Optical analogy to diffraction of electrons in a polycrystalline lattice

Objects of the experiment

- Understanding the deformation of the spot diffraction pattern into a ring-shaped pattern
- Determination of the ring diameter as function of the wave length

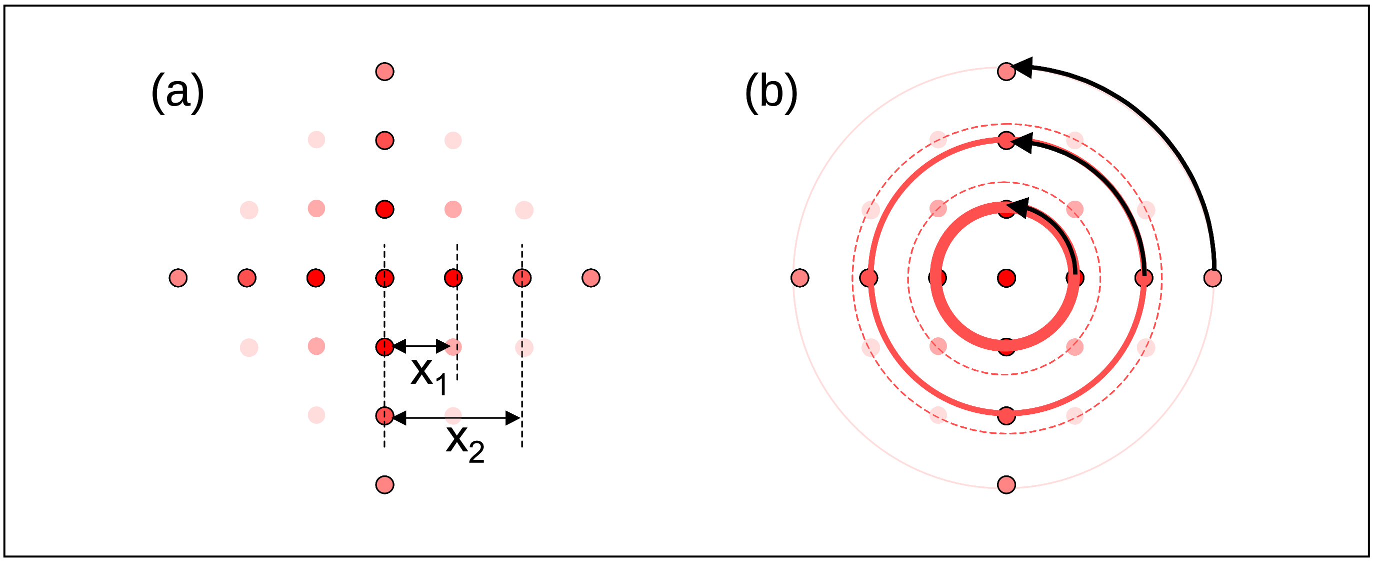
Principles

This experiment illustrates the Debye-Scherrer method used for instance in the electron diffraction method by means of visible light.

To show the optical analogy to diffraction parallel, monochromatic light passes through a cross grating. The diffraction pattern of the crossed grating at rest consists of spots of light which are arranged around the central beam in a network-like pattern (Fig. 1 (a) left). By rotating the cross grating the diffraction pattern is deformed into rings arranged concentrically around the central spot (Fig. 1 (b) right). Thus the rotation of the cross grating simulates a powder situation where all possible orientations of the cross grating in one plane contribute to the diffraction pattern.

At rest the diffraction pattern of the cross grating is comparable to a Laue diagram of single crystals (see experiment P7.1.2.2). The lattice spacing g (i.e. slit spacing) can be determined by using equation (III) of experiment P5.3.1.3:

Fig. 1: Schematic illustration of the diffraction pattern of a cross-grating at rest for monochromatic light (a), rotating the cross-grating changes the spot like pattern into a ring pattern (b). The rotation corresponds to diffraction of light on randomly orientated 2-dimensional lattices in a plane.



