XRD

Experiment

PHYSICS LAB 403

TABLE OF CONTENT

i.

(P6.3.6.1)

Fine structure of the characteristic x- radiation of a molybdenum anode .

Fine structure of the characteristic x-radiation of a molybdenum anode

Objects of the experiment

- Investigating the fine structure of the characteristic x-radiation of molybdenum by means of Bragg reflection at an NaCl monocrystal in the fifth diffraction order.
- Identifying the characteristic K_α, K_β and K_γ lines.
- Resolving the fine structure of the K_α line as a line doublet and determining the wavelength interval $\Delta\lambda$ within the doublet.

Principles

On closer examination, the characteristic K_α and K_β lines of the x-radiation prove to be line doublets. The two doublets can be resolved by means of Bragg reflection at an NaCl monocrystal when measured in a higher diffraction order. However, they differ in their physical nature.

The K_β doublet consists of the pure K_β line, i.e. transitions of excited atoms from the M-shell to the K-shell, and the K_γ line, i.e. transitions from the N-shell to the K-shell. The wavelength interval $\Delta\lambda$ between the two lines is just 1.2 pm (see table 1), so that they can only be resolved at a high resolution.

Fig. 1 Diagram of fine structure of the characteristic line K_α

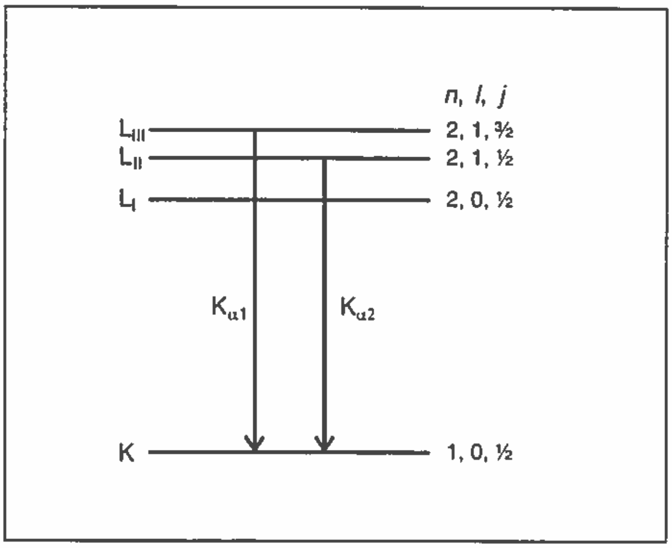

Table 1: Transition energies E, wavelengths λ and relative components of the characteristic K_α, K_β and K_γ lines of molybdenum (weighted mean values according to [1])

	$\frac{E}{\text{keV}}$	$\frac{\lambda}{\text{pm}}$	Relative proportion
K_α	17.44	71.08	1.000
K_β	19.60	63.26	0.170
K_γ	19.97	62.09	0.027
Doublet $K_\beta + K_\gamma$	19.65	63.09	

The fine structure of the K_α line arises from the fine structure of the L-shell, and thus ultimately from the spin-orbit characteristic of the electrons. The L-shell actually consists of three sub-shells, designated L_I, L_{II} and L_{III} in x-ray spectroscopy. The transitions from these sub-shells to the K-shell with emission of an x-ray is subject to the selection rules

$$\Delta l = \pm 1,\ \Delta j = 0, \pm 1 \qquad \text{(I)}$$

for the change of the orbital angular momentum l and the total angular momenturm j on transition. Thus, two transitions from the L-shell to the K-shell are permitted, designated $K_{\alpha 1}$ and $K_{\alpha 2}$ (see Fig. 1). Table 2 shows the values generally found in the literature for molybdenum. According to these, the wavelength interval within the K_α doublet is $\Delta\lambda$ = 0.43 pm.

Table 2: Wavelengths λ (calculated from literature specifications [1] for transition energies) and relative proportions of K_α radiation of molybdenum

Line	$\frac{\lambda}{\text{pm}}$	Relative proportion
$K_{\alpha 1}$	70.93	1.000
$K_{\alpha 2}$	71.36	0.525

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Apparatus

1 X-ray apparatus 554 811

1 End-window counter
for α, β, γ and x-ray radiation 559 01

additionally required:

1 PC with Windows 9x/NT

The object of the experiment is to resolve this fine structure by means of Bragg reflection at an NaCl monocrystal at higher diffraction orders.

According to Bragg's law of reflection, the following relationship exists between the wavelength λ of the incident characteristic radiation and the glancing angle ϑ at which we may expect an intensity maximum:

$$n \cdot \lambda = 2 \cdot d \cdot \sin\vartheta \quad \text{(II)}$$

n: diffraction order,
d = 282.01 pm: lattice plane spacing of NaCl

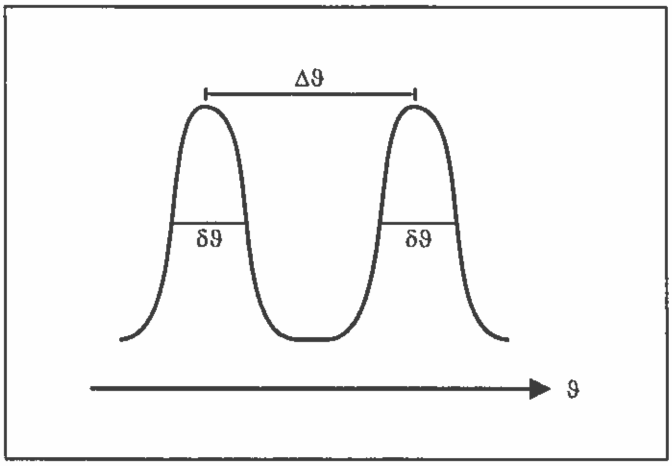

Fig. 2 Definition of the angular width δϑ and the angular spacing Δϑ of two intensity maxima.

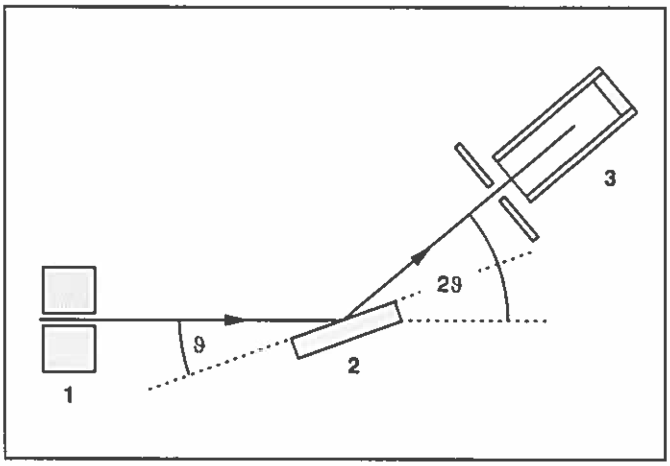

Fig. 3 Diagram showing the diffraction of x-rays at a monocrystal 1 collimator, 2 monocrystal, 3 counter tube

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 µSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

The wavelength interval Δλ of two lines thus corresponds to the angular spacing

$$\Delta\vartheta = \frac{n \cdot \Delta\lambda}{2 \cdot d \cdot \cos\vartheta} \quad \text{(III)},$$

which increases with the diffraction order. It is important to distinguish between the angular spacing Δϑ and the angular width δϑ of an intensity maximum. This latter should be smaller than the angular spacing so that the two lines can be observed separately (see Fig. 2). The angular width is determined by the opening slit of the counter tube (see Fig. 3), its distance from the crystal and the divergence of the incident x-ray beam, and remains constant even for higher diffraction orders. Thus, the K_α doublet can be resolved in the diffraction order $n = 5$.

Setup

Setup in Bragg configuration:

Fig. 4 shows some important details of the experiment setup. To set up the experiment, proceed as follows (see also the Instruction Sheet for the x-ray apparatus):

- Mount the collimator in the collimator mount (a) (note the guide groove).
- Attach the goniometer to guide rods (d) so that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm. Connect ribbon cable (c) for controlling the goniometer.
- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat (e) and connect the counter tube cable to the socket marked GM TUBE.
- By moving the sensor holder (b), set the distance s_2 between the target arm and the slit diaphragm of the sensor seat to approx. 6 cm.

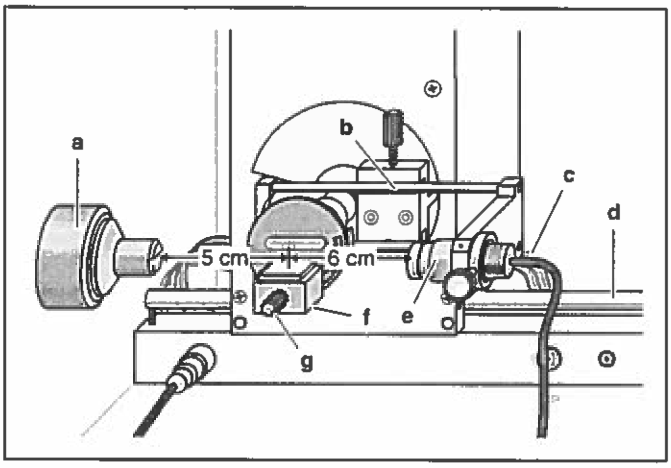

Fig. 4 Experiment setup in Bragg configuration

- Mount the target holder (f) with target stage.
- Loosen knurled screw (g), place the NaCl crystal flat on the target stage, carefully raise the target stage with crystal all the way to the stop and gently tighten the knurled screw (prevent skewing of the crystal by applying a slight pressure).
- If necessary, adjust the mechanical zero position of the goniometer (see Instruction Sheet for x-ray apparatus).

Notes:

NaCl crystals are hygroscopic and extremely fragile. Store the crystals in a dry place; avoid mechanical stresses on the crystal; handle the crystal by the short faces only.

If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, the distance should not be too small, as otherwise the angular resolution of the goniometer is no longer sufficient.

Preparing the PC-based measurement:

- Connect the RS-232 output and the serial interface on your PC (usually COM1 or COM2) using the 9-pin V.24 cable (supplied with x-ray apparatus).
- If necessary, install the software "X-ray Apparatus" under Windows 9x/NT (see Instruction Sheet for x-ray apparatus) and select the desired language.

Carrying out the experiment

- Start the software "X-ray Apparatus", check to make sure that the apparatus is connected correctly, and clear any existing measurement data using the button [D] or the F4 key.
- Set the tube high voltage U = 35 kV, the emission current I = 1.00 mA and the angular step width $\Delta\beta$ = 0.1°.
- Press the COUPLED key for 2ϑ coupling of target and sensor.

a) First order of diffraction:

- To record the first diffraction order, set the lower limit of the target angle to 5.5° and the upper limit to 8.0°, and set the measuring time per angular step to Δt = 10 s.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- When the measurement is finished, open the "Settings" dialog with the button [Settings] or F5 and enter the lattice plane spacing for NaCl to show the wavelength-dependency of the counting rate.
- Save the measurement series under a suitable name using the button [Save] or by pressing F2.

b) Fifth order of diffraction:

- To record the fifth diffraction order, set the lower limit of the target angle to 32.5° and the upper limit to 40.5°, and
- Set the measuring time per angular step to Δt = 400 s.

Note: Due to the low counting rate to be expected, you need to set a relatively long measuring time to obtain a satisfactory statistical accuracy. In this setting, the total measuring time is 9 h.

- Start measurement and data transfer to the PC by pressing the SCAN key.
- When the measurement is finished, open the "Settings" dialog with the button [Settings] or F5 and enter the lattice plane spacing for NaCl to show the wavelength-dependency of the counting rate.
- Save the measurement series under a suitable name using the button [Save] or by pressing F2.

Measuring example

Fig. 5 shows the diffraction spectrum measured in the first order, and Fig. 6 shows the spectrum for the fifth order of diffraction.

a) First order of diffraction:

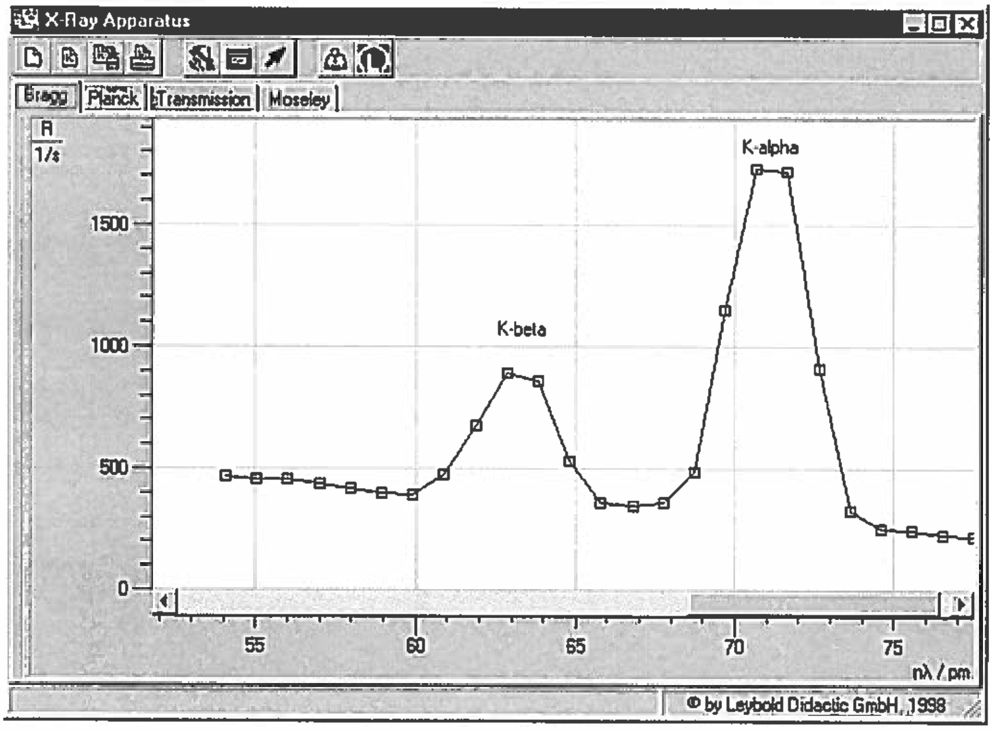

Fig. 5 Diffraction spectrum of x-rays in Bragg reflection in the first order at an NaCl monocrystal
Parameters: U = 35 kV, I = 1 mA, Δt = 10 s

b) Fifth order of diffraction:

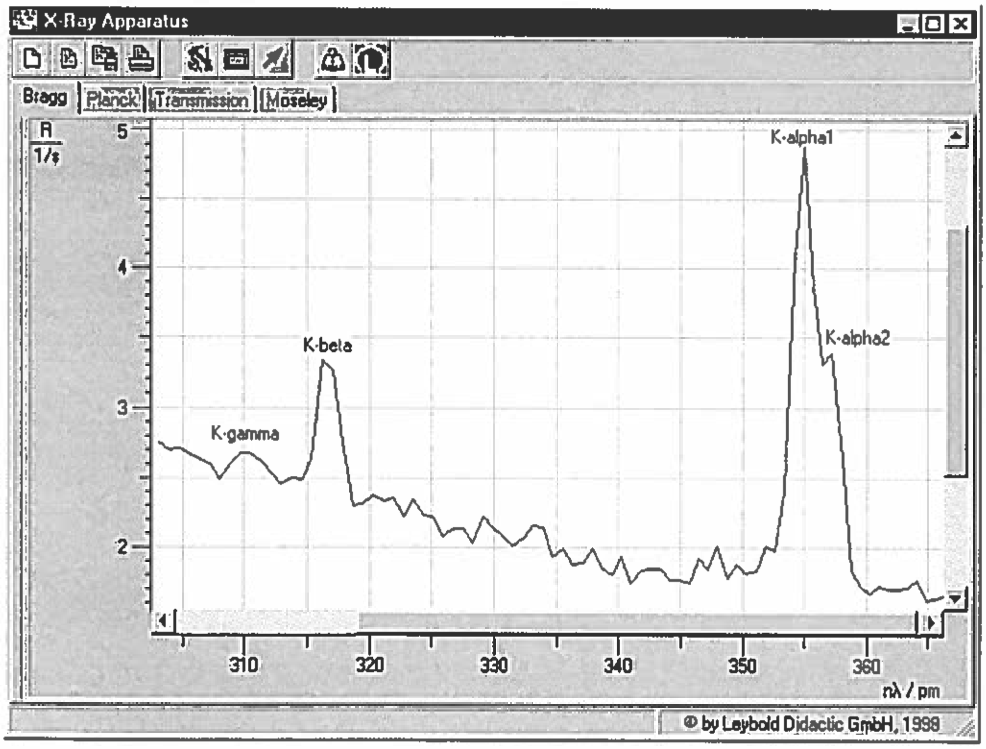

Fig. 6 Diffraction spectrum of x-rays in Bragg reflection in the fifth order at an NaCl monocrystal
Parameters: U = 35 kV, I = 1 mA, Δt = 400 s

Evaluation

- In the diagram, click the right mouse button to access the evaluation functions of the software "X-ray Apparatus" and select the command "Display Coordinates".
- Drag the mouse pointer across the peaks and read the corresponding $n \cdot \lambda$ values in the bottom left corner of the window.

a) First order of diffraction:

Table 3: Measuring results for the first diffraction order and literature value for the characteristic wavelengths (cf. table 1)

	Measurement result	Literature value
Line doublet	$\frac{\lambda}{pm}$	$\frac{\lambda}{pm}$
K_α	71.0	71.08
$K_\beta + K_\gamma$	63.1	63.09

b) Fifth order of diffraction:

Table 4: Measuring results for the fifth diffraction order and literature value for the characteristic wavelengths (cf. tables 1 and 2)

	Measurement result		Literature value
Lines	$\frac{5 \cdot \lambda}{pm}$	$\frac{\lambda}{pm}$	$\frac{\lambda}{pm}$
$K_{\alpha 1}$	355	71.0	70.93
$K_{\alpha 2}$	357	71.4	71.36
K_β	316.7	63.34	63.26
K_γ	310.3	62.06	62.09

Splitting of doublet K_α:

$\Delta\lambda = 0.4$ pm Literature value: $\Delta\lambda = 0.43$ pm

Splitting of doublet $K_\beta + K_\gamma$:

$\Delta\lambda = 1.28$ pm Literature value: $\Delta\lambda = 1.17$ pm

Results

The characteristic K_α und K_β lines we observe in the first diffraction order split into doublets. We can observe this split in the fifth diffraction order.

The fine structure of the K_α doublet is a consequence of the fine structure of the L-shell. The K_β doublet is composed of the pure K_β line and the K_γ line.

Additional information

Strictly speaking, the K_β and K_γ lines also show a fine structure due to the fine structure of shells M and N. However, this split is so slight that we cannot observe it with the means at hand. Table 1 shows the weighted mean values of the respective individual lines from this substructure.

Literature

[1] C. M. Lederer and V. S. Shirley, Table of Isotopes, 7th Edition, 1978, John Wiley & Sons, Inc., New York, USA.

ii.

(P6.3.3.3)

Duane – Hunt relation and determination of Planck's constant.

Duane-Hunt relation and determination of *Planck*'s constant

Objects of the experiment

- To determine the limit wavelength λ_{min} of the bremsstrahlung continuum as a function of the high voltage U of the x-ray tube.
- To confirme the Duane-Hunt relation.
- To determine Planck's constant.

