Determination of diffraction intensity due to multiple slits and grids

Related topics

Huygens principle, interference, Fraunhofer and Fresnel diffraction, coherence, laser

Principle and task

Multiple slits which all have the same width and the same distance among each other, as well as transmission grids with different grid constants, are submitted to laser light. The corresponding diffraction patterns are measured according to their position and intensity, by means of a photo diode which can be shifted.

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	4
Slide mount, lateral. adjust., cal.	08082.03	1
Lens holder	08012.00	2
Object holder, 5×5 cm	08041.00	1
Lens, mounted, f +20 mm	08018.01	1
Lens, mounted, f +100 mm	08021.01	1
Photoelement f. opt. base plt.	08734.00	1
Diaphragm, 3 single slits	08522.00	1
Diaphragm, 4 multiple slits	08526.00	1
Diffraction grating, 4 lines/mm	08532.00	1
Diffraction grating, 8 lines/mm	08534.00	1
Diffraction grating, 10 lines/mm	08540.00	1
Diffraction grating, 50 lines/mm	08543.00	1
Multi-range meter A	07028.01	1
PEK carbon resistor 1 W 5 % 2.2kOhm	39104.23	1
Connecting cord, 750 mm, red	07362.01	1
Connecting cord, 750 mm, blue	07362.04	1

Problems

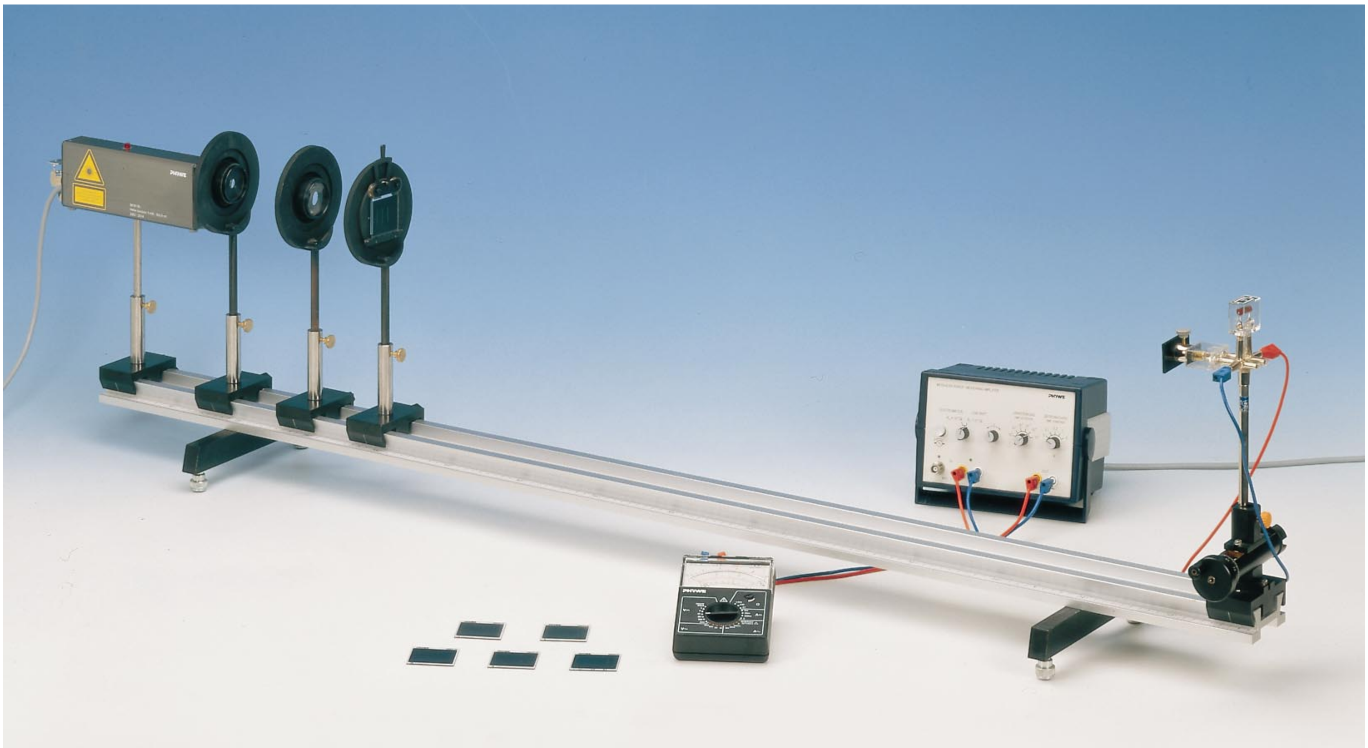
1. The position of the first intensity minimum due to a simple slit is determined, and the value is used to calculate the width of the slit.
2. The intensity distribution of the diffraction patterns of a threefold, fourfold and even a fivefold slit, where the slits all have the same widths and the same distance among each other, is to be determined. The intensity relations of the central peaks are to be assessed.
3. For transmission grids with different lattice constants, the position of the peaks of several orders of diffraction is to be determined, and the found value used to calculate the wavelength of the laser light.

