Related topics

Huygens principle, interference, Fraunhofer and Fresnel diffraction, Fresnel's zone construction, coherence, laser, Airy disk, Airy ring, Poisson's spot, Babinet's theorem, Bessel functions, resolution of optical instruments.

Principle and task

Pin hole diaphragms and circular obstacles are illuminated with laser light. The resulting intensity distributions due to diffraction are measured by means of a photo diode.

Equipment

Laser, He-Ne 1.0 mw, 220V AC	08181.93	1
Universal measuring amplifier	13626.93	1
Optical profile bench l = 60 cm	08283.00	1
Base f.opt.profile-bench, adjust.	08284.00	2
Slide mount f. opt. pr.-bench, h 80 mm	08286.02	3
Slide mount, lateral.adjust., cal.	08082.03	1
Object holder, 5×5 cm	08041.00	1
Screen, metal, 300×300 mm	08062.00	1
Screen, with diffracting elements	08577.02	1
Photoelement f. opt. base plt.	08734.00	1
Multi-range meter A	07028.01	1
PEK carbon resistor 1 W 5 % 2.2 kOhm	39104.23	1
Connecting cord, 500 mm, red	07361.01	1
Connecting cord, 500 mm, blue	07361.04	1

Problems

1. The complete intensity distribution of the diffraction pattern of a pin hole diaphragm (D_1 = 0.25 mm) is determined by means of a sliding photo diode. The diffraction peak intensities are compared with the theoretical values. The diameter of the pin hole diaphragm is determined from the diffraction angles of peaks and minima.
2. The positions and intensities of minima and peaks of a second pin hole diaphragm (D_2 = 0.5 mm) are determined. The diffraction peak intensities are compared with the theoretical values. The diameter of the pin hole diaphragm is determined.
3. The positions of minima and peaks of the diffraction patterns of two complementary circular obstacles (D^*_1= 0.25 mm and D^*_2= 0.5 mm) are determined. Results are discussed in terms of Babinet's Theorem.

Set-up and procedure

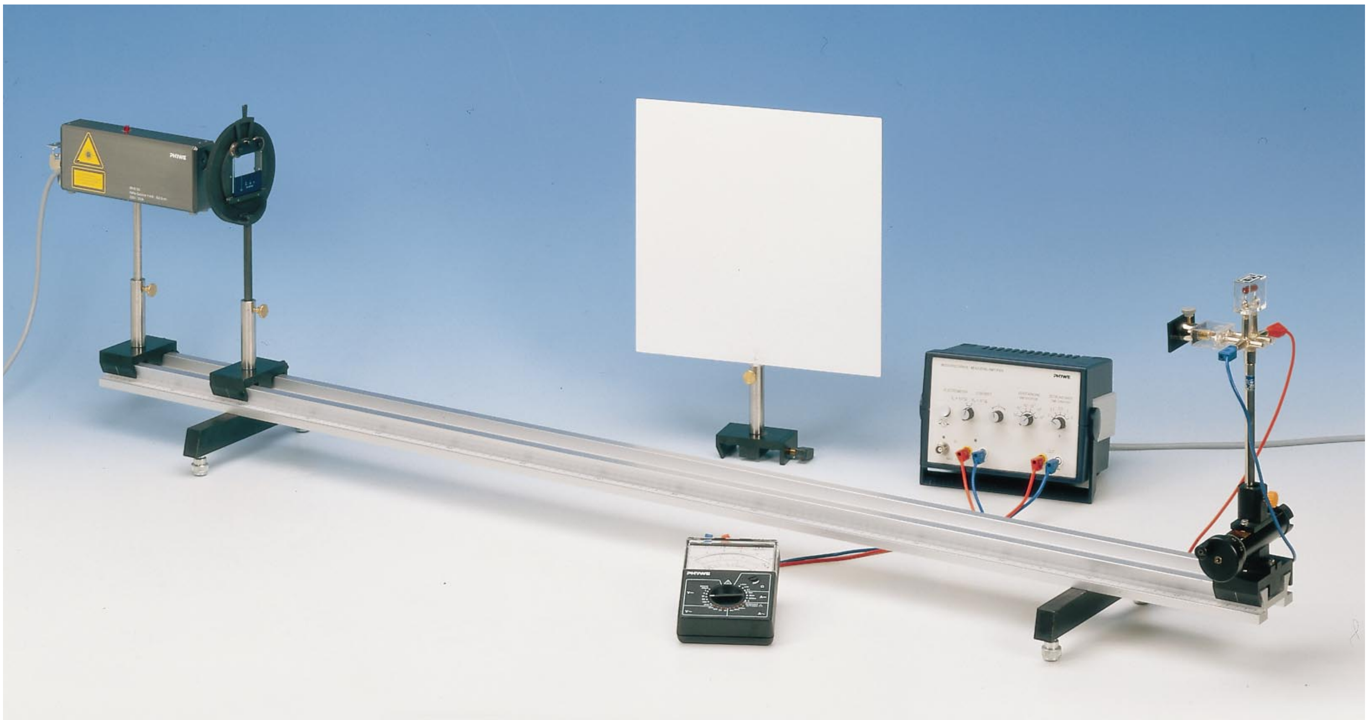
The complete measurement set-up is shown in Fig. 1. The slide mount for the laser and the slide mount for measurement are situated at the extremities of the optical bench, the diffracting object is situated at a distance of 19 cm.
Before starting measurements, it must be made sure that the laser beam impinges at the centre of the diffracting objects. This is the case if the diffraction rings on the metal screen set immediately before the slit diaphragm for this purpose are in the centre of the screen and have a homogeneous distribution. This is obtained by carefully adjusting the diaphragm with the diffraction objects laterally and in height.