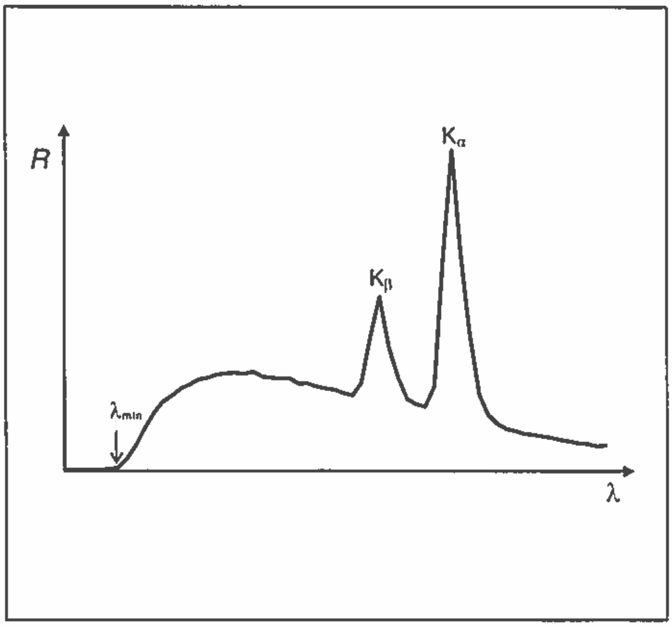

Fig. 1 Emission spectrum of an x-ray tube with the limit wavelength λ_{min} of the bremsstrahlung continuum and the characteristic K_α and K_β lines.

Principles

The bremsstrahlung continuum in the emission spectrum of an x-ray tube is characterized by the limit wavelength λ_{min} (see Fig. 1), which becomes smaller as the tube high voltage increases (see experiment P6.3.3.2). In 1915, the American physicists *William Duane* and *Franklin L. Hunt* discovered an inverse proportionality between the limit wavelength and the tube high voltage:

$$\lambda_{min} \sim \frac{1}{U} \quad \text{(I).}$$

This Duane-Hunt relationship can be sufficiently explained by examining some basic quantum mechanical considerations: As the wavelength amda and the frequency ν for any electromagnetic radiation are related in the manner

$$\lambda = \frac{c}{\nu} \quad \text{(II)}$$

$c = 2.9979 \cdot 10^8$ m s^{-1}: velocity of light

the minimum wavelength λ_{min} corresponds to a maximum frequency ν_{max} respectively a maximum energy

$$E_{max} = h \cdot \nu_{max} \quad \text{(III)}$$

h: Planck's constant

of the emitted x-ray quanta. However, an x-ray quantum attains maximum energy at precisely the moment in which it acquires the total kinetic energy

$$E = e \cdot U \quad \text{(IV)}$$

$e = 1.6022 \cdot 10^{-19}$ A s: elementary charge

of an electrode decelerated in the anode. It thus follows that

$$\nu_{max} = \frac{e}{h} \cdot U \quad \text{(V)}$$

respectively

$$\lambda_{min} = \frac{h \cdot c}{e} \cdot \frac{1}{U} \quad \text{(VI)}$$

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Apparatus

1 X-ray apparatus 554 811

1 End-window counter
for α, β, γ and x-ray radiation 559 01

additionally required:

1 PC with Windows 95/98/NT

Equation (VI) corresponds to Duane and Hunt's law. The proportionality factor

$$A = \frac{h \cdot c}{e} \quad \text{(VII)}$$

can be used to determine Planck's constant h when the quantities c and e are known.

A goniometer with NaCl crystal and a Geiger-Müller counter tube in the Bragg configuration together comprise the spectrometer in this experiment. The crystal and counter tube are pivoted with respect to the incident x-ray beam in 2ϑ coupling (cf. Fig. 2).

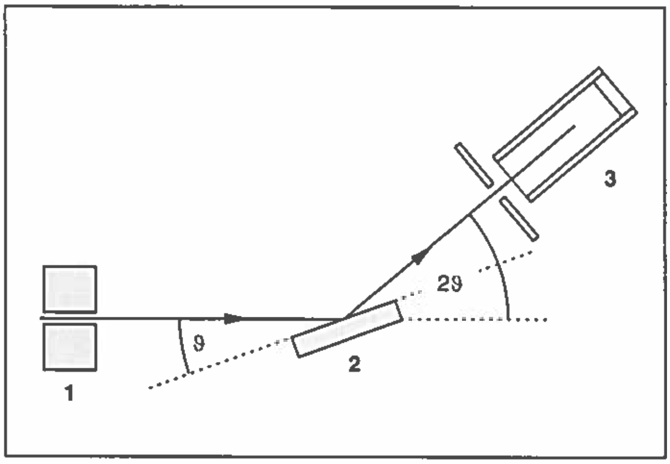


Fig. 2 Schematic diagram of diffraction of x-rays at a monocrystal and 2ϑ coupling between counter-tube angle and scattering angle (glancing angle)
1 collimator, 2 monocrystal, 3 counter tube

In accordance with Bragg's law of reflection, the scattering angle ϑ in the first order of diffraction corresponds to the wavelength

$$\lambda = 2 \cdot d \cdot \sin \vartheta \quad \text{(VIII).}$$

d = 282.01 pm: lattice plane spacing of NaCl

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

Setup

Setup in Bragg configuration:

Fig. 3 shows some important details of the experiment setup. To set up the experiment, proceed as follows (see also the Instruction Sheet for the x-ray apparatus):

- Mount the collimator in the collimator mount **(a)** (note the guide groove).
- Attach the goniometer to guide rods **(d)** so that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm. Connect ribbon cable **(c)** for controlling the goniometer.
- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat **(e)** and connect the counter tube cable to the socket marked GM TUBE.
- By moving the sensor holder **(b)**, set the distance s_2 between the target arm and the slit diaphragm of the sensor receptor to approx. 6 cm.
- Mount the target holder **(f)** with target stage.
- Loosen knurled screw **(g)**, place the NaCl crystal flat on the target stage, carefully raise the target stage with crystal all

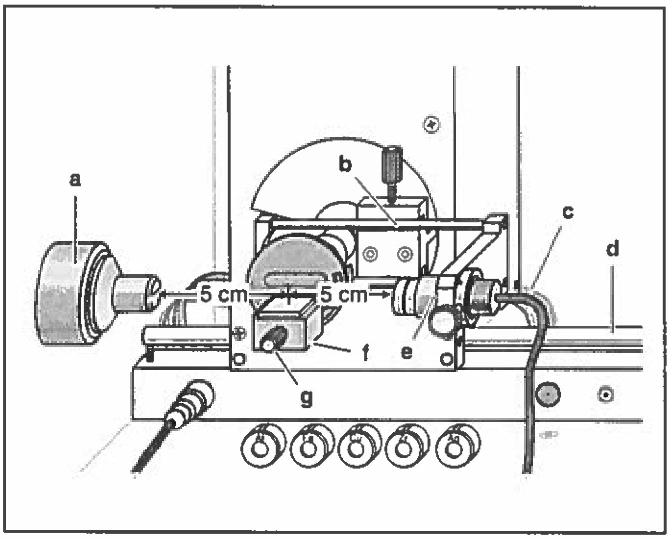


Fig. 3 Experiment setup in Bragg configuration

Tab. 1: Recommended parameters for recording the measurement series

$\frac{U}{kV}$	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{\beta_{min}}{grd}$	$\frac{\beta_{max}}{grd}$	$\frac{\Delta\beta}{grd}$
22	1.00	30	5.2	6.2	0.1
24	1.00	30	5.0	6.2	0.1
26	1.00	20	4.5	6.2	0.1
28	1.00	20	3.8	6.0	0.1
30	1.00	10	3.2	6.0	0.1
32	1.00	10	2.5	6.0	0.1
34	1.00	10	2.5	6.0	0.1
35	1.00	10	2.5	6.0	0.1

the way to the stop and gently tighten the knurled screw (prevent skewing of the crystal by applying a slight pressure).
- If necessary, adjust the mechanical zero position of the goniometer (see Instruction Sheet for x-ray apparatus).

Notes:

NaCl crystals are hygroscopic and extremely fragile. Store the crystals in a dry place; avoid mechanical stresses on the crystal; handle the crystal by the short faces only.

If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, the distance should not be too small, as otherwise the angular resolution of the goniometer is no longer sufficient.

Preparing the PC-based measurement:

- Connect the RS-232 output and the serial interface on your PC (usually COM1 or COM2) using the 9-pin V.24 cable (supplied with x-ray apparatus).
- If necessary, install the software "X-ray Apparatus" under Windows 95/98/NT (see Instruction Sheet for x-ray apparatus) and select the desired language.

Carrying out the experiment

- Start the software "X-ray Apparatus", check to make sure that the apparatus is connected correctly, and clear any existing measurement data using the button [icon] or the F4 key.
- Set the tube high voltage U = 22 kV, the emission current I = 1.00 mA, the measuring time per angular step Δt = 30 s and the angular step width $\Delta\beta$ = 0.1°.
- Press the COUPLED key to activate 2ϑ coupling of target and sensor and set the lower limit of the target angle to 5.2° and the upper limit to 6.2°.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Additionally record measurement series with the tube high voltages U = 24 kV, 26 kV, 28 kV, 30 kV, 32 kV, 34 kV and 35 kV; to save measuring time, use the parameters from table 1 for each series.
- To show the wavelength-dependency, open the "Settings" dialog with the button [icon] or F5 and enter the lattice plane spacing for NaCl.
- When you have finished measuring, save the measurement series under an appropriate name by pressing the button [icon] or the F2 key.

Measuring example and evaluation

Determining the limit wavelength λ_{min} as a function of the tube high voltage U:

For each recorded diffraction spectrum (see Fig. 4):

- In the diagram, click the right mouse button to access the evaluation functions of the software "X-ray Apparatus" and select the command "Best-fit Straight Line".
- Mark the curve range to which you want to fit a straight line to determine the limit wavelength λ_{min} using the left mouse button.
- Save the evaluations under a suitable name using the button [icon] or by pressing F2.

Confirming the Duane-Hunt relation and determining Planck's constant

- For further evaluation of the limit wavelengths λ_{min} determined in this experiment, click on the register "Planck".
- Position the pointer over the diagram, click the right mouse button, fit a straight line through the origin to the curve λ_{min} = f (1/U) and read the slope A from the bottom left corner of the evaluation window (see Fig. 5).

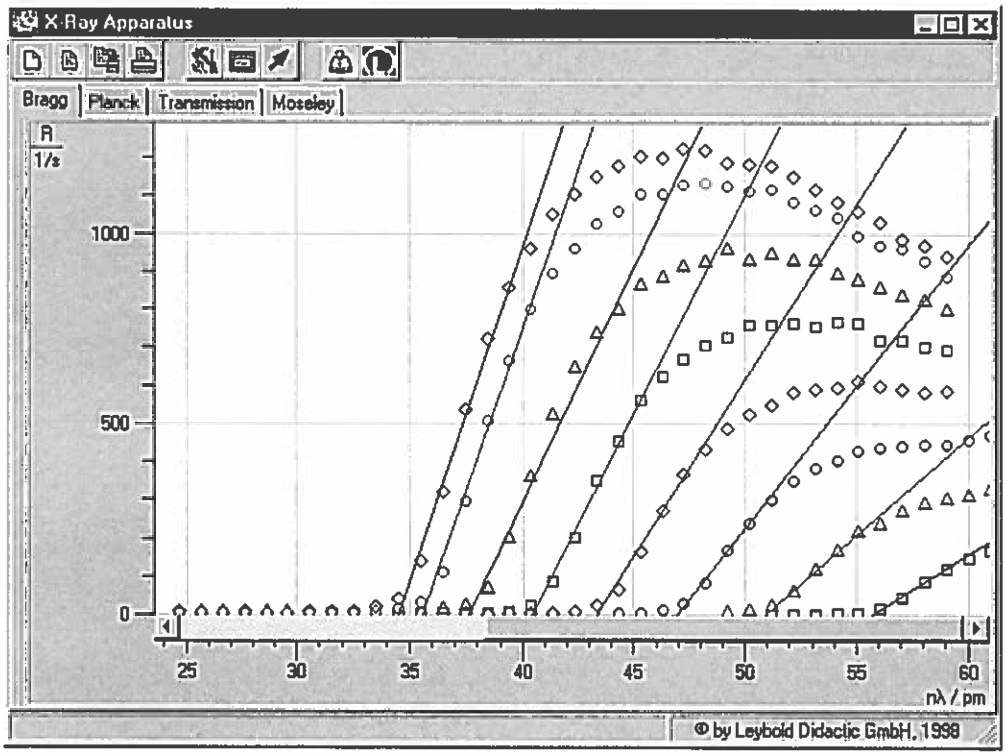


Fig. 4 Sections from the diffraction spectra of x-radiation for the tube high voltages U = 22, 24, 26, 28, 30, 32, 34 and 35 kV (from right to left) with best-fit straight line for determining the limit

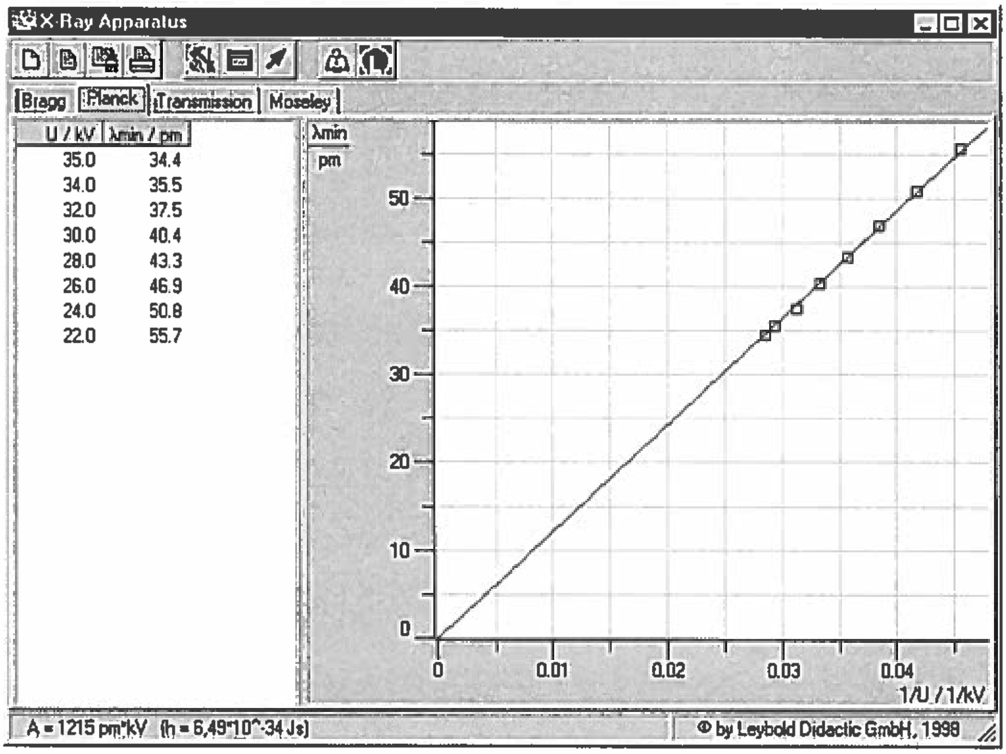


Fig. 5 Evaluation of the data $\lambda_{min} = f(1/U)$ for confirming the Duane-Hunt relation and determining Planck's constant

The best-fit straight line gives us

A = 1215 pm kV

When we insert this value in equation (VII), we can calculate Planck's constant as:

$h = 6.49 \cdot 10^{-34}$ J s

Literature value:

$h = 6.626 \cdot 10^{-34}$ J s

iii

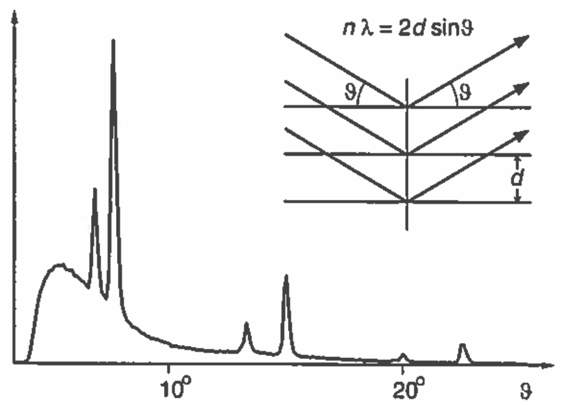
(P6.3.3.1)

Bragg reflection: diffraction of X-rays at monocrystal.

Bragg reflection: diffraction of x-rays at a monocrystal

Objects of the experiment

- To investigate Bragg reflection at an NaCl monocrystal using the characteristic x-ray radiation of molybdenum.
- To determine the wavelength for the characteristic K_α and K_β x-ray radiation of molybdenum.
- To confirm Bragg's law of reflection.
- To verify the wave nature of x-rays.



Principles

In 1913, *H. W.* and *W. L. Bragg* realized that the regular arrangement of atoms and/or ions in a crystal can be understood as an array of lattice elements on parallel lattice planes. When we expose such a crystal to parallel x-rays, additionally assuming that these have a wave nature, then each element in a lattice plane acts as a "scattering point", at which a spherical wavelet forms. According to *Huygens*, these spherical wavelets are superposed to create a "reflected" wavefront. In this model, the wavelength λ remains unchanged with respect to the "incident" wave front, and the radiation directions which are perpendicular to the two wave fronts fulfill the condition "angle of incidence = angle of reflection".

Constructive interference arises in the rays reflected at the individual lattice planes when their path differences Δ are integral multiples of the wavelength λ.

$$\Delta = n \cdot \lambda \text{ with } n = 1, 2, 3, \ldots \quad \text{(I)}$$

As Fig. 1 shows for two adjacent lattice planes with the spacing d, we can say for the path differences Δ_1 and Δ_2 of the incident and reflected rays with the angle ϑ:

$$\Delta_1 = \Delta_2 = d \cdot \sin\vartheta$$

so that the total path difference is

$$\Delta = 2 \cdot d \cdot \sin\vartheta. \quad \text{(II)}$$

(I) and (II) give us Bragg's law of reflection:

$$n \cdot \lambda = 2 \cdot d \cdot \sin\vartheta \quad \text{(III)}$$

The angle ϑ is known as the glancing angle.

In this experiment, we verify Bragg's law of reflection by investigating the diffraction of x-rays at an NaCl monocrystal in which the lattice planes are parallel to the cubic surfaces of the unit cells of the crystal. The lattice spacing d of the cubic

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Apparatus

1 X-ray apparatus 554 811

1 End-window counter for α, β, γ and x-ray radiation 559 01

additionally required:

1 PC with Windows 9x or Windows NT

face-centered NaCl crystal is half the lattice constant a_0. We can thus say [1]

$2 \cdot d = a_0 = 564.02$ pm

The measurements are conducted using the built-in goniometer of the x-ray apparatus (554 811). The x-rays are detected using a GM counter tube (end-window counter) which is swiveled in tandem with the NaCl crystal in a 2_ coupling with respect to the incident light; this means that the counter tube always advances by an angle which is twice that of the crystal (cf. Fig. 2).

The x-ray radiation consists of the bremsstrahlung continuum and several sharply defined lines which correspond to the characteristic x-ray radiation of the Mo anode and which originate in the K_α and K_β transitions of the molybdenum atoms. This characteristic radiation is particularly suitable for investigating Bragg's law. Its properties are known from the literature [2] and summarized in table 1. Table 2 shows the corresponding glancing angles at which the diffraction maxima of the characteristic radiation are to be expected for scattering at an NaCl monocrystal (d = 282.01 pm) up to the third diffraction order.