Set-up and procedure

Experimental set-up is shown in fig. 1. With the assistance of the f = 20 mm and f = 100 mm lenses, a widened and parallel laser beam is generated, which must impinge centrally on the photocell with the slit aperture, the photocell being situated approximately at the centre of its shifting range. The diffracting objects are set in the object holder. It must be made sure the diffraction objects which are to be investigated are set vertically in the object holder, and uniformly lit.

Caution: Never look directly into a non attenuated laser beam

Fig. 1: Experimental set-up to investigate the diffraction intensity of multiple slits and grids. (Positions of the components on the optical bench: laser = 2.5 cm; f/20 mm lens = 14.5 cm; f/100 mm lens = 27.5 mm; diffracting objects = 33 cm; slide mount lateral adjustm., calibr. = 147. 5 cm).



The laser and the measuring amplifier should warm up for about 15 minutes before starting measurements, in order to avoid undesirable intensity fluctuations. The photocell is connected to the $10^4\Omega$ input of the measuring amplifier (amplification factor 10^3-10^5). The 2.2 kΩ resistor is connected in parallel to the photocell. When the amplification factor is changed, the zero point of the measurement amplifier must be checked while the photocell is covered, and corrected if necessary.
The diffraction intensity values are determined for the multiple slits by shifting the photocell in steps of 0.1 mm – 0.2 mm. For the transmission grids, the positions of diffraction peaks must be determined so as to be able to calculate the wavelength of the laser light. For the 50 lines/mm transmission grid, the secondary peaks are outside the shifting range of the photocell, so that in this case the position of the diffraction reflexes must be marked on a sheet of paper and their distance measured with a ruler.

Theory and evaluation

If monochromatic light of wavelength λ impinges on a system of parallel and equidistant slits, the following will be true for the light intensity I of beams deflected by an angle φ:

$$I(\varphi) \propto b^2 \cdot \frac{\sin^2\left(\frac{\pi}{\lambda}\cdot b\sin\varphi\right)}{\left(\frac{\pi}{\lambda}\cdot b\sin\varphi\right)^2} \cdot \frac{\sin^2\left(\frac{p\pi}{\lambda}\cdot g\sin\varphi\right)}{\sin^2\left(\frac{\pi}{\lambda}\cdot g\sin\varphi\right)} \qquad (1)$$

(b = width of slit; g = distance between slits; p = number of slits)

According to Fraunhofer, the minima and the peaks of a single slit are called 1st class interferences, whereas the interaction of several slits yields 2nd class interferences.
Observing only a single slit (1st factor), this yields a minimum intensity when the numerator becomes zero. In this case, the following is valid:

$$\sin\varphi_k = \frac{k \cdot \lambda}{b}\ ;\ (k = 1,2,3\ldots) \qquad (2)$$

The angular position of the 1st class peaks is given approximately through:

$$\sin\varphi_k{}^* = \frac{2k^* + 1}{2} \cdot \frac{\lambda}{b}\ ;\ (k^* = 1,2,3\ldots) \qquad (3)$$