Furthermore, it must be assured that the displacement trajectory of the photo cell diaphragm coincides with the meridian of the diffraction pattern.

In order to assure satisfactory local resolution during the determination of the diffracted intensity, the length of the diaphragm slit must be reduced symmetrically in such a way that the height of the slit is equal to its width. This can be done for example using two strips of black cardboard fixed with adhesive tape to the diaphragm.

Caution: Never look directly into a non attenuated laser beam

Fig. 1: Experimental set-up: Intensity of diffractions due to pin hole diaphragms and circular obstacles.



Before carrying out measurements, the laser and the measuring amplifier should be allowed to warm up for about 15 minutes.
Photovoltaic current is directly proportional to the intensity of impinging light. The current, converted to voltage, is measured by means of the measurement amplifier and a 2.2 kΩ resistor set in parallel to the photo diode. The typical adjustment parameters for the measuring amplifier are: “Low-Drift Mode”, amplifying factor $10^4 – 10^5$; time constant 0.1 s.
In order to determine the intensity of the diffraction pattern, the photo diode is shifted in steps of 0.3 mm, using the measurement shifting slide mount. During this procedure, the positions of the extremes must be determined with particular care.

Theory and evaluation

If a plane wave impinges on a diaphragm of diameter D, due to reasons of symmetry, the corresponding diffraction pattern consists of a central bright circle (Airy disk) surrounded by alternating concentric bright and dark rings (Airy rings).
The intensity distribution is given by

$$I(\varphi) = I_0 \left[\frac{2J_1\left(\frac{\pi \cdot D}{\lambda}\sin\varphi\right)}{\frac{\pi \cdot D}{\lambda}\sin\varphi} \right]^2 \quad \text{(J1 = Besselfunction first order)} \qquad (1)$$

The expected theoretical values for the diffraction angle φ of the bright and dark rings (peaks and minima) as well as for the normalised intensities of the peaks derived from (1) are given in Table 1.