Safety notes

The x-ray apparatus fulfills all German regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 µSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation, inspect it for damage and check to make sure that the high voltage shuts off when the sliding doors are opened (see Instruction Sheet of x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

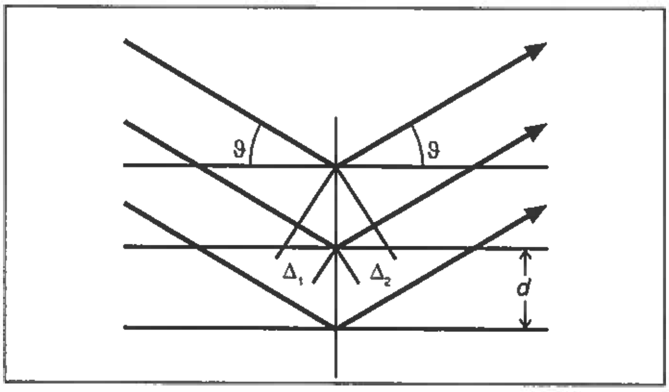


Fig. 1 Diagram of the reflection of x-rays at the lattice planes of a monocrystal.
Δ_1, Δ_2: path differences,
ϑ: glancing angle,
d: spacing of lattice planes

Table 1: Energy *E*, frequency ν and wavelength λ of the characteristic x-ray radiation of molybdenum (weighted mean values [1])

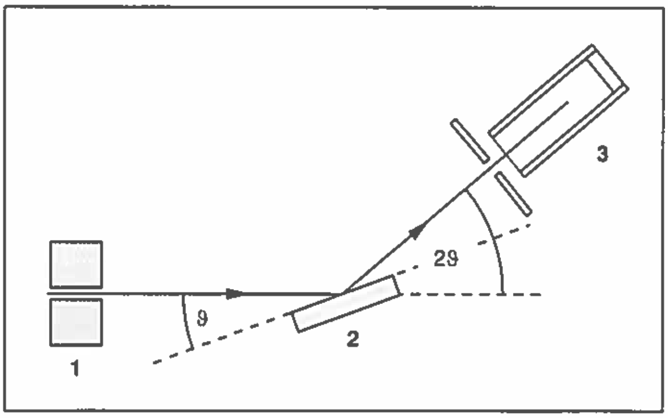
	$\frac{E}{\text{keV}}$	$\frac{\nu}{\text{EHz}}$	$\frac{\lambda}{\text{pm}}$
K_α	17.443	4.2264	71.080
K_β	19.651	4.8287	63.095

keV = 10^3 eV, EHz = 10^{18} Hz, pm = 10^{-12} m

Table 2: Glancing angle ϑ of the characteristic x-ray radiation of molybdenum for diffraction at an NaCl monocrystal up to the third order

n	$\vartheta(K_\alpha)$	$\vartheta(K_\beta)$
1	7.24°	6.42°
2	14.60°	12.93°
3	22.21°	19.61°

Fig. 2 Diagram showing the principle of diffraction of x-rays at a monocrystal and 2ϑ coupling between counter-tube angle and scattering angle (glancing angle)
1 collimator, 2 monocrystal, 3 counter tube



General remarks

In principle, you can conduct measurements in both manual scan and autoscan modes of the x-ray apparatus (see the Instruction Sheet of the x-ray apparatus). You can record the measured values manually by reading the values from the display field and writing them in a table, using a chart recorder or via a PC.

The fastest and most convenient measurement is in autoscan mode with simultaneous registration of measured values and subsequent evaluation on a Windows 9x/NT PC. This type of measurement is described in your Instruction Sheet.

The data is transmitted to the PC via the RS-232 serial interface on the x-ray apparatus. The software "X-ray Apparatus", supplied with the device, enables you to record, display and evaluate the data stream supplied by the x-ray apparatus. The program contains detailed online help which you can access by pressing F1. Please refer to the Instruction Sheet of the x-ray apparatus for details on installing the software.

The Instruction Sheet also describes recording data under Windows 3.1.

- Adjust the sensor seat (b) until the distance s_2 between the target arm and the slit diaphragm of the sensor seat is approx. 6 cm.
- Attach the target holder with target stage (f).
- Loosen knurled screw (g), lay the NaCl crystal flat on the target stage, carefully raise the stage as far at it will go and then tighten the knurled screw with care (press against the screw lightly to prevent it from stripping).
- Adjust the zero position of the goniometer measuring system as necessary (see Instruction Sheet of x-ray apparatus).

Notes:

NaCl crystals are hygroscopic and fragile. Store the crystals in a dry place. Avoid mechanical stresses on the crystal; handle the crystal by the short faces only.

If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, this distance must not be too small, as otherwise the angular resolution of the goniometer is no longer great enough to separate the characteristic K_α and K_β lines.

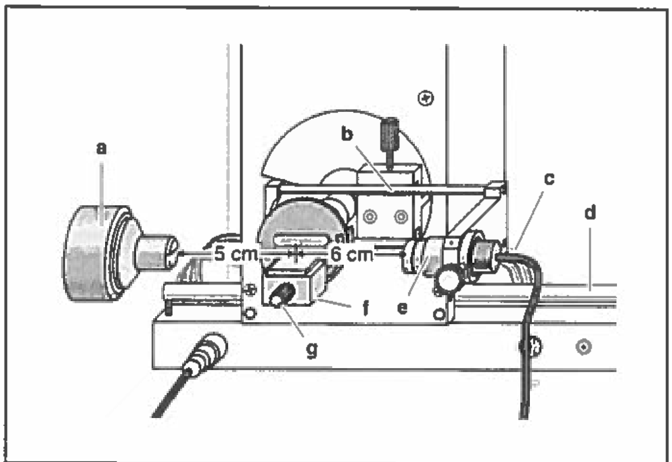
Setup

Setting up the Bragg configuration:

Fig. 3 shows some important details of the experiment setup. Specifically, you need to carry out the following steps (see also Instruction Sheet of x-ray apparatus):

- Mount the collimator in the collimator mount (a) (note the guide groove).
- Attach the goniometer to the guide rods (d) in such a way that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm. Connect the ribbon cable (c) for controlling the goniometer.
- Remove the cap of the end-window counter, insert the end-window counter in the sensor seat (e) and connect the counter tube lead to the socket marked GM-Tube.

Fig. 3 Experiment setup in Bragg configuration



Preparing a PC-based measurement:

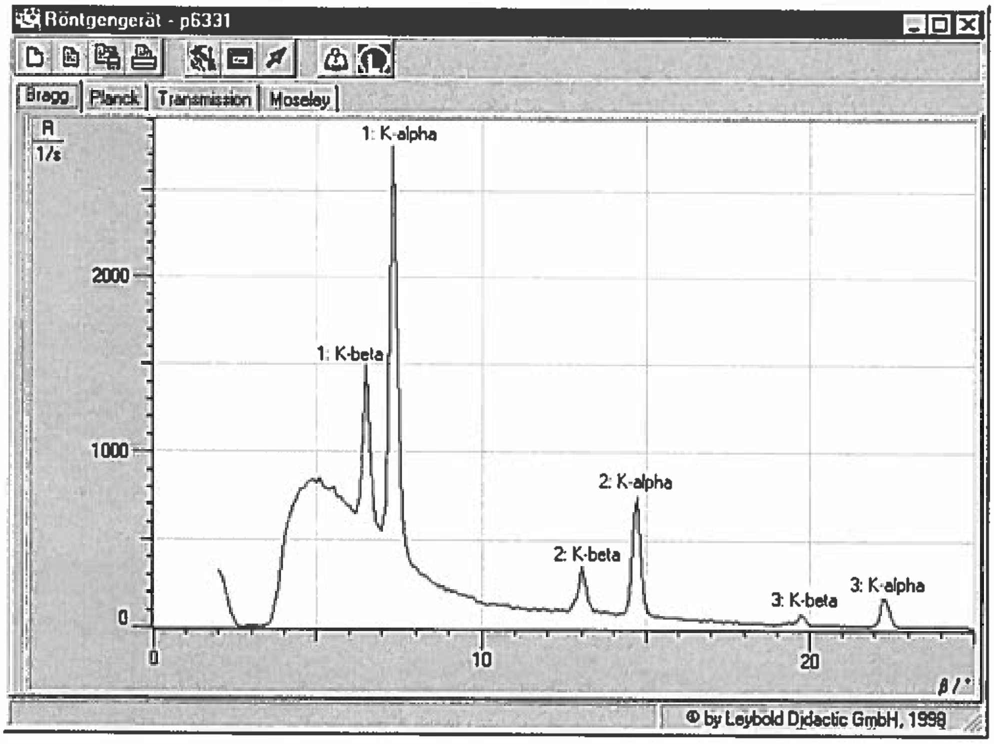
- Connect the RS-232 output to the serial interface on the PC (usually COM1 or COM2) using the 9-pin V.24 cable (included with the x-ray apparatus).
- If you have not already done so, install the software "X-ray Apparatus" under Windows 9x/NT (see Instruction Sheet of x-ray apparatus) and select the desired language.

Carrying out the experiment

- Start the program "X-ray Apparatus", check to make sure that the x-ray apparatus is properly connected and delete any existing measurement data by clicking the button or pressing F4.
- Set the x-ray high voltage U = 35.0 kV, emission current I = 1.00 mA, measuring time per angular step Δt = 10 s and angular step width $\Delta\beta$ = 0.1°.
- Press the COUPLED key on the device to enable 2ϑ coupling of the target and sensor; set the lower limit value of the target angle to 2° and the upper limit to 25°.
- Press the SCAN key to start the measurement and data transmission to the PC.
- When the measurement is finished, save the measurement series to a file under a suitable name using the button or F2.

Measuring example

Fig. 4 shows the measured diffraction spectrum.



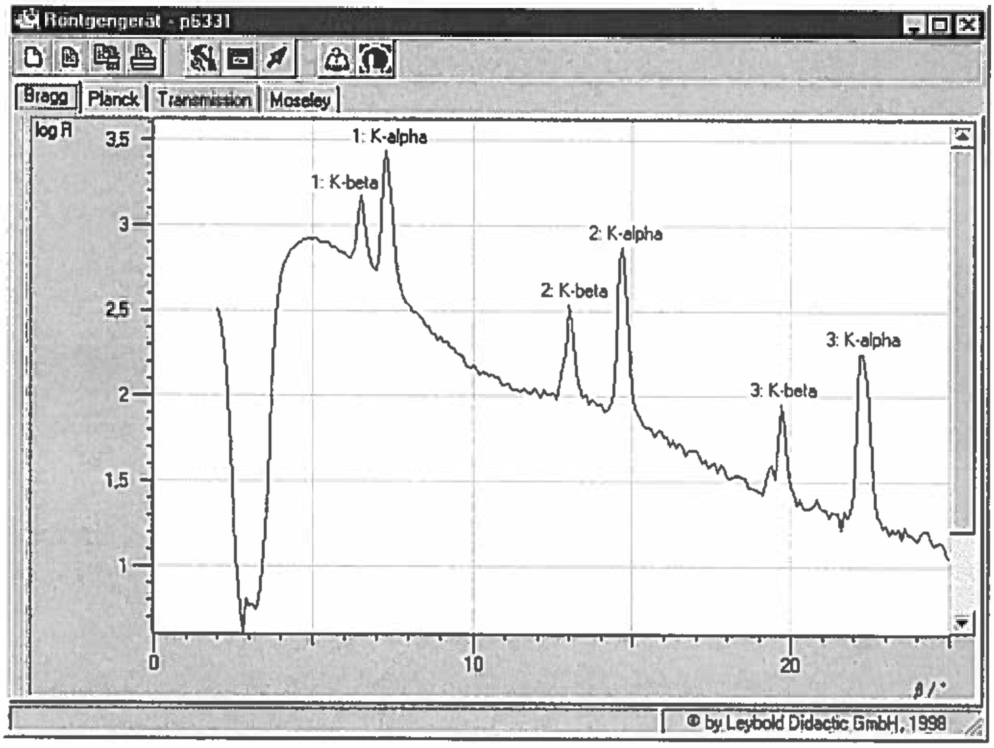


Fig. 4 Diffraction spectrum of x-ray radiation for *Bragg* reflection to the third order at an NaCl monocrystal
Top: linear representation of counting rate R
Bottom: logarithmic representation of counting rate R
Parameters of x-ray tube: U = 35 kV and I = 1 mA

Evaluation

- Access the evaluation functions of the software "X-ray Apparatus" by clicking the right-hand mouse button and select the command "Calculate Peak Center".
- Using the left mouse button, mark the "entire width" of the peaks; if desired, insert the calculated peak center β and the peak width σ in the diagram with Alt+T and note the center as the glancing angle in the measurement table (see tables 3 and 4).
- Save your measurements and evaluations to a suitably named file with the button or by pressing F2.
- Using the glancing angle ϑ and the lattice plane spacing *d* = 282.01 pm, calculate the wavelength λ using Bragg's law of reflection (IV) (see tables 3 and 4).
- Find the mean values for the individual diffraction orders of the measured wavelengths (see table 5).

Table 3: Measured glancing angles of the Mo K_α line and the calculated wavelengths λ for the first through third diffraction orders

n	$\vartheta(K_\alpha)$	$\frac{\lambda(K_\alpha)}{\text{pm}}$
1	7.24°	71.08
2	14.60°	71.09
3	22.20°	71.04

Table 4: Measured glancing angles of the Mo K_β line and the calculated wavelengths λ for the first through third diffraction orders

n	$\vartheta(K_\beta)$	$\frac{\lambda(K_\beta)}{\text{pm}}$
1	6.42°	63.07
2	12.94°	63.15
3	19.58°	63.01

Table 5: Mean value and literature value [2] for the characteristic wavelength λ

	$\frac{\lambda(K_\alpha)}{\text{pm}}$	$\frac{\lambda(K_\beta)}{\text{pm}}$
Mean value	71.07	63.08
Literature value	71.08	63.09

Results

The close agreement of the experimentally determined wavelengths for the characteristic lines with the literature values in table 5 verify the validity of Bragg's law. This simultaneously confirms the wave nature of x-rays, as this property was assumed in the process of deducing this law.

Additional information

The characteristic K_α and K_β lines actually consist of multiple, adjacent discrete lines, which can be observed separately at higher diffraction orders (see Physics Leaflet P 6.3.3.4). Table 1 shows the weighted mean values of the respective individual lines from this substructure.

Literature

[1] Handbook of Chemistry and Physics, 52nd Edition (1971–72), The Chemical Rubber Company, Cleveland, Ohio, USA.

[2] C. M. Lederer and V. S. Shirley, Table of Isotopes, 7th Edition, 1978, John Wiley & Sons, Inc., New York, USA.

iv

(P6.3.2.1)

Investigating the attenuation of x-rays as a function of the absorber material and absorber thickness.

Investigating the attenuation of x-rays as a function of the absorber material and absorber thickness

Objects of the experiment

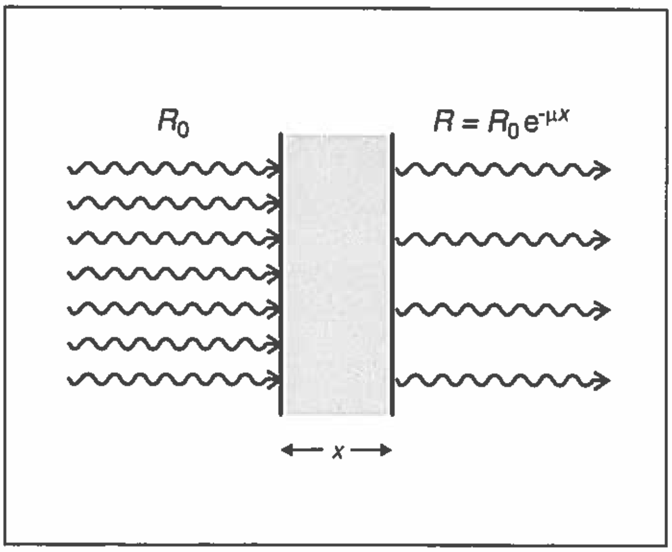
- To investigate the attenuation of x-rays as a function of the absorber thickness.
- To verify Lambert's law of attenuation.
- To investigate the attenuation of x-rays as a function of the absorber material.
- To confirme the wavelength-dependency of attenuation.

Principles

When we speak of attenuation of x-rays, we mean the decrease in intensity that occurs when the radiation passes through matter. This attenuation is caused mainly by two effects: scattering and absorption.

Although absorption and attenuation are different physical phenomena, the transilluminated object is often referred to —inaccurately— as an absorber; this should more properly be termed an attenuator. However, this description will follow the traditional usage in some places and refer to absorbers instead of attenuators.

The scattering of x-ray quanta at the atoms of the attenuator material causes a part of the radiation to change direction. This reduces the intensity in the original direction. This scattering can be either elastic or entail an energy loss or shift in wavelength, i.e. inelastic scattering.



In absorption, the entire energy of the x-ray quanta is transferred to the atoms or molecules of the irradiated material as excitation or ionizing energy.

If R_0 is the original counting rate in front of the attenuator and R is the counting rate behind it, we can quantify the transmission of the radiation to characterize the permeability of an attenuator using:

$$T = \frac{R}{R_0} \quad \text{(I).}$$

The greater the so-called transmittance of an attenuator is, the lower is its attenuating capacity.

The transmittance depends on the thickness of the attenuator. If we assume that the properties of the incident radiation remain unchanged in spite of attenuation, an increase in the thickness x by the amount dx will cause a decrease in the transmittance T by the amount dT. The relative reduction in transmission is proportional to the absolute increase in thickness:

$$-\frac{dT}{T} = \mu \cdot dx \quad \text{(II).}$$

The proportionality factor μ is referred to as the linear attenuation coefficient.

As the transmittance $T = 1$ for $x = 0$, integration of equation (II) gives us

$$T = e^{-\mu \cdot x} \quad \text{(III)}$$

or

$$\ln T = -\mu \cdot x \quad \text{(IV).}$$

This relationship is known as Lambert's law of attenuation after *Johann Heinrich Lambert*, the 18th century scientist and philosopher.

The aim of this experiment is to verify Lambert's law of attenuation. It also demonstrates that the attenuation depends on the attenuating material and the wavelength of the x-rays.

0608-Ste

Apparatus

1 X-ray apparatus	554 811
or	
1 X-ray apparatus	554 812
1 Goniometer	554 83
1 End-window counter for α, β, γ and x-ray radiation	559 01
1 Set of absorbers x-ray	554 834

- Mount the target holder.
- Press the ZERO key to return the target and sensor arms to the zero position.
- Check the zero position of the empty diaphragm of the set of absorbers and the sensor and correct this if necessary (see "Adjusting the zero position of the measuring system" in the Instruction Sheet of the x-ray apparatus).
- By moving the goniometer, set a distance of approx. 5 cm between the collimator of the x-ray apparatus and the empty diaphragm, and set a distance of approx. 5 cm between the empty diaphragm and the sensor slit by moving the sensor holder (b).

Setup

Set up the experiment as shown in Fig. 1.

- Mount the collimator in the collimator mount (a) (note the guide groove).
- Attach the goniometer to guide rods (d) and connect ribbon cable (c) for controlling the goniometer.
- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat (e) and connect the counter tube cable to the socket in the experiment chamber marked GM TUBE.
- Demount the target holder (g) of the goniometer and remove the target stage from the holder.
- Place the guide edge of the set of absorbers I (f) in the 90° curved groove of the target holder and carefully slide it into the target holder as far as it will go.

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

The goniometer is positioned solely by electric stepper motors.

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

Carrying out the experiment

a) Attenuation as a function of the absorber thickness:

a1) Without zirconium filter:

- Set the tube high voltage to U = 21 kV.
- Set the emission current I = 0.05 mA.

Note: The counting rate should not appreciably exceed 1500/s. This avoids having to correct for dead time.

- Press the key TARGET.
- Set the angular step width $\Delta\beta$ = 0° (see "Activating an exposure timer" in the Instruction Sheet of the x-ray apparatus).
- Set the measuring time Δt = 100 s.
- Using the ADJUST knob, set the angular positions of the absorbers (approx. 0°, 10°, 20°, 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your experiment results (see table 1).

a2) With zirconium filter:

- Mount the zirconium filter on the collimator (this suppresses the short-wave component of the bremsstrahlung radiation generated at U = 21 kV almost entirely).
- Set the emission current I = 0.15 mA and the measuring time Δt = 200 s.
- Using the ADJUST knob, set the angular positions of the absorbers (approx. 0°, 10°, 20°, 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key, display the mean counting rate R after the measuring time elapses by pressing REPLAY and write down your results (see table 2).

b) Attenuation as a function of the absorber material:

b1) Without zirconium filter:

- Replace set of absorbers I (absorbers of different thicknesses) with set of absorbers II (absorbers of different materials, d = 0.05 cm).
- Remove the zirconium filter.
- Set the tube high voltage to U = 30 kV (this ensures that the radiation also penetrates the thick absorbers).
- Set the emission current I = 0.02 mA and the measuring time Δt = 30 s.