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Apparatus

1 Cross-grating, 5000/cm, rotatable 555 629

1 Halogen lamp, 12 V/90 W 450 63
1 Halogen light 450 64
1 Picture Slider 450 66
1 Transformer 2 …12 V, 120 W 521 25
1 Pair of cables 1m, red and blue.......................... 501 46

1 Lens, f = +100 mm 460 03
1 Holder with spring clips 460 22
1 Translucent screen.. 441 53
1 Tape measure 1m / 1mm 311 78

1 Small optical bench 460 43
5 Leybold multiclamp 301 01
1 Stand base V-shape... 300 01
or
1 Optical bench with standardised profile, 1 m...... 460 32
5 Optic riders.. 460 373

$$g = \lambda \cdot \frac{k}{x_k} \cdot d \qquad \text{with } k = 1, 2, 3... \qquad \text{(I)}$$

λ: monochromatic wave length

g: slit or lattice spacing (the same in x- and y-direction)

d: distance between the screen and the cross grating

x_k; distance of the k-th spot from the center beam in x- or y-direction

For a rotating cross grating the lattice constant g of the "randomly orientated 2-dimensional lattices in one plane" can thus be determined by measuring the diameter 2·r of the rings.

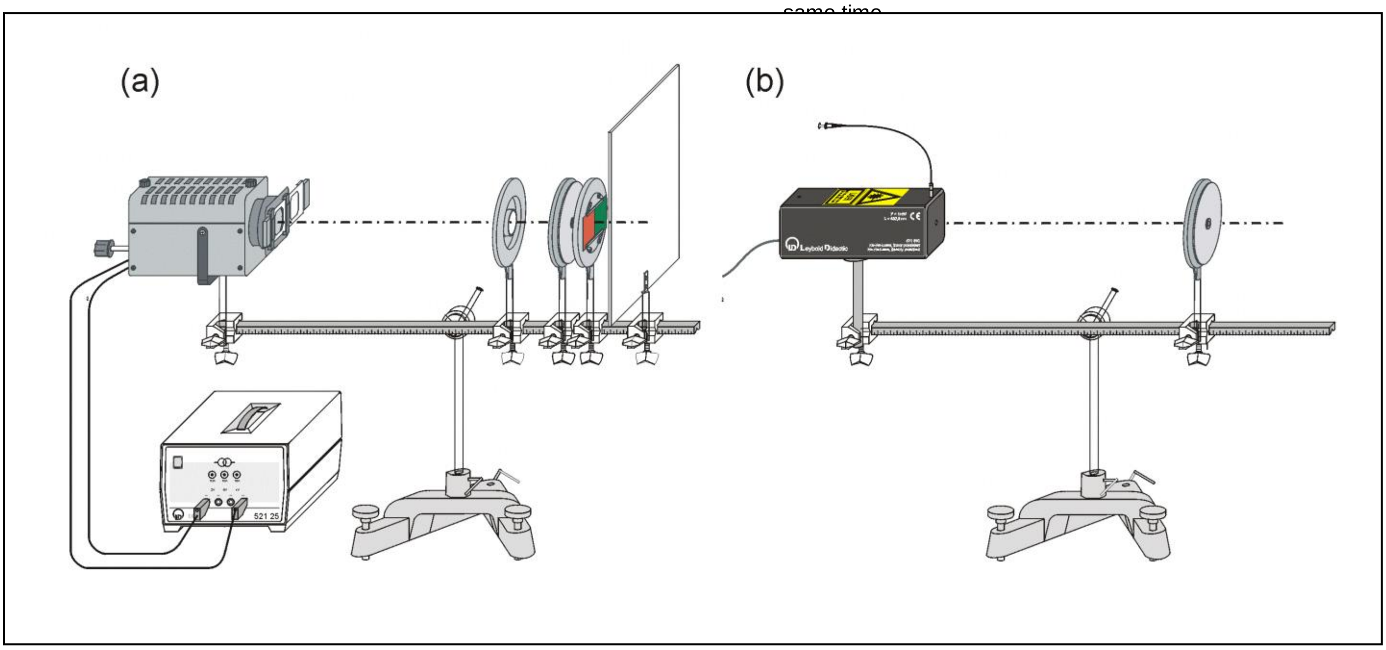
Setup

Note: The experiment can be performed with different light sources and various optical benches. In this setup the small optical bench is described for both the halogen lamp and the laser. For setting up with optical bench 460 32 refer also to the instruction sheet 555 629. If using the optical bench 460 310 the instructions for optical bench 460 32 can be followed.

