pattern observed on the screen is considered as a superposition of an (infinitely) great number of partial bundles coming from the slit aperture. In certain directions, the superposition of all partial bundles leads to destructive or constructive interference, respectively. Fig. 1 suggests a simple approach to make it plausible that dark fringes occur at positions where every partial bundle from one half of the slit is associated with exactly one partial bundle from the other half so that they cancel each other. For the partial bundles coming from the slit under the angle $\theta$, this is true in those cases where path difference $\delta$ between the central ray and the rim ray is an integer multiple $m$ of half the wavelength $\lambda$ of the light:

$$\delta = m \cdot \frac{\lambda}{2} \quad m = 1,2,3,... \quad (1)$$

where $\delta = \frac{a}{2} \sin \theta \quad (2)$

Using trigonometry, we can show that:

$$\tan \theta = \frac{\nu}{D} \quad (3)$$

For small diffraction angles the following relation holds approximately:

$$\sin \theta \approx \tan \theta \approx \frac{\nu}{D}$$

Thus, from the condition for destructive interference (1), the wavelength is obtained:
This relation establishes a connection between the wavelength $\lambda$ and the geometry of the experiment. If the slit width $a$ is known, Eq. (4) enables the wavelength $\lambda$ to be determined. On the other hand, it is possible to determine the size of a diffraction object like hair or string from a diffraction experiment with monochromatic light of known wavelength.

**Double slit:**

An explanation is possible if wave properties are assigned to the light and if the slits are considered to be two coherent light sources whose light bundles superimpose. The superposition leads to destructive and constructive interference in certain directions. In a simple approach, the light bundles coming from the slits are first subdivided into (infinitely) many partial bundles. Then it can be made clear with the aid of Fig. 2 that maximum intensity occurs in directions in which there is exactly one partial bundle from the second slit which corresponds to any partial bundle from the first slit so that both interfere constructively. For light bundles that emerge under the angle $\theta$ this is true each time when the path difference $\delta$ between the principal rays is an integer multiple of the wavelength $\lambda$ of the light:

$$\delta = m \cdot \lambda \quad m = 0, \pm 1, \pm 2, \ldots$$

(1)

where

$$\delta = d \sin \theta$$

(2)

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**Fig. 2 Schematic representation for the diffraction of light at a double slit**

- $d$: distance between the slit
- $D$: distance between the screen and the slit
- $y$: distance of the 2nd intensity minimum from the centre
- $\theta$: direction in which the 2nd destructive interference is observed
- $\delta$: path difference
- $m$: order of interference pattern
For small diffraction angles the following relation holds approximately:

\[ \sin \theta \approx \tan \theta \approx \frac{y}{D} \]  \hspace{1cm} (3)

Thus, from the condition for constructive interference (1), the wavelength is obtained:

\[ \lambda = \frac{y}{m} \cdot \frac{d}{D} \]  \hspace{1cm} (4)

Hence, the intensity maxima are located on the screen at the positions (measured from the centre of the diffraction pattern)

\[ y_m = \frac{m \lambda L}{d}, \quad m = 0, \pm 1, \pm 2, \ldots \]  \hspace{1cm} (5)

i.e. they are spaced at the distance

\[ \Delta y = y_{m+1} - y_m = \frac{\lambda D}{d} \]  \hspace{1cm} (6)

Exactly in the middle between two intensity maxima there is an intensity minimum. Therefore the distance between a minimum and the next one is also given by Eq. (6).

Setup

- Direct the laser toward a viewing screen some 5 m away, ensure that no one is in the path of the beam and then switch on.

- Insert the aperture in a slide holder and place it in the beam at a distance of about 4 meters from the screen, so that the beam passes through the slits and darken the room. The Fraunhofer diffraction pattern for the aperture used will be observed on the screen.

- Any features of the pattern needed for measurement should be marked with a pencil, the laser switched off and the required measurements made.
**Procedure:**

**single slit:**
- Insert a single slit in a slide holder, the diffraction pattern will be observed on the screen.
- Change the slit width and notice what happens to the diffraction pattern.

**Measurement of hair diameter:**

- Attach a hair in a slide holder, the diffraction pattern will be observed on the screen.
- Mark the location of the two first-order minima on the screen.
- Measure the distance $\Delta y$ between these minima.
- Measure the distance $D$ between the screen and the hair.
- Using the wavelength of the laser, compute the diameter of the hair.

**Double slit:**
- Insert a double slit in a slide holder, the diffraction pattern will be observed on the screen.
- Mark the location of 20 minima on the screen.
- Measure the distance $\Delta y$ between these minima.
- Measure the distance $D$ between the screen and the slits.
- Compute the wavelength of the laser.

**Results:**

**Single Slit:**

With decreasing slit width $a$:
- The intensity in the centre becomes (weaker - stronger – remains the same).
- The intensity maxima become (broader-narrower) in width.
- The distance between the intensity minima (decreases-increases-doesn't change).
- The diffraction pattern moves more and more (into-away from) the geometric shadow of the slit diaphragm.
Measurement of hair diameter:

By using $\lambda = \frac{y}{m} \cdot \frac{a}{D}$ calculate the diameter of the hair $a$.

The distance between the two first-order minima

$2y = \frac{y}{m} \cdot m = \frac{a}{D}$

The distance between the screen and the hair

$D = \frac{a}{\lambda}$

The wavelength of the He-Ne laser

$\lambda = \frac{a}{D}$

The diameter of the hair

$a = \frac{\lambda D}{a}$

Double slit:

By using $\lambda = \frac{ya}{D}$ calculate the wavelength of the He-Ne laser.

The distance between the screen and the hair

$D = \frac{a}{\lambda}$

Separation of the slits

$d = 0.24 \text{ mm}$

The separation between 20 minima

$20y = \frac{ya}{D}$

$y = \frac{a}{\lambda}$

$\lambda = \frac{yd}{a}$

error =

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