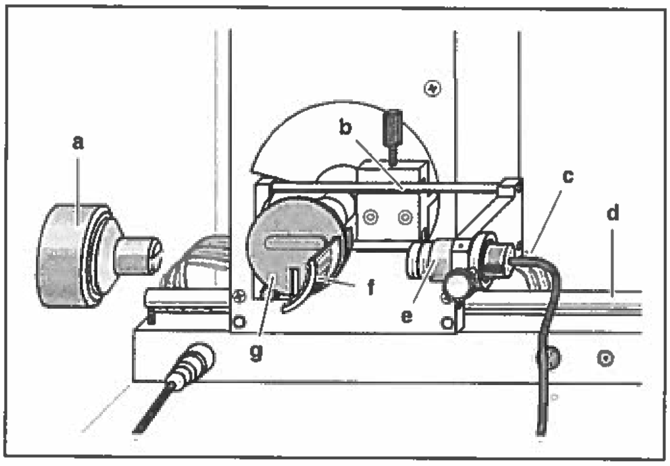


Fig. 1 Setup for investigating the attenuation of x-rays as a function of the thickness of the absorber material.

- Using the ADJUST knob, set the angular positions of the first three absorbers (approx. 0°, 10° and 20°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your results.
- Set the emission current I = 1.00 mA and the measuring time Δt = 300 s.
- Using the ADJUST knob, set the angular positions of the four remaining absorbers (approx. 30°, 40°, 50° and 60°) one after another, start the measurement with the SCAN key and display the mean counting rate R after the measuring time elapses by pressing REPLAY. Write down your experiment results (see table 3).

b2) With zirconium filter:

- Attach the zirconium filter and repeat the measurement as described for b1) (see table 4).

b3) Measuring the background effect:

- Set the parameters U = 0 kV and I = 0 mA and measure the counting rate R_1 of the background effect for a measuring time of Δt = 300 s.

Measuring example

a) Attenuation as a function of the absorber thickness:

Tab. 1: Counting rate R as a function of thickness d of the aluminum absorber (U = 21 kV, I = 0.05 mA, Δt = 100 s, without zirconium filter)

	$\frac{R}{s^{-1}}$
0	977.9
0.5	428.6
1.0	210.1
1.5	106.1
2.0	49.10
2.5	30.55
3.0	16.11

Tab. 2: Counting rate R as a function of thickness d of the aluminum absorber (U = 21 kV, I = 0.15 mA, Δt = 200 s, with zirconium filter)

$\frac{d}{mm}$	$\frac{R}{s^{-1}}$
0	969.4
0.5	426.1
1.0	197.3
1.5	84.29
2.0	40.51
2.5	19.48
3.0	9.52

b) Attenuation as a function of the absorber material:

Tab. 3: Counting rate R as a function of the absorber material (U = 30 kV, d = 0.05 cm, without zirconium filter)

Absorber	Z	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{R}{s^{-1}}$
none		0.02	30	1841
C	6	0.02	30	1801
Al	13	0.02	30	1164
Fe	26	1.00	300	93.3
Cu	29	1.00	300	16.63
Zr	40	1.00	300	194.3
Ag	47	1.00	300	106

Tab. 4: Counting rate R as a function of the absorber material (U = 30 kV, d = 0.05 cm, with zirconium filter)

Absorber	Z	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{R}{s^{-1}}$
none		0.02	30	718.3
C	6	0.02	30	698.4
Al	13	0.02	30	406.1
Fe	26	1.00	300	29.24
Cu	29	1.00	300	6.016
Zr	40	1.00	300	113.9
Ag	47	1.00	300	24.52

Background effect: R_1 = 0.243 s^{-1}

Evaluation and results

a) Attenuation as a function of the absorber thickness:

When we insert the measurement data from tables 1 and 2 in equation 1, we obtain the transmittance *T*. Fig. 2 shows how this depends on the thickness *d* of the absorber. The plotted curve conforms to the exponential function to be expected from equation (III).

Fig. 3 shows a floating-point representation in accordance with equation (IV). In this representation, the attenuation of x-ray radiation (monochromatized using the zirconium filter) can be described very well using a straight line through the origin that has a slope which corresponds to the linear attenuation coefficient μ = 15.7 cm^{-1}.

For non-monochromatic (unfiltered) x-ray radiation, the slope of the straight line through the origin fitted according to equation (IV) gives us a slightly smaller value of μ = 14.2 cm^{-1} for the attenuation coefficient. Also, we can note deviations from the linear curve. The attenuation cannot be described using a single attenuation coefficient; rather, the radiation has a larger high-energy component than the measurement with Zr filter, so that less attenuation occurs for the same absorber thickness.

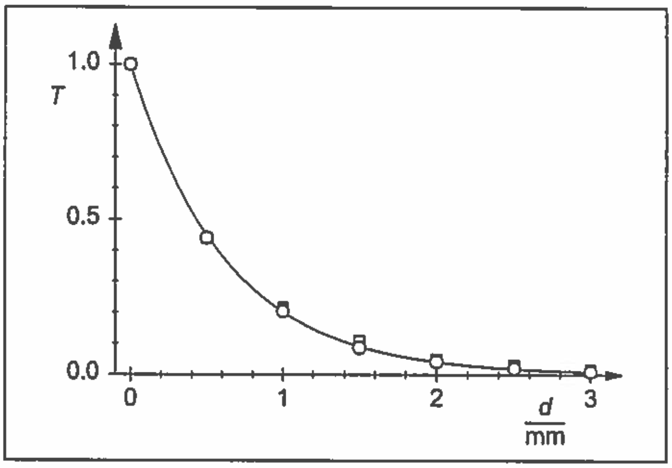


Fig. 2 Transmittance *T* as a function of the thickness d of the aluminum absorbers
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

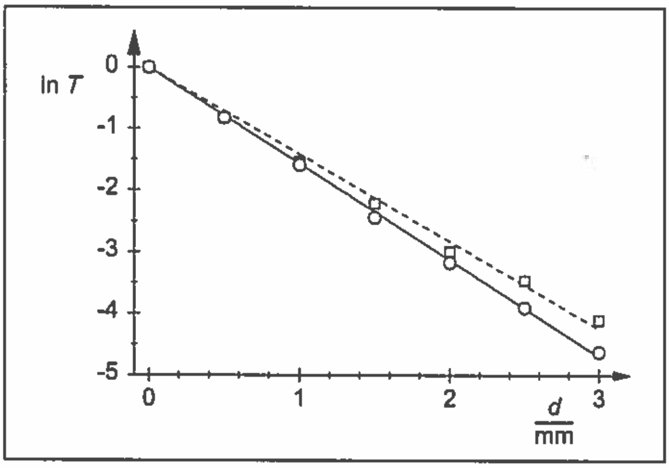


Fig. 3 Floating-point representation of transmission *T* as a function of the thickness *d* of the aluminum absorbers
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

b) Attenuation as a function of the absorber material:

Assuming that the counting rate is proportional to the emission current *I*, it is possible to scale the counting rates from tables 3 and 4 (after subtracting the background effect) to the emission current *I* = 1.00 mA.

Using the scaled data, equation (I) gives us the transmission *T* (see tables 5 and 6), which we can use to calculate the linear attenuation coefficient μ for *d* = 0.05 cm by means of equation (IV).

Fig. 4 shows the relationship between the linear attenuation coefficient μ and the atomic number *Z*. Below *Z* = 40 (Zr), the attenuation coefficient increases steeply as the atomic number rises. When *Z* reaches 40, we observe an abrupt decrease, which is more apparent for the filtered radiation. This reduction is due to the fact the certain excitations are no longer possible in Zr (binding energy of the K shell is too great, see experiment P6.3.4.5). The unfiltered radiation contains a high-energy component which can still generate this excitation, so that the decrease in μ is less.

Tab. 5: Counting rate *R* (*I* = 1.00 mA), transmittance *T* and linear attenuation coefficient μ as a function of the atomic number *Z* of the absorber material (*U* = 30 kV, *d* = 0.05 cm, without zirconium filter).

Z	$\frac{R}{s^{-1}}$	T	$\frac{\mu}{cm^{-1}}$
none	$92.0 \cdot 10^3$	1.000	0
6	$90.0 \cdot 10^3$	0.978	0.445
13	$58.3 \cdot 10^3$	0.634	9.11
26	93.1	$1.01 \cdot 10^{-3}$	138
29	16.4	$0.178 \cdot 10^{-3}$	173
40	194	$2.11 \cdot 10^{-3}$	123
47	106	$1.15 \cdot 10^{-3}$	135

Tab. 6: Counting rate R (I = 1.00 mA), transmittance T and linear attenuation coefficient μ as a function of the atomic number Z of the absorber material (U = 30 kV, d = 0.05 cm, with zirconium filter).

Z	$\frac{R}{s^{-1}}$	T	$\frac{\mu}{cm^{-1}}$
none	$35.9 \cdot 10^3$	1.000	0
6	$34.9 \cdot 10^3$	0.972	0.568
13	$20.3 \cdot 10^3$	0.565	11.4
26	29.0	$0.808 \cdot 10^{-3}$	142
29	5.77	$0.161 \cdot 10^{-3}$	175
40	114	$3.18 \cdot 10^{-3}$	115
47	24.3	$0.677 \cdot 10^{-3}$	146

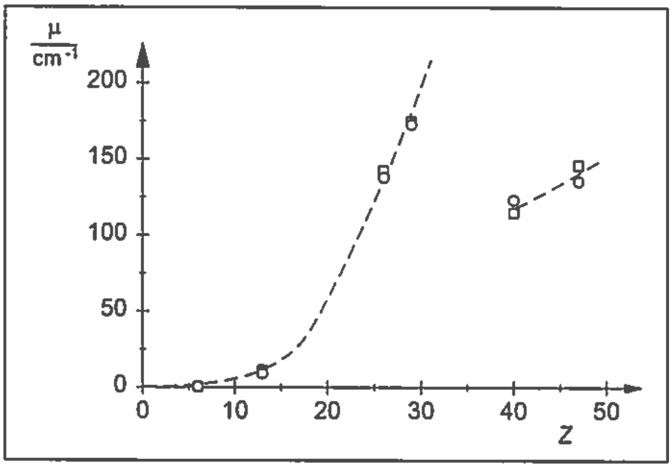


Fig. 4 Linear attenuation coefficient μ as a function of the atomic number Z of the absorber
Circles: measurement with zirconium filter
Squares: measurement without zirconium filter

V

(P6.3.2.1)

X-ray Photography**:** fogging

of **film** stock due to xrays.

X-ray photography: fogging of film stock due to x-rays

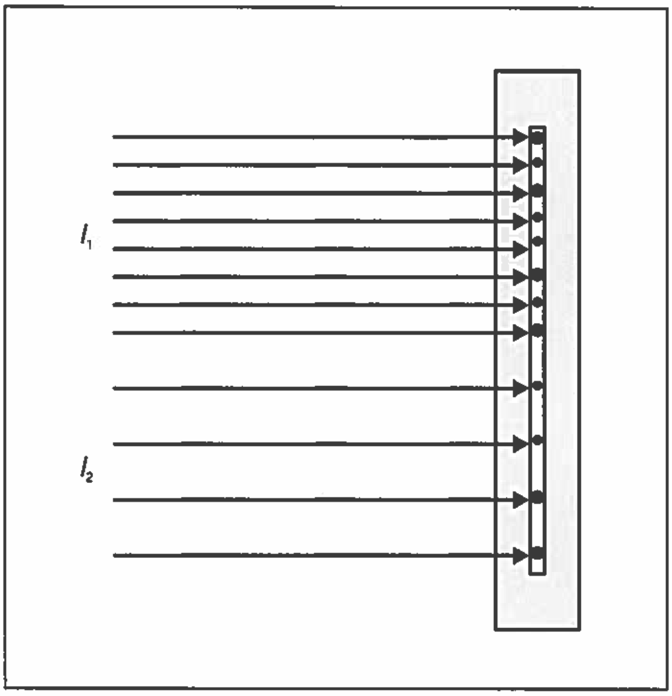
Objects of the experiment

- Detecting x-rays by means of fogging of film stock packed in light-tight envelopes.
- Investigating the relationship between the exposure dose and the degree of fogging of the film.

Principles

When x-rays strike a photosensitive layer the silver halogenide is broken down into silver atoms and halogen atoms, just as in exposure to visible light. At weak and moderate x-ray intensities, the number of seeds (silver atoms) formed is proportional to the number of incident x-ray quanta. In the process of development, silver seeds cause a fogging of the film. The degree of fogging is a measure of the intensity of x-radiation and the exposure time, i.e. the time in which the radiation could act on the film.

X-ray films can be films for daylight instant cameras as well as films requiring darkroom development. These films are exposed to the x-rays in their light-tight packaging and then developed. Alternatively, standard commercially available photographic paper can also be used. Just as in the case of x-ray film, this produces a negative, i.e. the more intensive the radiation and/or the longer the exposure time, the darker the image is.



Fogging of film stock due to x-rays

0808-Ste

Apparatus

1 X-ray apparatus 554 811
or
1 X-ray apparatus 554 812

1 Film holder x-ray 554 838
1 Film pack 2 (x-ray film) 554 892

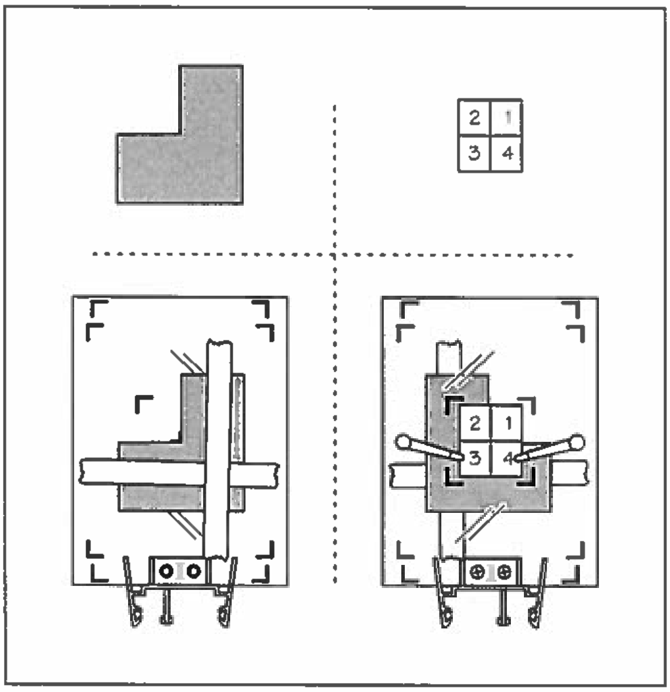


Fig. 1 Producing a film mask and preparing the x-ray film

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 µSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

Setup

Preparations:

- Create a film mask made of lead sheeting a least 2 mm thick as shown in Fig. 2, top left.
- Divide the packed x-ray film into four fields of equal size on both sides of the film using a soft pencil and number these from 1 to 4 (see Fig. 1 top right).

Notes:

Do not mark the film with a felt-tip pen, as common felt-tip inks can penetrate the film packing and affect the film.

When demonstrating film fogging, the direction in which the x-rays fall on the film is not important.

- Attach the film mask to the free side of the film holder x-ray using adhesive tape and clamp the x-ray film on the other side so that initially field 1 is visible through the mask (see Fig. 1 below).

Mounting in the x-ray apparatus:

- Remove the collimator from the experiment chamber, as well as the goniometer or plate capacitor x-ray (if mounted).
- Mount the experiment rail with film holder in the experiment chamber of the x-ray apparatus.
- Attach the film holder x-ray to the experiment rail so that the Plexiglas pane is facing the zero point of the scale and the marking bump (a) of the clamp rider is at the 180 mm point of the scale.

  In this case, the distance d from the plane of the film to the focal spot of the x-ray tube should be around 290 mm.

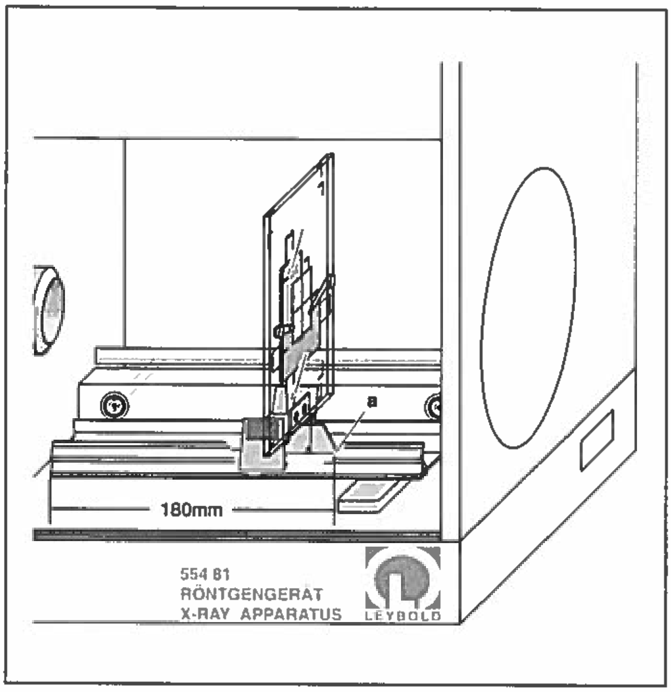


Fig. 2 Setup for investigating the fogging of film stock due to x-rays

Carrying out the experiment

a) Film fogging as a function of the emission current *I*:

- Set the tube high voltage U = 20 kV, measuring time Δt = 20 s and $\Delta\beta$ = 0.0°.
- Set the emission current I = 0.25 mA and press SCAN to start the exposure timer.
- Turn the x-ray film so that field 2 is now exposed.
- Increase the emission current to I = 0.50 mA and press SCAN to start the exposure timer.
- Turn or rotate the x-ray film to expose field 3 with I = 0.75 mA and field 4 with I = 1.00 mA.
- Develop and fix the x-ray film as described in the Instruction Sheet for filmpack 2 (2.5 ml developer, developing time 1.5 min, 3.5 ml fixer, fixing time 4 min.).

b) Film fogging as a function of the exposure time Δt:

- Prepare a new x-ray film and mount it so that field 1 is exposed first.
- Set the measuring time Δt = 5 s and press SCAN to start the exposure timer.
- Expose field 2 with Δt = 10 s, field 3 with Δt = 15 s and field 4 with Δt = 20 s.
- Develop and fix your x-ray film.

c) Exposure at a constant product of emission current *I* and exposure time Δt:

- Prepare a new x-ray film and mount it so that field 1 is exposed first.
- Set the emission current I = 0.25 mA and measuring time Δt = 40 s and press SCAN to start the exposure timer.
- Expose field 2 with I = 0.50 mA and Δt = 20 s, field 3 with I = 0.72 mA and Δt = 15 s and field 4 with I = 1.00 mA and Δt = = 10 s.
- Develop and fix your x-ray film.