If several slits act together, the minima of the single slits always remain. Supplementary 2nd class minima appear when the 2nd factor also becomes zero.
For a double slit (p = 2), the zero points can be easily calculated by simple transformation of the 2nd factor. Equation (1) then yields:

$$4\cos^2\left(\frac{\pi}{\lambda}\cdot g\sin\varphi\right) \qquad (4)$$

This expression becomes zero for

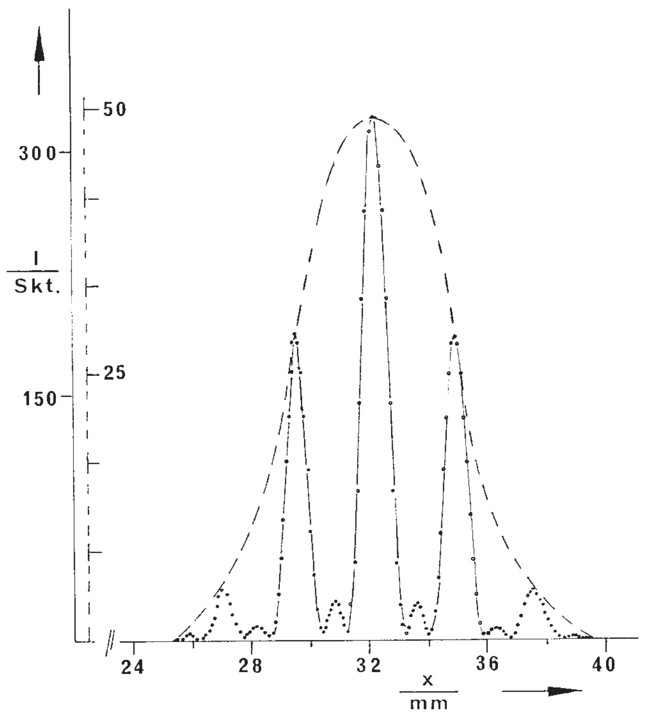


Fig. 2: Diffraction intensity I as a function of the position x for a threefold slit, b_1 = 0.1 mm and g = 0.25 mm. Distance between threefold slit and photocell: L = 107 cm. For comparison, the intensity distribution of a single slit, b = 0.1 mm, is entered as a dotted line.

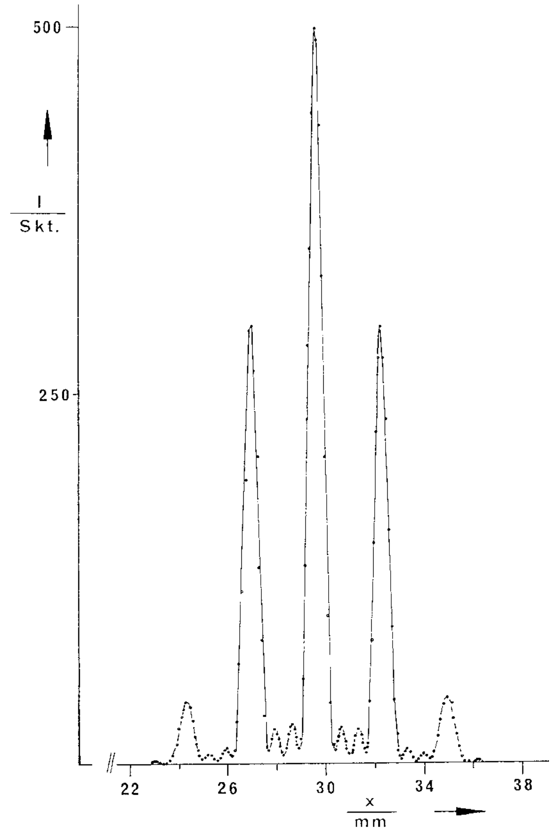
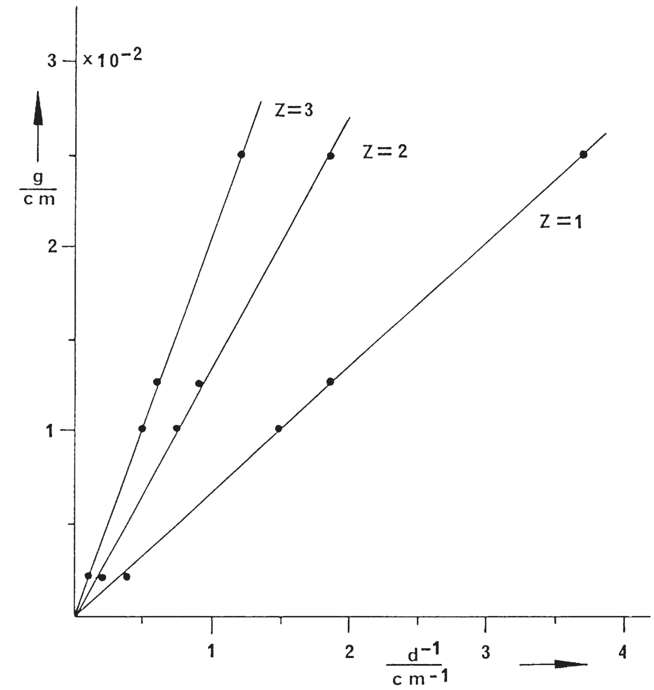