a) Assembly with halogen lamp

- Mount the halogen light and the translucent screen on opposite sides of the optical bench according Fig. 2 (a).
- Adjust the halogen light in such a manner that the light from the lamp is parallel.
- Insert the 1 mm diaphragm into the image slider of the halogen light.
- Place the lens f = +100 mm on an optic rider between halogen lamp and translucent screen and move the lens until the aperture is focused on the screen sharply. It is recommended to use the 2f configuration, i.e. adjust the distance between lens and screen to approx. 200 mm.
- Place the cross grating on an optic rider between lens and translucent screen. The flywheel has to be on the side of the translucent screen.
- Place the holder with spring clips between the translucent screen and the cross-grating and insert the red color filter.
- It might also be necessary to adjust the halogen lamp or the lens to obtain sharp spots.

Fig. 2: Optical setup for observing a light spot pattern and a ring-shaped pattern.
(a) Using a halogen lamp and a red or green color filter allows to compare the rings for different wave lengths at the same time.



b) Assembly with laser

- Mount the laser on the optical bench according Fig. 2 (b).
- Arrange the cross-grating in the path of the laser beam in such a manner that the flywheel is on the side that points away from the laser.
- Direct the laser beam to the opening of the cross-grating to observe the diffraction pattern on a wall at some distance.

Safety notes

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

- Never look into the direct or reflected laser beam.
- No observer must feel dazzled.

Carrying out the experiment

1. Observation of light spots and ring pattern

- After the optical adjustment which usually includes also the rotation of the cross-grating a red light spot pattern according Fig. 1. (a) should be visible.
- Now gently turn the cross-grating and observe how the red spots start to move on a circular path as depicted in Fig. 1 (b).
- Put the cross-grating into rapid rotation.

Note: Two rings are visible. Depending on the darkness of the laboratory and the adjustment a third ring might be visible. While the solid rings depicted in Fig. 1 (b) have a high intensity, the dotted rings are hardly visible.

- If using a halogen lamp repeat the experiment with no color filter.

2. Determination of the ring diameter for different color filters (for halogen lamp only)

- Insert the red color filter into the holder with spring clips.
- Put the cross-grating into rapid rotation and measure the diameter of the red rings and the distance d between the cross grating and the translucent screen.
- Repeat the experiment with the green color filter.

Hint: For direct observation of red and green rings at the same time the red and the green color filter has to be inserted according Fig. 2 (a). Putting the cross grating into rapid rotation allows to observe a ring pattern of green and red half rings.

Measuring example

The following data have been obtained by using the setup with an halogen lamp:

Table 1: Diameter 2r of red rings

	$\frac{2 \cdot r}{mm}$
first ring	7.0
second ring	14.0
third ring	21.0

Table 2: Diameter 2r of green rings

	$\frac{2 \cdot r}{mm}$
first ring	6.0
second ring	12.0
third ring	18.0

Distance between translucent screen and cross-grating:

d = 55 mm.

Evaluation and results

Gently rotating the cross-grating shows how the light spots move on concentric circles (rings) around the central beam. From the observation of the ring pattern with no color filter follows that the diameter of the red rings is larger than for the blue rings.

The measurement of the diameter $2 \cdot r$ allows to estimate the lattice constant g of the cross-grating by using equation (I):

red color filter − average wave length: λ = 630 nm

average lattice constant: g = 9.9 μm

green color filter − average wave length: λ = 550 nm

average lattice constant: g = 11.4 μm

This result is within the limits of error in accordance with the 1000 lines / cm of the cross-grating, i.e. g ~ 10 μm.

Supplementary information

For the diffraction of electrons on a poly-crystalline graphite sample the diameter of the diffraction rings depends on the kinetic energy of the electrons (compare experiment P6.1.5.1). The larger the kinetic energy of the electrons the smaller is the diameter of the rings in the Debye-Scherrer diffraction pattern. This can be compared with this experiment where the ring diameter for green light (i.e. smaller wave length, larger energy) is smaller then for red light (i.e. larger wave length, lower energy). From the ring-shaped diffraction pattern the lattice parameters can be determined.

LD DIDACTIC GmbH . Leyboldstrasse 1 . D-50354 Huerth / Germany . Phone: (02233) 604-0 . Fax: (02233) 604-222 . E-mail: info@ld-didactic.de