Measuring example

d = 290 mm, U = 20 kV

a) Varying the emission current *I*:

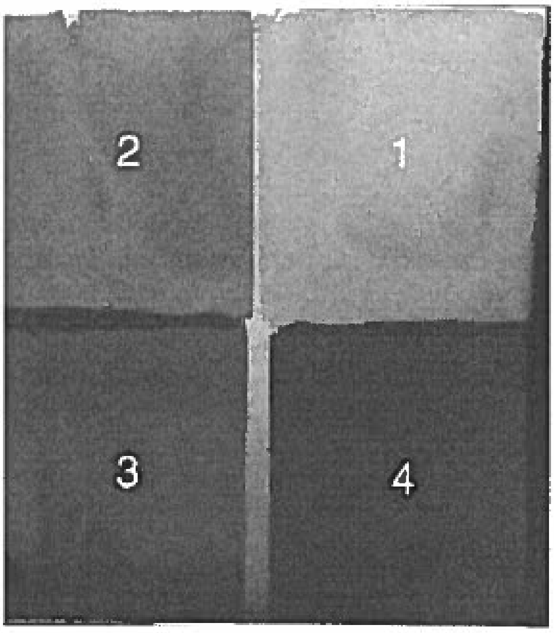


Fig. 3 Fogging intensities of the x-ray film at Δt = 20 s
Field 1: I = 0.25 mA, field 2: I = 0.50 mA, field 3: I = 0.75 mA, field 4: I = 1.00 mA

Table 1: Product of $I \cdot \Delta t$ for the four fogged films (see Fig. 3)

Field	$\frac{I}{\text{mA}}$	$\frac{\Delta t}{\text{s}}$	$\frac{I \cdot \Delta t}{\text{mAs}}$
1	0.25	20	5
2	0.5	20	10
3	0.75	20	15
4	1.00	20	20

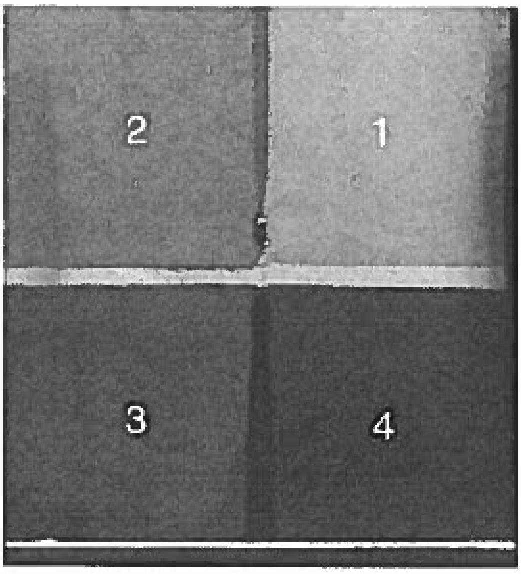


Fig. 4 Fogging intensities of the x-ray film at $I = 1.00$ mA
Field 1: $\Delta t = 5$ s, field 2: $\Delta t = 10$ s,
field 3: $\Delta t = 15$ s, field 4: $\Delta t = 20$ s

b) Varying the exposure time Δt:

Table 2: Product of $I \cdot \Delta t$ for the four fogged films (see Fig. 4)

Field	$\frac{I}{\text{mA}}$	$\frac{\Delta t}{\text{s}}$	$\frac{I \cdot \Delta t}{\text{mAs}}$
1	1.00	5	5
2	1.00	10	10
3	1.00	15	15
4	1.00	20	20

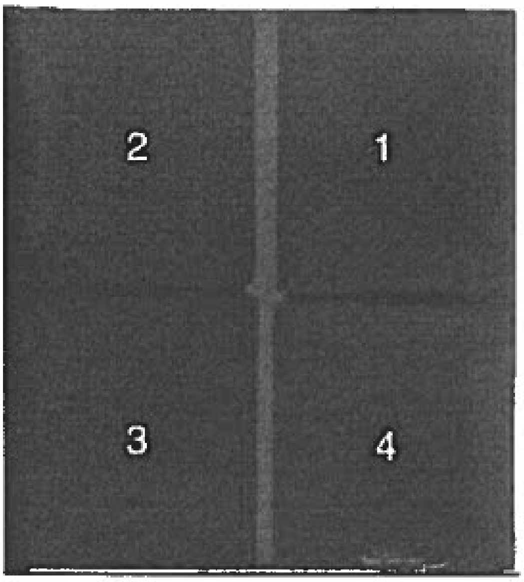


Fig. 5 Fogging of x-ray film at a constant product of $I \cdot \Delta t$
Field 1: $I = 0.25$ mA, $\Delta t = 5$ s,
Field 2: $I = 0.50$ mA, $\Delta t = 10$ s,
Field 3: $I = 0.72$ mA, $\Delta t = 14$ s,
Field 4: $I = 1.00$ mA, $\Delta t = 20$ s

c) Exposure at a constant product of $I \cdot \Delta t$

Table 3: Product of $I \cdot \Delta t$ for the four fogged films (see Fig. 5)

Field	$\frac{I}{\text{mA}}$	$\frac{\Delta t}{\text{s}}$	$\frac{I \cdot \Delta t}{\text{mAs}}$
1	0.25	40	10
2	0.50	20	10
3	0.72	14	10.1
4	1.00	10	10

Evaluation

The fogging of the x-ray film depends on the product of the emission current I and the exposure time Δt, and increases with the product.

As the emission current I is proportional to the exposure dose rate j of the x-rays (see experiment P6.3.1.4), the product of $I \cdot \Delta t$ is proportional to the exposure dose.

$$J = j \cdot \Delta t \qquad \text{(I).}$$

Results

The fogging of the x-ray film increases with the exposure dose J of the x-radiation.

Additional information

As the fogging of x-ray film is a measure of the time integral over the exposure dose rate, x-ray films are often used for measuring the radiation dose. The degree of fogging is registered quantitatively by means of photometric measurements.

Persons whose work exposes them to radiation hazards wear badges with packed x-ray film, called film dosimeters, so that the absorbed radiation dose can be monitored. Film dosimeters can also be used to measure the exposure dose e.g. of γ radiation.

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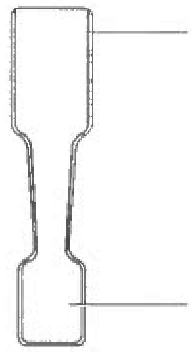


Instruction sheet 554 895

X-ray film (554 895)

1 developer and fixer
2 film

1 Description

The X-ray film is a highly sensitive film for X-, γ- and β- rays for immediate development. Each film is lightproof and packaged in developer and fixer solution, so that processing is possible in daylight without a laboratory.

2 Technical data

Name:	ECO 30
Film format:	30 mm x 40 mm
Packaging content:	25 films
Processing time (developing, fixing, washing)	approx. 1 min
Optimum temperature:	20°C

3 Storage

- Keep X-ray film in cool place free of frost.

Safety notes

- Avoid contact with the eyes.
- Do not swallow.
- Touch film only with gloves during washing.

4 Experiments with X-ray apparatus (554 81)

4.1 Experiments on film blackening

- Remove collimator.

Film distance from collimator holder:	15 cm
Tube voltage:	35 kV
Tube current:	100 µA
Film orientation:	Embossed circle front
Exposure time:	5-40 s depending on desired blackening

4.2 Transillumination image of a small plate

- Remove collimator.
- Select minimum distance between film and object.

Film distance from collimator holder	20 cm
Tube voltage:	35 kV
Tube current:	100 µA
Film orientation:	Embossed circle front
Exposure time:	5 s

The exposure time depends on the object to be illuminated

4.3 Laue diagram with NaCl crystal

- Mount aperture on collimator and crystal on aperture

Film distance from crystal	15 mm
Tube voltage:	35 kV
Tube current:	1 mA
Film orientation:	Embossed circle front
Exposure time:	appprox. 900-1500 s

4.4 Debye Scherrer photographs with NaCl powder:

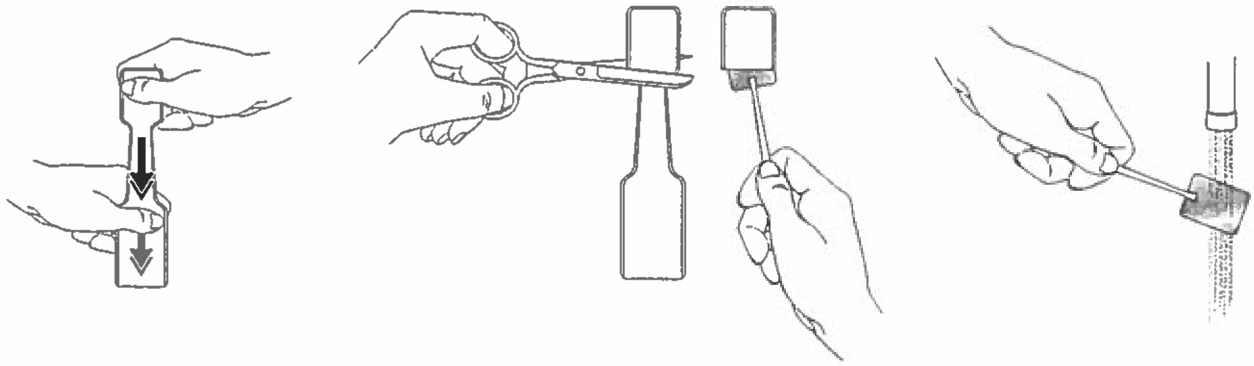
- Mount aperture on collimator and crystal on aperture

Film distance from powder	15 mm
Tube voltage:	35 kV
Tube current:	1 mA
Film orientation:	Embossed circle front
Exposure time:	Approx. 9000 s.

5 Processing

5.1 Developing and Fixing

5.2 Washing



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(P6.3.2.1)

Determining the Ion Dose rate of x-ray tube with molybdenum anode.

Determining the ion dose rate of the x-ray tube with molybdenum anode

Objects of the experiment

- To introduce and to explanate the terms ion dose (exposure dose) and ion dose rate for quantifying the action of x-rays.
- To determine the ion dose rate in an air-filled plate capacitor by measuring the ionization current.

Principles

Dosimetry is the quantitative measurement of the effects that x-rays cause when passing through matter and which can be used to detect x-rays. Dosimetry is thus important for medical and technical applications as well as in radiation protection. It does not represent a measurement of the actual intensity of the x-radiation. Such a determination would require e.g. calorimetric measurements in which the entire x-radiation is absorbed and converted into heat. However, with suitable calibration, measurements of dose and time can be used as a measure of the radiation intensity.

Dose and dose rate:

In terms of radiation, the dose can be defined on the basis of both the ionizing action and the energy absorption of the x-rays when they pass through matter. The first case is the measure of the ion dose (also called the exposure dose) and the second the absorbed dose.

The ion dose (exposure dose)

$$J = \frac{dQ}{dm} \qquad (I)$$

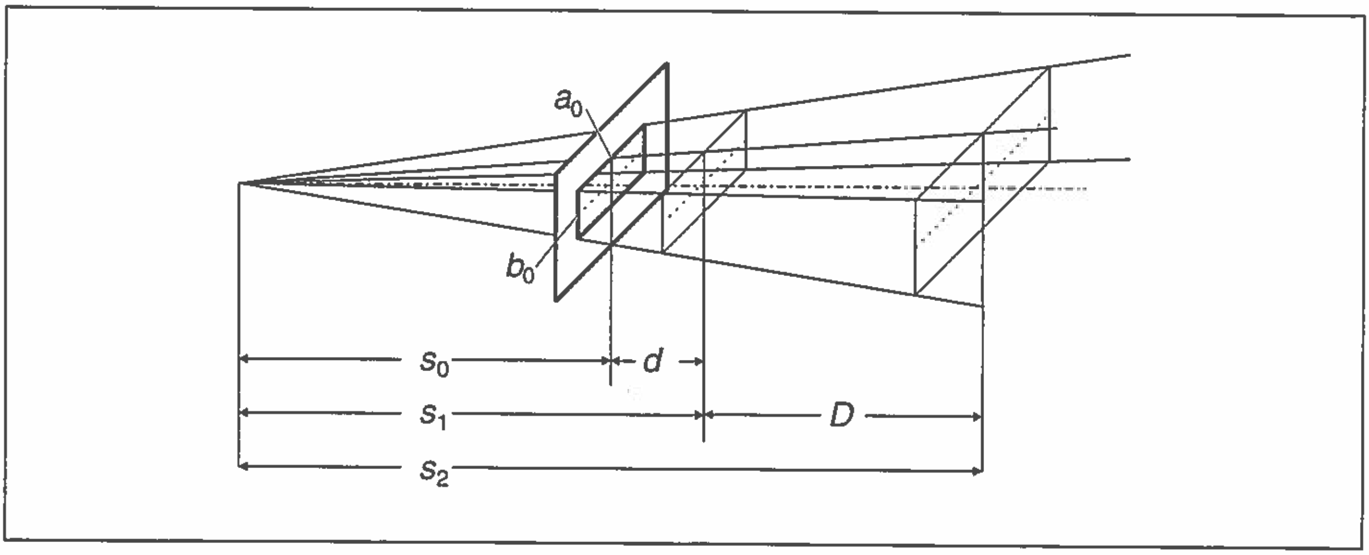
is the quotient of the charge dQ generated in air by charge carriers of one sign due to irradiation, and the mass dm of the irradiated volume element. Its derived SI unit is the coulomb per kilogram ($C\,kg^{-1}$): $1\ C\,kg^{-1} = 1\ As\,kg^{-1}$

The absorbed dose

$$K = \frac{dW}{dm} \qquad (II)$$

is the quotient of the energy dW absorbed by the irradiated material and the mass dm of the irradiated volume element. Its derived SI unit is the gray (Gy): $1\ Gy = 1\ J\,kg^{-1}$

Fig. 1 Diagram of beam path in plate capacitor, for calculating the irradiated volume V



Apparatus

1 X-ray apparatus		554 811
or		
1 X-ray apparatus		554 812
1 Plate capacitor x-ray		554 840
1 Power supply 450 V DC		522 27
1 Electrometer amplifier		532 14
1 STE resistor 1 GΩ, 0.5 W		577 02
1 Voltmeter, U ≤ 300 V DC, input resistance ≥ 10 MΩ	e.g.	531 100
1 Voltmeter, U ≤ 10 V DC	e.g.	531 100
1 Screened cable BNC/4 mm		575 24
Connecting leads		

The effective intensity of the x-rays is defined as the quotient of dose and time. The ion dose rate is defined as

$$j = \frac{dJ}{dt} \qquad \text{(III)},$$

measured in A kg^{-1}, and the absorbed dose rate is defined as

$$k = \frac{dK}{dt} \qquad \text{(IV)}$$

measured in Gy s^{-1} = W kg^{-1}.

Determining the ion dose rate:

The ion dose rate can be measured in an air-filled plate capacitor by measuring the saturation value of the ionization current I_C (see experiment P6.3.1.3). This is determined as

$$I_C = \frac{dQ}{dt};$$

Safety notes

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö).

The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 µSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened (see Instruction Sheet for x-ray apparatus).
- Keep the x-ray apparatus secure from access by unauthorized persons.

Do not allow the anode of the x-ray tube Mo to overheat.

- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.

using (I) and (II), this gives us:

$$j = \frac{dI_C}{dm} \qquad \text{(V)}$$

As x-rays diverge as they propagate and are attenuated in air, the ion dose rate j is a location-dependent quantity, and would require a great deal of effort to measure. It is easier to measure the mean ion dose rate

$$\langle j \rangle = \frac{I_C}{m}, \qquad \text{(VI)}$$

for which we need to determine the total ionization current I_C and the mass

$$m = \rho \cdot V \qquad \text{(VII)}$$

of the total irradiated volume V.

The density ρ of air is calculated as

$$\rho = \rho_0 \cdot \frac{T_0}{T} \cdot \frac{p}{p_0} \qquad \text{(VIII)}$$

with ρ_0 = 1.293 kg m^{-3} , T_0 = 273 K and p_0 = 1013 hPa from the temperature T and barometric pressure p in the experiment chamber. The volume V can be calculated with the aid of Fig. 1.

Calculating the irradiated volume V:

In Fig. 1, the focal spot of the x-ray tube is presumed to closely approximate a point. The rectangular diaphragm in front of the plate capacitor shapes the radiation cone of the x-ray tube into a beam which penetrates the volume V of air to be calculated.

The distance between the focal spot and the rectangular diaphragm is s_0 = 15.5 cm. The dimensions of the diaphragm are a_0 = 4.5 cm and b_0 = 0.6 cm. The x-rays propagate in a straight line, and thus illuminate at any given distance s from the focal spot a rectangle behind the diaphragm with the dimensions

$$a(s) = \frac{s}{s_0} \cdot a_0 \text{ and } b(s) = \frac{s}{s_0} \cdot b_0 \qquad \text{(IX)}.$$

The irradiated volume of air in the plate capacitor is thus equivalent to the integral

$$V = \int_{s_1}^{s_2} a(s) \cdot b(s) \cdot ds \qquad \text{(X)}.$$

with the integral limits

$$s_1 = s_0 + d \text{ and } s_2 = s_0 + d + D \qquad \text{(XI)}$$

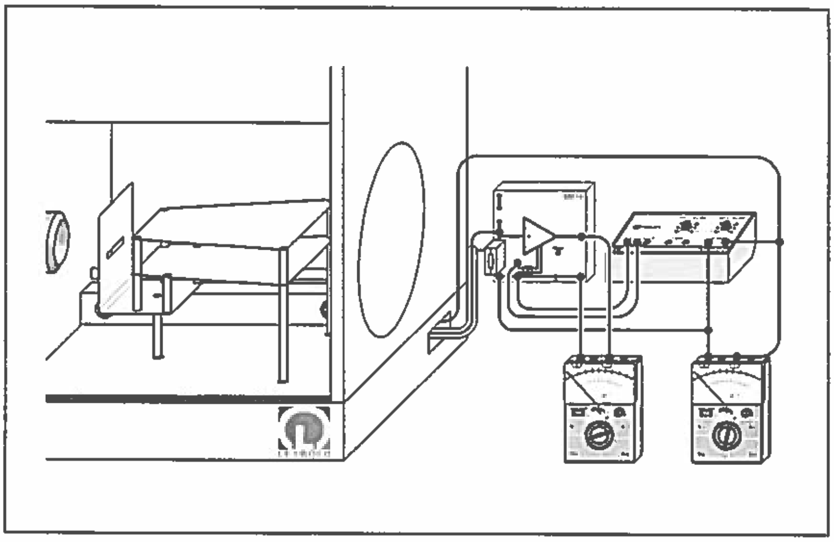
d = 2.5 cm: distance from diaphragm to plate capacitor
D = 16.0 cm: length of plate capacitor.

This gives us

$$V = \frac{1}{3} \cdot \frac{a_0 \cdot b_0}{s_0^2} \cdot \left(s_2^3 - s_1^3\right)$$

and thus

$$V = a_0 \cdot b_0 \cdot D \cdot \left(\frac{s_2^2 + s_2 s_1 + s_1^2}{s_0^2}\right) = 125 \text{ cm}^3 \qquad \text{(XII)}.$$



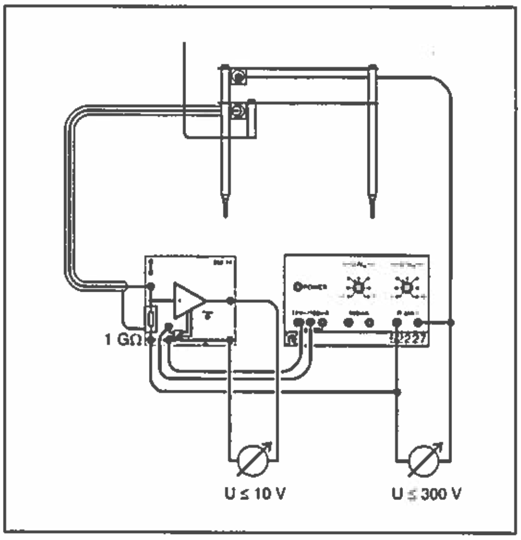


Fig. 2 Experiment setup for measuring the ionization current in a plate capacitor

Fig. 3 Connecting the plate capacitor and the electrometer amplifier for determining the ionization current

Setup

Set up the experiment as shown in Fig. 2. Fig. 3 shows the electrical connections of the plate capacitor and the electrometer amplifier for determining the ionization current.