Table 1:

n	Minima	Peaks	I_n/I_0
0			1
1	$\sin\varphi_1 = 1.220\,\frac{\lambda}{D}$	$\sin\varphi'_1 = 1.638\,\frac{\lambda}{D}$	0.0175
2	$\sin\varphi_2 = 2.232\,\frac{\lambda}{D}$	$\sin\varphi'_2 = 2.679\,\frac{\lambda}{D}$	0.00416
3	$\sin\varphi_3 = 3.238\,\frac{\lambda}{D}$	$\sin\varphi'_3 = 3.699\,\frac{\lambda}{D}$	0.00160
4	$\sin\varphi_4 = 4.241\,\frac{\lambda}{D}$	$\sin\varphi'_4 = 4.710\,\frac{\lambda}{D}$	0.00078

Fig. 2 shows the intensity distribution of the diffraction pattern of a diaphragm with diameter D_1 = 0.25 mm obtained empirically.
The distance of the extremes of the n^{th} order situated left and right of the central maximum is represented through Δx_n. Their arithmetic averages are taken for evaluation as well as the averages of the corresponding intensity peaks.
The values indicated in table 2 for the pin diaphragm with diameter D_1 as well as for intensity ratios I_n/I_0 are obtained from $\sin\varphi \approx \tan\varphi = \Delta x/L$ (L = 120.5 cm = distance between the diffracting object and the slit diaphragm) and λ = 632.8 nm.

Table 2

n	Minima Δx/mm	Minima D_1/mm	Peaks Δx/mm	Peaks D_1/mm	I_n/I_0 (exp.)	I_n/I_0 (theor.)
0					1	1
1	3.78	0.246	4.93	0.254	2.6 Skt/160 Skt = 0.016	0.01750
2	6.75	0.252	7.95	0.257	0.64 Skt/160 Skt = 0.004	0.00416
3	9.75	0.253	10.95	0.257	0.22 Skt/160 Skt = 0.0014	0.00160
4	12.60	0.257				

$D_1 = (0.254 \pm 0.004)$ mm ; $\Delta D_1 / D_1 = \pm 1.5\,\%$

Fig. 2: Diffracted intensity I vs position x of the photodiode, using a diaphragm with D_1 = 0.25 mm.

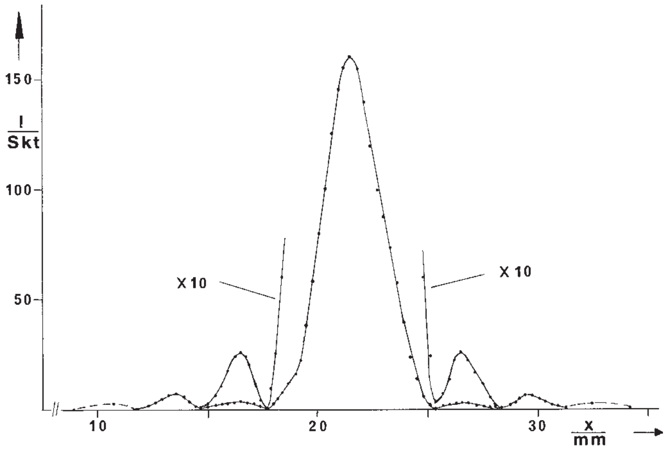


Table 3 shows the corresponding results of diffraction at the diaphragm with D_2 = 0.5 mm (without figure).

Table 3

n	Minima Δx/mm	Minima D_2/mm	Peaks Δx/mm	Peaks D_2/mm	I_n/I_0 (exp.)	I_n/I_0 (theor.)
0					1	1
1	2.18	0.427	2.7	0.463	17 Skt/840 Skt = 0.020	0.01750
2	3.59	0.474	4.17	0.491	3.3 Skt/840 Skt = 0.0039	0.00416
3	5.00	0.493	5.65	0.499	1.4 Skt/840 Skt = 0.0017	0.00160
4	6.38	0.507				

$D_2 = (0.479 \pm 0.027)$ mm; $\Delta D_2 / D_2 = \pm 5.6\,\%$

If the pin hole diaphragms are substituted by complementary circular obstacles, (e.g. D^*_1 = 0.25 mm and D^*_2 = 0.5 mm), the observed diffraction patterns are very similar (Babinet’s theorem). The positions of the minima and peaks coincide with those of the corresponding complimentary pin hole diaphragms. Only the central peak is symmetrically crossed by two further minima.

If Fraunhofer observation is used, the brightness peak always lies in the geometrical shadow of the circular obstacle.