Fig. 3: Diffraction intensity I as a function of the position x for a fourfold slit with b_1 = 0.1 mm and g = 0.25 mm.

Fig. 4: Reciprocal distance of the diffraction peaks up to the 3rd order of diffraction (K = 3) as a function of the lattice constant.



$$\sin\varphi_h = \frac{2h+1}{2} \cdot \frac{\lambda}{g}; \; (h = 0,1,2,3\ldots) \qquad (5)$$

The following is valid for the intensity I of the main 2nd class peaks:

$$I \propto p^2 \qquad (6)$$

The main 2nd class peaks thus become more prominent as the number of slits increases. There still are (p - 2) secondary 2nd class peaks between the main peaks.

When light is diffracted through transmission grids with lattice constant g, the diffraction angle φ of the main peaks fulfils the following relation:

$$\sin\varphi_k = \frac{k\lambda}{g}\; ; \; (k = 0,1,2,3\ldots) \qquad (7)$$

Fig. 2 shows the diffraction intensity I for a threefold slit as a function of the position x of the photocell (distance between the diffracting object and the photocell; L = 107 cm). For comparison, the diffraction pattern of a single slit is entered as an envelope, with an adapted ordinate scale.

The minima of the single slit also remain in presence of corresponding multiple slits. For these, one obtains d = 0.095 mm from (2), with the distance $2 \cdot \Delta x$=14 mm between the two 1st class minima ($\sin\varphi \approx \tan\varphi$, L = 107 cm, λ = 632.8 nm). The number of secondary 2nd class peaks of the threefold slit is (p - 2) = 1.

Fig. 3 shows the diffraction figure of a fourfold slit. In this case, the number of 2nd class peaks is (p - 2) = 2. In the same way, diffraction through a fivefold slit (no figure) yields (p - 2) = 3-2nd class secondary peaks.

Table 1 gives the intensity values of the central peaks of the diffracting objects with p = 3 till p = 5, as well as the relative values determined empirically and according to (6).

Table 1

	exp.	theor.
I_{05} (p=5) = 720 Skt.		
I_{04} (p=4) = 500 Skt.	I_{05} / I_{04} = 1.44	$(5/4)^2$ = 1.56
I_{03} (p=3) = 300 Skt.	I_{05} / I_{03} = 2.40	$(5/3)^2$ = 2.78

Fig. 4 shows the distances between diffraction peaks measured for 4 different transmitting grids up to the 3rd order (K = 3) as a function of the lattice constant g. With (7), fig. 4 yields λ = 635 nm as an average value for the wavelength of the used laser light.