Mechanical setup:

- If necessary, demount the collimator of the x-ray apparatus and remove any experiment equipment from the chamber of the x-ray apparatus.
- Connect the adapter cable BNC/4 mm to the bottom capacitor plate (BNC socket) with the BNC plug and connect the connecting lead to the top capacitor plate (safety socket) of the plate capacitor x-ray.
- Lift the plate capacitor into the experiment chamber of the x-ray apparatus and insert the mounting plugs in the mounting sockets. Check to make sure that the capacitor plates are aligned parallel to the base plate of the x-ray apparatus, and correct as necessary.
- Feed the two cables into the free channel until they reappear on the right side of the x-ray apparatus

Electrical assembly:

- Connect the connecting lead to the positive pole of the 450 V DC power supply and connect the adapter cable BNC/4 mm to the electrometer amplifier fitted with the 1 GΩ resistor.
- Ground the electrometer amplifier to the negative terminal of the 450 V DC amplifier.
- Connect a voltmeter to measure the capacitor voltage U_C and the output voltage of the electrometer amplifier U_E.
- Plug in the x-ray apparatus to the mains power and switch it on.

Carrying out the experiment

- Determine the temperature ϑ and the barometric pressure p in the experiment chamber and use these to calculate the irradiated mass m according to equations (VII) and (VIII).

a) Saturation ionization current I_C as a function of the emission current I:

- Set the tube high voltage to U = 35 kV.
- Set the capacitor voltage $U_C \geq 140$ V, so that the saturation value of the ionization current I_C is reached.

To record a measurement series, increase the emission current I in steps from 0 mA to 1 mA and determine the ionization current I_C for each step from the voltage U_E at the output of the electrometer amplifier:

$$I_C = \frac{U_E}{1\ \text{G}\Omega}$$

- Write down your measuring results and the calculated mean ion dose rate.

b) Saturation ionization current I_C as a function of the tube high voltage U:

- Set the emission current I = 1.0 mA.
- Set the capacitor voltage UC ≥ 140 V.

Increase the tube high voltage U in steps from 5 kV to 35 kV and determine the corresponding ionization current I_C.

- Write down your measuring results and the calculated mean ion dose rate.

Measuring example and evaluation

T = 303 K and p = 1017 hPa:

From equation (VIII) we can calculate $\rho = 1.17\ \text{kg m}^{-3}$

and from (VII) and (XII) $m = 0.147\ 10^{-3}$ kg

Thus, in accordance with (VI) the mean ion dose rate is

$$\frac{\langle J \rangle}{\mu\text{A} \cdot \text{kg}^{-1}} = \frac{I_C}{\text{nA}} \cdot \frac{1}{0.147\ \text{kg}}$$

a) Measurements as a function of the emission current I:

Tab. 1: Saturation value of the ionization current I_C and the mean ion dose rate $< j >$ as a function of the emission current I of the x-ray tube, tube high voltage U = 35 kV.

$\frac{I}{mA}$	$\frac{I_C}{nA}$	$\frac{<j>}{\mu A \cdot kg^{-1}}$
0.0	0.02	0.14
0.1	0.48	3.27
0.2	0.92	6.27
0.3	1.30	8.86
0.4	1.72	11.7
0.5	2.10	14.3
0.6	2.45	16.7
0.7	2.80	19.1
0.8	3.20	21.8
0.9	3.55	24.2
1.0	3.90	26.6

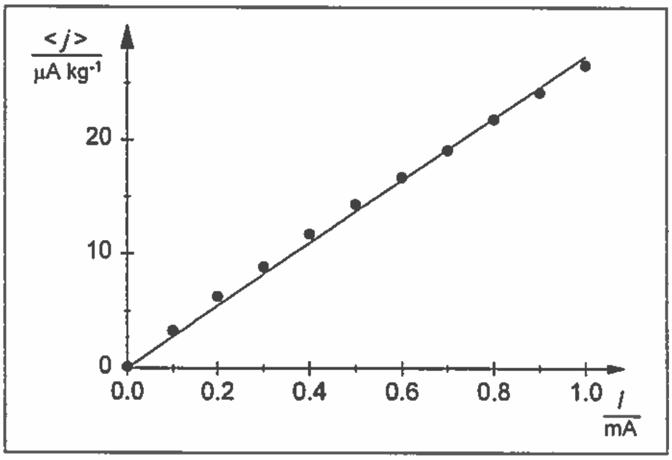


Fig. 4 Mean ion dose rate $< j >$ as a function of the emission current I of the x-ray tube, U = 35 kV

b) Saturation ionization current I_C as a function of the tube high voltage U:

Tab. 2: Saturation value of ionization current I_C and mean ion dose rate $< j >$ as a function of the tube high voltage U, emission current I = 1.0 mA

$\frac{U}{kV}$	$\frac{I_C}{nA}$	$\frac{<j>}{\mu A \cdot kg^{-1}}$
5.0	0.02	0.14
7.5	0.02	0.14
10.0	0.02	0.14
12.5	0.03	0.20
15.0	0.10	0.68
17.5	0.26	1.77
20.0	0.49	3.34
22.5	0.81	5.52
25.0	1.25	8.52
27.5	1.82	12.4
30.0	2.40	16.4
32.5	3.10	21.1
35.0	3.90	26.6

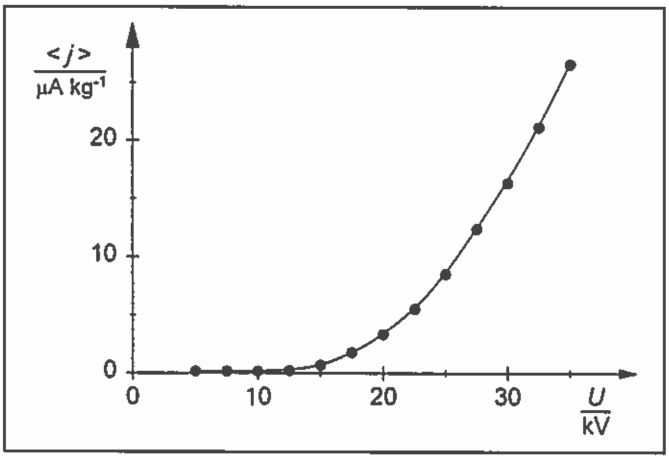


Fig. 5 Mean ion dose rate $< j >$ as a function of the tube high voltage, I = 1.0 mA

Results

At the maximum operating parameters of the x-ray tube (U = 35 kV, I = 1 mA), the mean ion dose rate in the plate capacitor is

$< j >$ = 26.6 $\mu A\ kg^{-1}$.

Additional information

In addition to the ion dose and the absorbed dose, the dose equivalent D is a further important quantity. It is measured in sieverts (Sv): 1 Sv = 1 J kg^{-1}.

A radiation with a specific dose equivalent has the same biological effect on tissues as hard x-rays generated with a voltage of 200 kV and having the corresponding absorbed dose. In x-ray and γ radiation, the absorbed dose K and the dose equivalent D are identical when K is measured in Gy and D in Sv. The conversion factor for the ion dose J is: 1 Sv ≙ 0.0308 As kg^{-1}.

The mean ion dose rate of 26.6 A kg^{-1} in the plate capacitor thus corresponds to a dose equivalent rate of 864 $\mu Sv\ s^{-1}$ resp. 3.11 Sv h^{-1}.

For comparison: in the measurements for type approval of the x-ray apparatus, a dose equivalent rate of over 10 Sv h^{-1} was measured in the radiation cone of the x-ray tube.

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Instruction sheet X-Ray Apparatus

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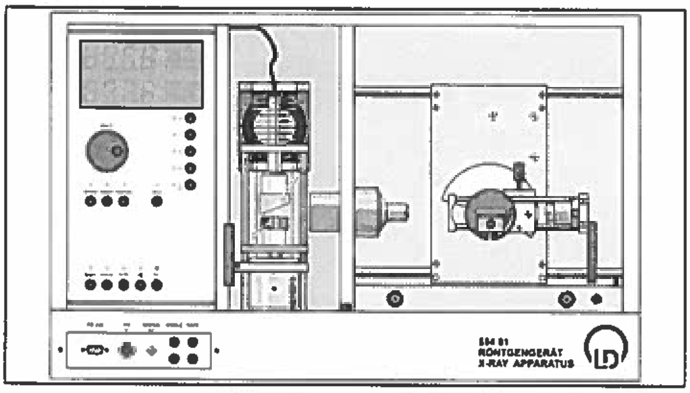


Instruction sheet 554 811

X-ray apparatus (554 811)
X-ray apparatus, without goniometer (554 812)

Radiation protection, administrative requirements

Before putting the X-ray apparatus into operation for the first time, it is your responsibility to notify all relevant authorities and obtain any permits required by the laws and regulations of your country.

The tube high voltage can only be switched on and X-rays generated when the safety circuits have been properly closed. Two mutually independent safety circuits secure the lead glass sliding doors. The maximum tube high voltage and maximum emission current are also monitored in a safety circuit.

Under the maximum operating conditions of U = 37 kV and I = 1.2 mA, which cannot be exceeded, the local dose rate at a distance of 10 cm from touchable surfaces is less than 1 µSv/h.

The X-ray apparatus thus fulfills all regulations goveming an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807 / 97 Rö).

Only the two lead glass sliding doors on the front of the X-ray apparatus may be opened. If the bottom or side plates are opened (impeded by safety screws), the type approval is void and the device may not be operated in Germany. The type approval is also void when the X-ray apparatus is repaired or manipulated in a manner not connected with the assembly of experiments in the laboratory. Repairs may only be carried out by the manufacturer, LD Didactic GmbH. The only exceptions to this are the replacement of the X-ray tube and any height adjustments of screws which are possible through holes in the bottom plate provided by the manufacturer for this purpose.

Depending on the legal requirements of your country, you may be required to maintain a history of your apparatus, analogous to the enclosed form.

Safety notes

The X-ray apparatus generates ionizing radiation which can exceed a local dose rate of 10 Sv/h in the X-ray tube's cone of radiation. This dose rate can damage living tissue even for short exposure times. The built-in protection and screening measures reduce the local dose rate outside of the X-ray apparatus to less than 1 µSv/h, a value which is on the order of magnitude of the natural background radiation. The high dose rate which is produced inside the device means that the operator must use special care when operating the X-ray apparatus.

The X-ray apparatus fulfills the safety requirements for electrical equipment for measurement, control and laboratory use according to DIN EN 61010 part 1 and is constructed so as to fulfill the requirements of protection class I. It is intended for operation in dry rooms which are suitable for electrical operating equipment or installations. When used as intended the X-ray apparatus is safe to operate.

- Keep the X-ray apparatus secure from access by unauthorized persons.
- Before putting the device into operation for the first time, check the rating plate (on rear of housing) to make sure that the mains voltage value given there agrees with the mains voltage at your location
- Inspect the housing and the control and display elements of the X-ray apparatus, particularly the lead glass panes and sliding doors as well as the lead glass tube surrounding the X-ray tube, carefully for damage before putting the device into operation.
- Also, test the two safety circuits to make sure that they are functioning properly (see section 6).

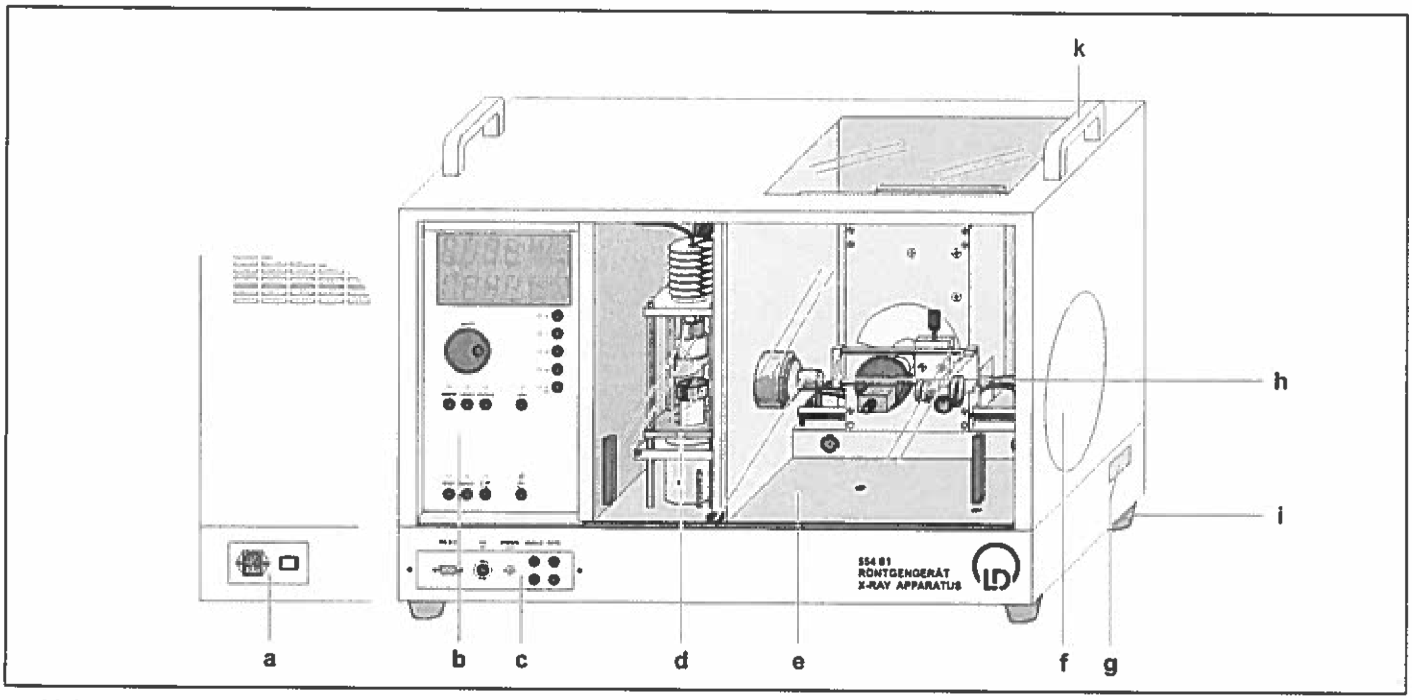
  If any faults or defects are noted, do not put the X-ray apparatus into operation. Notify your local LD Didactic GmbH *representative immediately.*
- Do not put live animals inside the X-ray apparatus.

Do not allow the anode of the X-ray tube to overheat:

- When putting the X-ray apparatus into operation, check to make sure that the ventilator in the tube chamber is turning.

Table of contents

1 Overview



a Mains power panel
b Control panel
c Connection panel
d Tube chamber (with -ray tube Mo)
e Experiment chamber (here with goniometer)
f Fluorescent screen
g Free channel
h Lock lever
I Feet
k Carrying handles

2 Description

The X-ray apparatus is a fully-featured, microprocessor-controlled device designed for conducting a wide variety of experiments in physics and related disciplines. Experiments at the boundary between physics and medicine include the transillumination of objects and observing them on a fluorescent screen or on an X-ray film, and experiments on ionization and dosimetry. In physics, the experiments range from atomic physics to solid-state physics.

You can set all parameters on the X-ray apparatus manually and read them from the digital display. The two arms of the two-circle goniometer (included with 554 811) can be controlled either individually or with 2:1 coupling, and either manually or automatically. Usually, the sensor on the sensor arm is a Geiger-Müller counter tube, while on the target arm a crystal, a scattering body or an absorber is pivoted or turned as the target. A rate meter for a Geiger-Müller counter tube (end-window counter) is also integrated. This means that you can use the X-ray apparatus as a stand-alone device, in conjunction with a computer via the built-in RS-232 interface or USB port or with an XY recorder connected.

It is possible to carry out the following experiments with the X-ray apparatus:

- Transillumination and X-ray photography
- Ionization and dosimetry
- Material-dependent and thickness-dependent attenuation of X-rays
- Continuum and characteristic lines, investigating the X-ray source
- Fine structure and shell model of the atom
- Energy-dependent absorption and K-edges
- Moseley's law and determining the Rydberg frequency
- Compton effect
- Duane-Hunt relation (determination of Planck's constant from the limit wavelength)
- Bragg reflection for determining the lattice plane spacing of various crystals
- Investigating crystal structures by means of Laue diagrams and Debye-Scherrer photographs
- X-ray diffraction analysis at polycrystalline metal foils and powder samples, texture

3 Scope of supply

a) X-ray apparatus (554 811)

1 Basic X-ray apparatus
1 X-ray tube Mo (554 82)
1 Goniometer (554 83)
1 NaCl monocrystal (554 78)
2 Quality certificates for X-ray tube and apparatus /*/
2 Copies of type approval /*/
1 Instruction sheet 554 811
1 Instruction sheet 554 82
1 Instruction sheet 554 83
1 CD-ROM "X-ray Apparatus"
1 V.24 cable, 9-pin (729 769) or
1 USB cable
1 Collimator
1 Zirconium filter
1 Protective plate
1 Dust cover
1 Allan wrench 4 mm

b) X-ray apparatus, without goniometer (554 812)

1 Basic X-ray apparatus
1 X-ray tube Mo (554 82)
2 Quality certificates for X-ray tube and apparatus /*/
2 Kopie Bauartzulassung /*/
2 Copies of type approval /*/
1 Instruction sheet 554 811
1 Instruction sheet 554 82
1 CD-ROM "X-ray Apparatus"
1 V.24 cable, 9-pin (729 769) or
1 USB cable
1 Collimator
1 Zirconium filter
1 Protective plate
1 Dust cover
1 Allan wrench 4 mm

/*/ Required for registration in Germany

4 Technical data

School X-ray apparatus with full protection, type-approved for use in Germany (NW 807 / 97)

Fulfills the more stringent limit values of European directive 96/29/Euratom dated 13 May 1996

Microprocessor control of tube high voltage, cathode current and goniometer

Tube high voltage: 0.0 ... 35.0 kV (stabilized DC voltage)

Emission current: 0.0 ... 1.0 mA

Visible X-ray tube with molybdenum anode:
K_α = 17.4 keV (71.1 pm), K_β = 19.6 keV (63.1 pm)

Fluorescent screen for transillumination experiments:
D = 15 cm

built-in rate meter:
maximum internal counting rate: 65,535 /s
maximum displayable counting rate: 9999 /s
voltage supply for Geiger-Müller counter tube: 500 V fixed
gate time for rate meter: 1 ... 9999 s

Two 4-digit displays (25 mm high) for
tube high voltage, emission current, counting rate, sensor and target angle, scanning range, angular step width or measuring time per angular step

Modes:
automatic and manual goniometer scan (sensor or target alone, 2:1 coupling),
exposure timer

Angular resolution of goniometer control: 0.1°

Angular range for goniometer control:
for target: 0° ... 360°
for sensor: -10° ... +160°

Lead-throughs:
high-voltage coaxial cable
BNC-coaxial cable
free channel for tubing, serial cable etc.

Outputs:
RS232 or USB port for data transmission to computer
analog output ANGLE proportional to scanning angle with 5 V / max. scanning angle for $\beta \geq 0°$ (accuracy: ±3%)
analog output RATE proportional to counting rate with 5 V / 10000 /s for $\beta \geq 0°$ (accuracy: ±3%)

Safety circuit:
two independent relay circuits in front doors which de-energize when door is open.

Mains voltage: see rating plate on rear of housing

Power consumption: 120 VA

Protection: see fuse rating on rear of housing

Dimensions: 67 cm × 48 cm × 34 cm

Weight: 37 kg

5 Notes on putting into operation and transporting

Users must exercise special care where the X-ray apparatus is concemed:

- Immediately after unpacking the X-ray apparatus, inspect it for transportation damage and check to make sure that the delivery is complete (see section 3).

  If the X-ray apparatus appears to be damaged in spite of the special packing, do not put the apparatus into operation! Notify your local LD Didactic GmbH *representative immediately.*
- Test the safety circuits for proper function each time before putting the device into operation (see section 6).

Only transport the X-ray apparatus in its special packing and on a pallet.:

- We recommend that you retain the original packing for this purpose.
- Dismantle the collimator and pack it in separate packing for the shipment.
- Screw the goniometer tight if necessary.

6 Testing the function of the safety circuits

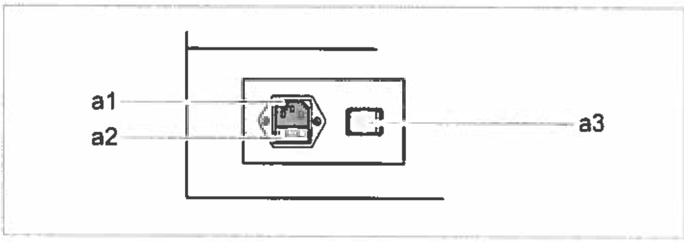
Test the function of the safety circuits as follows each time before putting the X-ray apparatus into operation:

- Connect the X-ray apparatus to the mains supply and switch it on (see section 7).
- Close and lock the lead glass sliding doors.
- Set the emission current I = 1 mA and the tube high voltage U = 5 kV (see section 7)
- Actuate the HV ON/OFF key and check whether the high-volt-age indicator lamp above this switch flashes and the cathode of the X-ray tube illuminates.
- Press down the lock button between the two lead glass sliding doors and check whether the cathode heating is cut off (heating filament is no longer luminous).
- One after another, open the lead glass sliding doors to the tube chamber and the experiment chamber, each time checking whether the high voltage indicator lamp goes out.

  If any error occurs during this procedure, shut down the X-ray apparatus and do not operate it further. Notify your local LD Didactic GmbH *representative immediately.*

7 Components

a) Mains power panel:

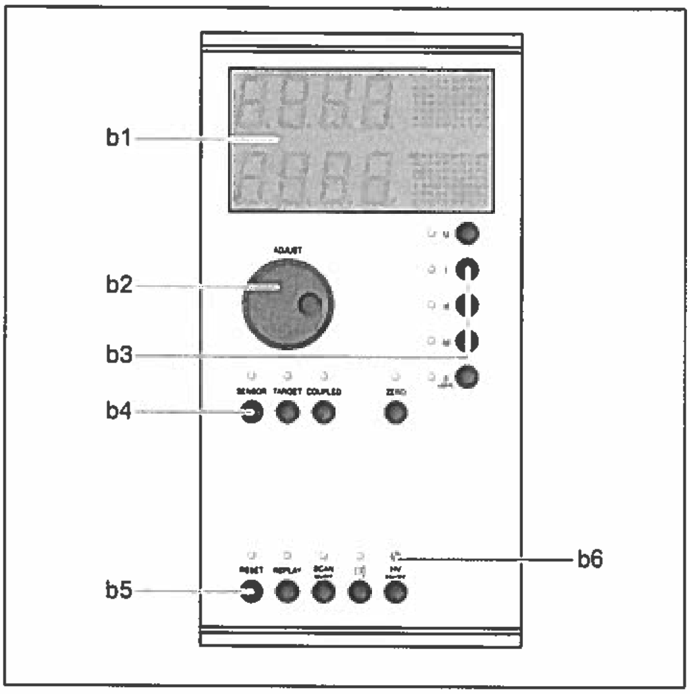


a1 Appliance connector
a2 Fuse holder
a3 Mains power switch

b) Control panel:

The X-ray apparatus is controlled using a number of keys to set the parameters and select the operating mode, a knob for setting the desired value of the selected parameter and a display panel which shows the set value. For each pushbutton, an LED indicates the corresponding parameter selection.

Depending on the respective state of the X-ray apparatus it is not possible to actuate all keys at all times. In particular, some keys have no function when the goniometer (554 83) is not mounted.



b1 Display field
b2 Knob
b3 Parameter selector keys
b4 Scan-mode keys
b5 Operational keys
b6 High-voltage indicator lamp

b1) Display panel:

Top display field:

shows the current counting rate
(number height: 25 mm, unit of measure: LED dot matrix)

Bottom display field:

shows the quantity selected using a key
(number height: 25 mm, unit of measure: LED dot matrix)

In "coupled" scanning mode, the angular position of the target appears in the bottom display field; the top display field can be toggled between the counting rate and the angular position of the sensor by pressing the COUPLED key.

b2) ADJUST knob:

enables you to set the desired values.

This incremental control element can be turned in both directions and has a dynamic response, i.e. the values change by greater increments when the knob is turned rapidly. The apparatus accepts the displayed values when a key is pressed.

b3) Parameter selector keys:

Key U:

activates display and setting of the tube high voltage *U*.

Value range: 0.0-35.0 kV
Step width: 0.1 kV
Default: 5.0 kV

The set value is displayed regardless of whether the tube high voltage is switched on (see keys SCAN ON/OFF and HV ON/OFF).

Key I:

activates display and setting of the emission current *I*.

Value range: 0.00-1.00 mA
Step width: 0.01 mA
Default: 0.00 mA

The set value is displayed regardless of whether the emission current is flowing.

Key Δt:

activates display and setting of the measuring time (per angular step) Δ*t*.

Value range: 1-9999 s
Step width: 1 s
Default: 1 s

Key Δβ:

when the goniometer (554 83) is mounted, this activates the display and setting of the angular step width Δβ for auto-scan mode.

Value range: 0.0°-20.0°
Step width: 0.1°
Default: 0.1°

The setting Δβ = 0.0° deactivates auto-scan mode and activates "exposure-timer" mode.

Key β LIMITS:

when the goniometer (554 83) is mounted, this activates the display and definition of the upper and lower limit angles for auto-scan mode. A measurement cannot be started when the upper limit is less than the lower limit. The display flashes until this situation is corrected.

The first time this key is pressed, the display panel shows the symbol .↓.. You can now set the lower limit angle.

The second time this key is pressed, the display panel shows the symbol ·↑·. You can now set the upper limit angle.

The symbol ↕ in the display panel indicates the setting Δβ = 0.0°. Auto-scan mode is deactivated.

b4) Scanning-mode keys:

Key SENSOR:

when the goniometer (554 83) is mounted, this key activates "sensor" scanning in auto-scan or manual scan modes.

You can define the limit angles of the sensor arm for auto-scan. Sensor arm movement can be controlled manually or automatically. The bottom display field shows the angular position of the sensor.

Key TARGET:

when the goniometer (554 83) is mounted, this key activates "target" scanning in auto-scan or manual scan modes.

You can define the limit angles of the target arm for auto-scan. Target arm movement can be controlled manually or automatically. The bottom display field shows the angular position of the target.

Key COUPLED:

when the goniometer (554 83) is mounted, this key activates "coupled" scanning in auto-scan or manual scan modes. You can define the limit angles of the target arm for auto-scan.

The sensor and target arms can be moved manually or automatically with an angular coupling of 2:1. In manually controlled movement, the reference point for the 2:1 coupling is the angular position of the target and the sensor before the COUPLED key is pressed, and for automatic movement the reference point is the zero point of the measuring system.

The bottom display field shows the angular position of the target. Pressing the COUPLED key toggles the upper display field between the counting rate and the angular position of the sensor.

Key ZERO:

when the goniometer (554 83) is mounted, this key causes the target and sensor arms to move to the zero position of the measuring system (see instruction sheet of the goniometer).

b5) Operational keys:

Key RESET:

when the goniometer (554 83) is mounted, this key causes the target and sensor arms to move to the zero position of the measuring system and resets all parameters to the default settings.

The tube high voltage is switched off.

Key REPLAY:

activates readout of the stored measured values.

The angular positions set manually using the ADJUST knob and the respectively corresponding counting rates averaged over the measuring time Δt are displayed in the display field and output via the RS-232 serial interface or USB port. The corresponding voltages are output at the sockets labeled ANGLE and RATE.

When the goniometer (554 83) is mounted, the position of the goniometer arms remains unchanged.

You can access the measured values as often as you like, as long as the RESET or SCAN keys are not pressed and the X-ray apparatus is not switched off.

Key SCAN ON/OFF:

switches the tube high voltage on and activates the measuring program (provided that the safety circuit is closed). The measured values are stored internally in the device.

This key can for $\Delta\beta > 0.0°$ (auto-scan mode) only be actuated with defined goniometer (key functions SENSOR, TARGET or COUPLED) or for $\Delta\beta = 0.0°$ (exposure-timer mode).

In auto-scan mode, the device first travels to the zero position of the measuring system and then to the lower limit angle. The tube voltage is then switched on. The scan starts as soon as the tube high voltage is present and an emission current is flowing. The starting and end points are the upper and lower limit angles set with β LIMITS.

In "exposure timer" mode, the tube high voltage is switched on. Once the tube high voltage is present and the emission current is flowing, the stopclock counts backward to indicate the remaining exposure time.

Key 🔈:

toggles the acoustic pulse indicator for the sensor on and off.

Key HV ON/OFF:

switches the tube voltage on and off.

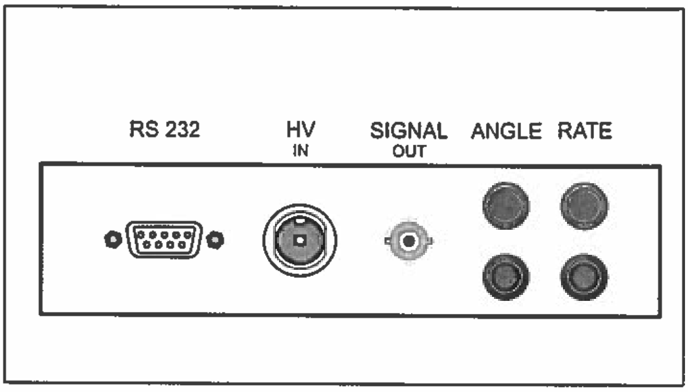
The tube high voltage can only be switched on when the safety circuits are closed.

b6) High voltage indicator lamp:

flashes when the tube high voltage is switched on.

The tube high voltage can be switched on using either the SCAN or HV ON/OFF key.

c) Connection panel:



RS-232 or USB output:

9-pin sub-D serial connector or USB port.

The interface is electrically (optoelectronically) isolated from the X-ray apparatus. The apparatus is connected to a computer via the supplied cable.

Input HV IN:

High voltage input, connected with high voltage output HV OUT in the terminal bracket of the experiment chamber.

The high voltage input enables e.g. experiments with a Geiger-Müller counter tube connected to an external counter.

Output SIGNAL OUT:

BNC output, connected with the BNC input SIGNAL IN of the terminal bracket of the experiment chamber.

BNC output enables e.g. experiments using sensors with BNC connector.

Output ANGLE:

Analog output for connecting an XY-recorder.

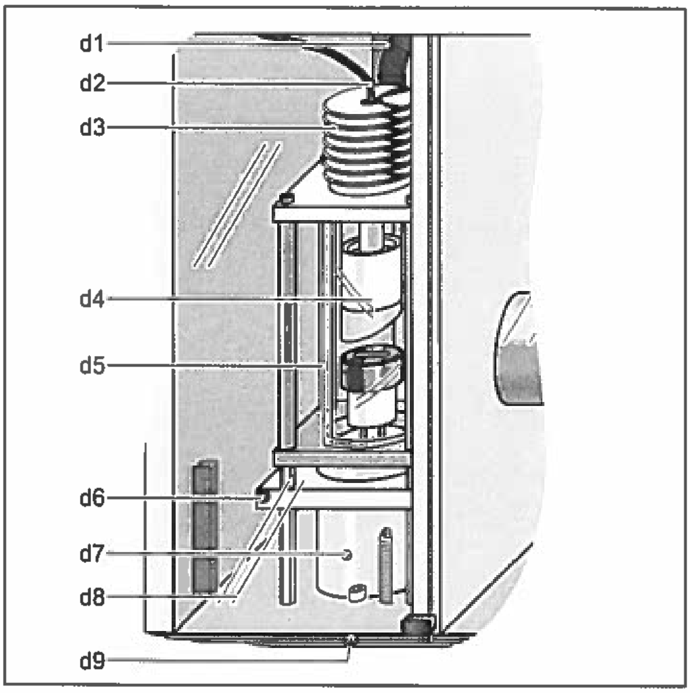
When the SCAN or REPLAY key is pressed, an angle-proportional voltage of 5 V / max. scanning angle is output for the target arm of the goniometer.

Output RATE:

Analog output for connecting an XY-recorder.

When the SCAN or REPLAY key is pressed, a voltage proportional to the counting rate is output with an amplitude of 0.5 V / 1000 /s.

d) Tube chamber:



d1 Ventilator
d2 High-voltage cable
d3 Heat sink
d4 X-ray tube
d5 Lead glass tube
d6 Clamping screw
d7 Tube socket with arresting screw
d8 Lead glass sliding door
d9 Height-adjustment screw (in bottom of X-ray apparatus)

The tube chamber accommodates the X-ray tube and serves as shielding for the X-ray tube.

Also during operation the X-ray tube is visible through the lead glass sliding door and the lead glass tube which surrounds the X-ray tube. This makes it possible e.g. to observe the change in the cathode temperature when the cathode current is varied.

Mounting and demounting the X-ray tube:

Do not remove the lead glass tube from the tube chamber. The mounting screws of the tube are compound-filled to prevent this.

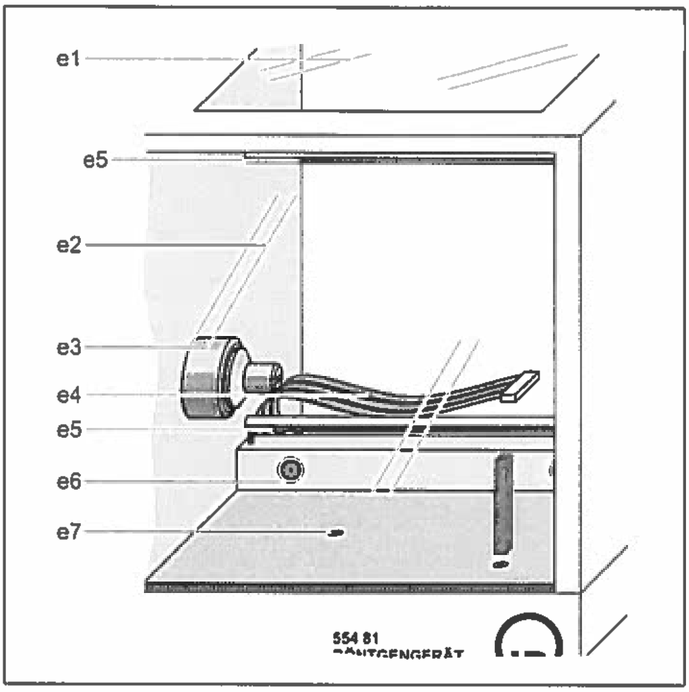
- Never loosen the mounting screws.

see instruction sheet of the X-ray tube Mo (554 82) or of the X-ray tube Cu (554 85).

Height adjustment of the x-ray tube:

see instruction sheet of the X-ray tube Mo (554 82) or of the X-ray tube Cu (554 85).

e) Experiment chamber:



e1 Collimator mount
e2 Guide rails
e3 Ribbon cable with connector
e4 Terminal bracket
e5 Mounting sockets
e6 Lead glass window
e7 Lead glass sliding door

The experiment chamber is designed to accommodate experiment equipment such as the goniometer (554 83), the film holder X-ray (554 838) or the plate capacitor X-ray (554 840), which all fit the mounting sockets.

The experiment equipment can be observed during the experiment directly through the lead glass sliding door in front of the experiment chamber and the lead glass pane above it.

Terminal bracket:

Input GM TUBE INTERNAL RATE METER:

coaxial socket for connecting an end-window counter (559 01).

Output HV OUT:

high-voltage output, connected with the high-voltage input HV IN in the connection panel.

The high voltage output enables e.g. experiments with a Geiger-Müller counter tube connected to an external counter.

Input SIGNAL IN:

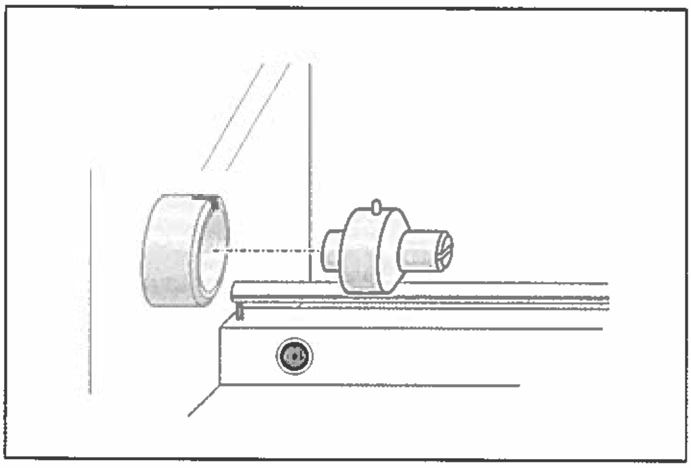
BNC input, connected with the BNC output SIGNAL OUT on the connection panel.

The BNC input enables e.g. experiments using sensors with BNC connector.

Mounting the goniometer:

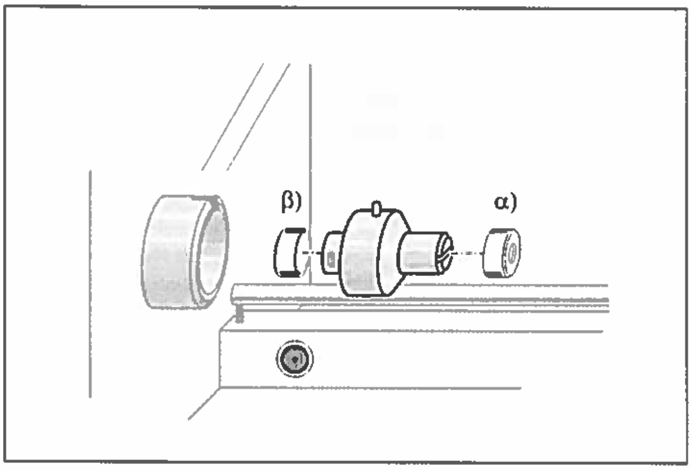
see instruction sheet of the goniometer (554 83).

Mounting the collimator:



- Turn the collimator so that the guide pin is lined up with the corresponding groove of the collimator seat and the collimator slit is vertical.
- Slide in the collimator until the ball of the pin snaps into the groove of the collimator seat.

Attaching the zirconium filter:



α) In most cases:

- plug the zirconium filter onto the collimator

β) When using the Compton accessory X-ray (554 836):

- Demount the collimator.
- Place the zirconium filter on the front end of the collimator.
- Remount the collimator together with the zirconium filter.

f) Fluorescent screen:

The fluorescent screen is a lead glass pane that is coated with a fluorescent material, and forms a radiation-tight seal of the experiment chamber; it serves as a simple proof of X-rays, e.g. in transillumination experiments using objects with different absorption characteristics. The "direct observation" of the incident X-rays is made possible through stimulation of luminescence phenomena. The diameter has been dimensioned so that the fluorescent screen is fully illuminated when the collimator is de-mounted.

Always be sure to attach the enclosed cover to the fluorescent screen to protect the fluorescent layer from ambient light.

g) Free channel:

The free channel is a conduit between the experiment chamber and the outside of the housing. In terms of radiation protection technology it is designed as a labyrinth, so that the experiment chamber can remain accessible even when the lead glass sliding door is closed and the X-ray tube is switched on.

The rectangular cross-section of the free channel (60 mm × 20 mm) allows you to lay e.g. a cable with 25-pin sub-D plug or a pump hose for evacuating an ionization chamber.

h) Lock lever:

must be depressed in order to open the properly closed lead glass sliding doors.

Pressing the lock lever switches off the emission current.

i) Feet:

Once it is unpacked from the original transport packing, the X-ray apparatus must always be set up on so that it rests only on its feet.

k) Carrying handles:

When not in its original packing, the X-ray apparatus can only be transported by its carrying handles.

8 Recording and evaluating measurement data

a) Rate measurements:

The X-ray apparatus internally generates a high voltage for a Geiger-Müller counter tube (end-window counter), counts its pulses continuously and displays these in the display panel every second as the counting rate 1/s (independently of the set measuring time Δt). When no counter tube is connected, the display reads 0.

Pressing the SCAN key causes the de-vice to store all measured counting rates in the internal memory.

b) Data output during scanning:

The angular position of the goniometer arm set in scan mode and the counting rate are shown in the display panel of the X-ray apparatus. The angular reading is updated for each new angular position of the goniometer arm and the counting rate is updated every second.

The output sockets ANGLE and RATE output voltages proportional to the angle and the counting rate respectively to permit the use of a chart recorder. The voltages change on each expiration of the set measuring time Δt per angular step. The voltage at the RATE output corresponds to the mean value of the counting rate over the measuring time Δt.

c) Data readout after scanning:

Once a scan is completed, you can display the entire contents of the measured-value storage using the REPLAY key. You can do this by using the ADJUST knob to manually set all angular positions of the goniometer arm set in scan mode.

The display panel shows the angular position and the counting rates averaged over the measuring time Δt per angular step. Proportional voltages are output via the output sockets ANGLE and RATE.

d) Recording data with the software "X-ray apparatus":

You can display and evaluate the data stream via the serial interface or the USB port using the software "X-ray apparatus" supplied with the device. To install the software, you need a computer on which Windows 95/NT or higher is properly installed. The program contains detailed help on the use of all functions, as well as numerous useful hints and experiment notes. You can access this help with F1 after starting the program, and print it out if desired.

The program SETUP.EXE on the enclosed CD-ROM prompts you to specify the preferred user-interface language and installation directory, and then installs the software automatically. After installation is complete, the software can be found in the "Start" menu under "Programs" → "X-ray Apparatus". You can uninstall the software at any time using the Software icon in the Control Panel. All future software updates (enhancements, patches) will be made available as they appear free of charge on our website http://www.ld-didactic.com.

After starting the software, press F5 ("Settings" → "General") to change the serial interface. You can also use this tab to change the language of the user interface at any time.

If the error message "X-ray apparatus not found" appears when the software starts, this may be due to one of the following reasons:

- the X-ray apparatus is switched off.
- the cable between the X-ray apparatus and the computer is not properly connected.
- the wrong serial interface has been defined.
- the REPLAY key is pressed.

e) Recording data with alternative software:

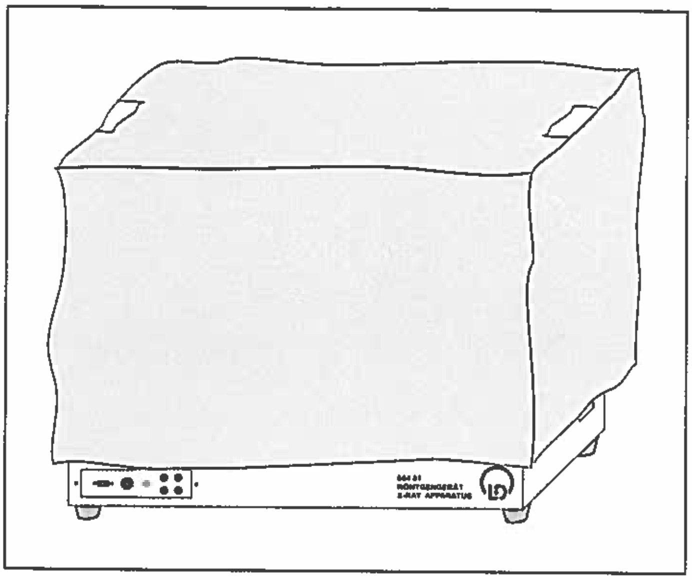
All usual programming languages can access the x-ray apparatus via XRayAPI.DLL (Windows) or libxrayapi.so (Linux). For this XRayAPI.DLL or libxrayapi.so has to be included and called. The necessary declarations for C/C++ are contained in XRayAPI.H. All three files are also contained in our free Developer Information from the Internet (http://www.ld-didactic.com).

Our LabVIEW driver for the x-ray apparatus is also free available on the Internet. In addition to the VIs (Virtual Instruments) for driving the x-ray apparatus, the driver also contains application examples.

LabVIEW is a registered trademark of National Instruments.

9 Care and maintenance

a) Storing the apparatus:

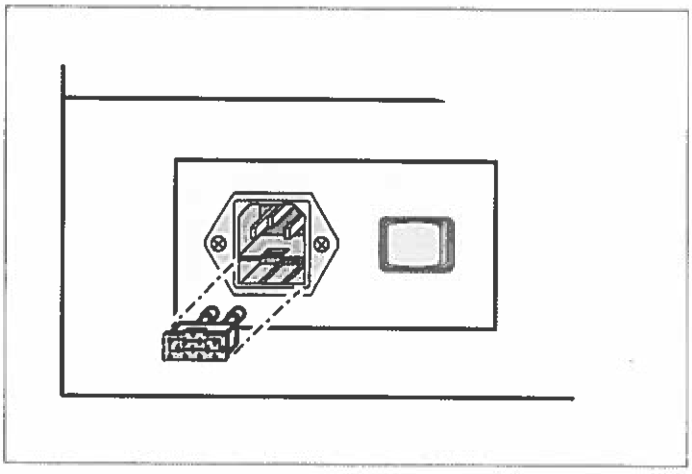


- Always attach the cover to protect the luminescent coating of the fluorescent screen from ambient light.
- Always cover the X-ray apparatus with the enclosed dust cover when storing for longer periods.

b) Cleaning:

- Clean all glass surfaces of the X-ray apparatus using only a mild glass cleaner (lead glass is very soft and sensitive to scratching).
- Do not clean the enameled surfaces of the X-ray apparatus with aggressive cleaning agents.

10 Changing the fuse



- Pry out the fuse holder.
- Check the reserve fuse for the correct rating (see technical data) and replace the defective fuse with the reserve fuse.
- Reinsert the fuse holder.

11 Operating and experimenting with the device

a) Putting the X-ray apparatus into operation:

- Connect the X-ray apparatus to the mains and switch it on.
- Press the key U.
- Use the ADJUST knob to set e.g. U =20 kV:

  The display panel shows the set value.
- Press the key I
- Use the ADJUST knob to set e.g. I =1.00 mA:

  The display panel shows the set value.
- Check to make sure that the lead glass sliding doors are properly closed, then press the HV ON/OFF key:

  The high voltage indicator starts flashing and the hot cathode of the X-ray tube becomes luminous. The system is now generating X-rays.
- Press the key I and use the ADJUST knob to vary the emission current I.

  The brightness of the hot cathode changes.

b) Selecting the measuring parameters:

- Press key U, I, Δt, Δβ or β LIMITS.
- Set the desired value with the ADJUST knob.

  The set value appears in the display field.
- Press any key to terminate parameter setup.

c) Manually positioning the goniometer arms:

The goniometer is positioned solely by means of electric stepper motors:

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

Either:

- Press SENSOR or TARGET.
- Set the desired value with the ADJUST knob.

  The set value appears in the display panel, the sensor or target arm moves to the desired angular position.

or:

- Press the key COUPLED.
- Set the desired target value with the ADJUST knob.

  The set value appears in the display panel, the target arm moves to the desired angular position and the sensor arm automatically moves with twice the set angular step width.

  Note: "Sensor angle = 2 × target angle" is only true when the setup was previously set to the zero position of the measuring system with the ZERO key or in the auto-scan mode.

d) Experiments with the fluorescent screen:

Experiments with the fluorescent screen provide an introduction to the linear propagation of x-rays. In addition, it is possible to observe the effect of the parameters emission current and tube high voltage on the brightness and contrast of the screen image.

- Carry out all experiments in a darkened room.
- Remove the protective cover from the fluorescent screen and demount the collimator.
- To obtain a sharp image, place the object to be transilluminated directly in front of the fluorescent screen; place the object in the ray path at a distance from the fluorescent screen to obtain an enlarged image.
- Close the lead glass sliding door of the X-ray apparatus.
- Set the desired values for the measuring parameters *I* and *U* and switch on the tube high voltage using the HV ON/OFF key.
- Vary the measuring parameters *I* and *U*.
- Replace the protective cover plate when the experiment is finished.

e) "Exposure timer" mode:

As the name implies, "exposure timer mode" lets you set e.g. the exposure times for X-ray films or the measuring time for measurements of individual counting rates.

- Mount the desired accessories (e.g. goniometer and sensor or film holder X-ray).
- Steer the sensor or target arm of the goniometer into position manually as necessary using the ADJUST knob.
- Vary the measuring parameters *I* and *U*.
- Set the angular step width $\Delta\beta = 0.0°$.
- Set the desired measuring time Δt.
- Start the measurement with the SCAN key:

  The measuring time remaining counts down to zero on the display panel. The target and sensor arms remain in the selected position.
- When the measuring time expires, press the REPLAY key.

  The display panel shows the counting rate averaged over the measuring time Δt.

f) Auto-scan mode:

In auto-scan mode, the goniometer arms move automatically when the SCAN key is pressed. You can choose between the scan modes "Target", "Sensor" or "Coupled".

During the scan the apparatus displays the current counting rate and the target position, or alternatively the sensor and target positions in coupled scanning mode (see COUPLED key). The X-ray apparatus additionally stores all measured values (angles and counting rates).

- To select scan mode, press TARGET, SENSOR or COUPLED.
- Press the β-LIMITS key and set the lower scan limit using the ADJUST knob.
- Press the β-LIMITS key again and set the upper scan limit using the ADJUST knob.
- Select the measuring parameters *I* and *U*.
- Select the angular step $\Delta\beta$.
- Set the desired measuring time per angular step Δt.
- If desired, connect a computer via the RS-232 serial interface or USB port and start the program "X-ray apparatus".
- Start the automatic scan with the SCAN key.
- If desired, press REPLAY and browse through the stored measurement data for each angular step using the ADJUST knob.

g) Manual scan mode:

In manual scan mode, the goniometer arms are positioned manually using the ADJUST knob. You can choose between the scan modes "Target", "Sensor" or "Coupled".

- To select scan mode, press key TARGET, SENSOR or COUPLED.
- Select the measuring parameters *I* and U.
- Set the measuring time per angular step $\Delta t = 1$.
- Where appropriate, connect a computer via the RS-232 serial interface or USB port and start the program "X-ray apparatus".
- Steer the goniometer arm into the desired position manually using the ADJUST knob.
- Wait for about two seconds until the counting rate for the new angular position appears in the display panel, then note the counting rate.

Note: For lower counting rates, such as occur in Bragg reflection for higher diffraction orders, an exposure timer can be activated for each angular position to enable more precise determi-nation of counting rates. In this case, you need to press the REPLAY key after expiration of the measuring time for each angular position in order to display the counting rate. However, this procedure is time-consuming.

h) Bragg reflection at an NaCl crystal:

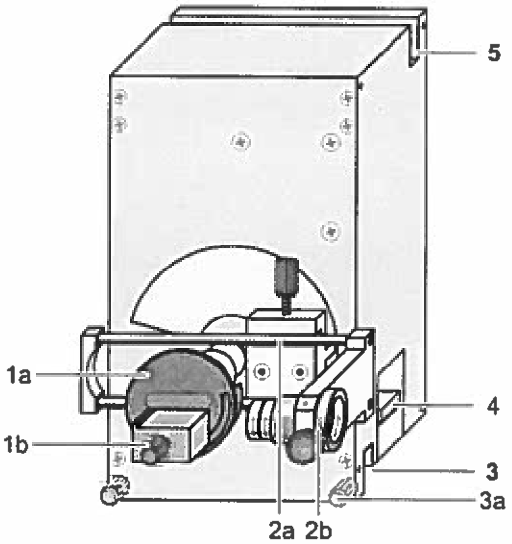
- Mount the collimator.
- Mount the goniometer (554 83) completely.
- Mount the end-window counter (559 01) as the sensor.
- Mount the NaCl crystal for Bragg reflection (554 78) as the target.
- Restore the setup to the zero position of the measuring system.
- Select the measuring parameters *U*, *I*, Δt and $\Delta\beta$:
  (e.g. U = 35.0 kV , I = 1.0 mA, Δt = 10 s and $\Delta\beta = 0.1°$).
- Press the key COUPLED.
- Set the upper and lower target limit angles to the desired values (e.g. 2.5° and 30°)
- Connect the X-ray apparatus to a computer via the RS-232 interface or USB port and start the software "X-ray Apparatus".
- Press SCAN to start recording.

viii

Instruction sheet Goniometer

Lehr– und Didaktiksysteme
LD Didactic GmbH
Leyboldstrasse 1 · D-50354 Huerth

06/05-W97-Sel



Instruction sheet 554 831

Goniometer (554 831)

1 **Target arm**
with target holder (1a), target stage (1b
2 **Sensor arm**
with sensor holder (2a), sensor seat (2b)
3 **Bottom guide groove**
with knurled screws (3a)
4 **Terminal pin connector**
5 **Top guide groove**

1 Description

The goniometer is a self-contained unit for mounting in the X-ray apparatus and is included in the scope of supply of the X-ray apparatus (554 811). It is equipped with two independently controllable stepping motors which move the sensor and target arms. The motion is defined using the keys in the control panel of the X-ray apparatus and initiated manually with the ADJUST knob or automatically with the SCAN key (see instruction sheet of the X-ray apparatus).

The target stage can accommodate e.g. the LiF crystal for Bragg reflection (554 77), the NaCl crystal for Bragg reflection (554 78), the aluminum scattering body from the Compton accessory X-ray (554 836) or other samples.

The entire goniometer unit can be shifted within the experiment chamber. The length of the sensor arm is variable, so that the angular resolution can be altered for the slit of the sensor.

Note

The goniometer is positioned solely by means of electric stepper motors:

- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

2 Technical data

Working principle:	stepping motors for target and sensor arms, which can be electronically coupled
Angular resolution:	0.1°
Angular range of target:	unlimited
Angular range of sensor:	approx. -10° to 170°
Sensor arm:	
Length of sensor arm:	approx. 40-110 mm
Width of sensor slit:	1 mm
Target stage:	
Sample clamping width:	3-9 mm
Area of platform:	25 mm x 28 mm
General data:	
Dimensions:	13.5 cm × 22.5 cm × 12.5 cm
Weight:	3 kg

3 Zero position of the measuring system

Warning: Each time the zero position of the measuring system is changed the old values of the zero position are overwritten in the microprocessor memory by the new values

The zero position of the goniometer measuring system is determined by arm movement toward two light barriers with subsequent step correction. The correction values with reference to the position of the light barriers are stored in the X-ray apparatus.

You can adjust the zero position of the measuring system most precisely using the experiment "Bragg reflection"; the adjustment is then with reference to the lattice planes of the monocrystal.

Additionally required:

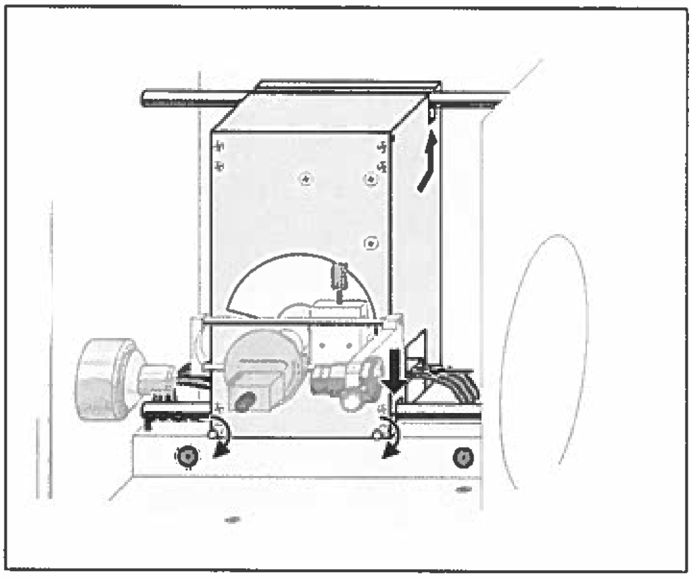
1 End-window counter for a, b, γ radiation and x-rays	559 01
1 NaCl crystal for Bragg reflection (in scope of supply of 554 811)	554 78

- Press the ZERO key to return the target and sensor arms to the current zero position.
- Mount the NaCl crystal and the end-window counter (see below).
- In coupled scanning mode, set the target to about 7.2° using the ADJUST knob.
- Set the tube high voltage U = 35.0 kV and emission current I = 1.00 mA and switch on the tube high voltage with HV ON/OFF.
- Switch between sensor and target scanning modes and locate the maximum counting rate for the first reflection maximum of the NaCl monocrystal under manual control .
- In coupled scanning mode, move the target back by 7.2° (even if this takes you into the negative range!).
- Save the positions of the target and the sensor as the "zero position of the measuring system" by pressing TARGET, COUPLED and β LIMITS simultaneously.
- To verify your adjustments, assume the angle 7.2° in coupled scanning mode and check the maximum counting rate.

Note:

It is easier to adjust the zero position of the measuring system with the help of the software "X-ray Apparatus". Please select "Settings", "Crystal Calibration" in the software and follow the instructions on the screen.

4 Mounting and demounting



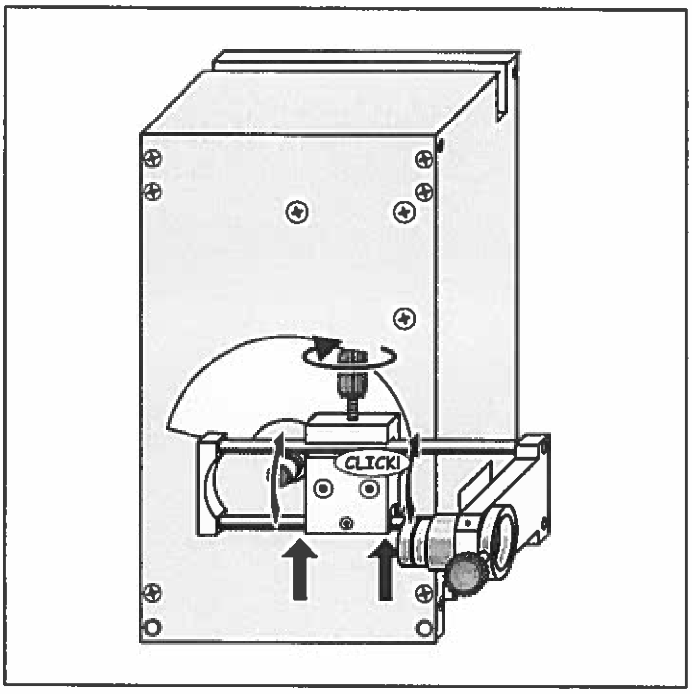
Mounting:

- Mount the target and sensor holders, if this has not already been done.
- Lay the ribbon cable of the X-ray apparatus out flat and to the right behind the bottom guide rod in the experiment chamber.
- Screw off the knurled screws of the bottom guide groove.
- Set the top guide groove over the top guide rod.
- Pivot the bottom section of the goniometer onto the bottom guide rail of the X-ray apparatus, raise the goniometer and place it in the assembly so that the bottom guide rod slides into the bottom guide groove of the goniometer.
- Slide the goniometer in the experiment chamber to the left and plug the ribbon cable into the connector of the goniometer (check to make sure that the polarity-reversal protectors line up).
- Slide the goniometer to the desired distance from the collimator, insert the knurled screws of the bottom guide slot and tighten them.
- Mount the sensor.

Demounting:

- Remove the sensor from its seat.
- Screw off the knurled screws of the bottom guide groove of the goniometer.
- Slide the goniometer in the experiment chamber to the left and unplug the ribbon cable from the connector on the goniometer.
- Manually steer the sensor arm of the goniometer to the 0° position.
- Lift the goniometer until it touches the top guide rod, lift the bottom section of the goniometer forward and lower it until the upper section of the goniometer can also be lifted forward.

5 Mounting/ demounting the sensor holder



Mounting:

- Remove the target holder.
- Loosen the knurled screw on the sensor arm.
- First insert the bottom guide rail of the sensor holder in the bottom groove of the sensor arm and then insert the top guide rail into the top groove until it snaps in.
- Set the desired distance between the target and the sensor and then fix the sensor holder in position with the corresponding knurled screw.

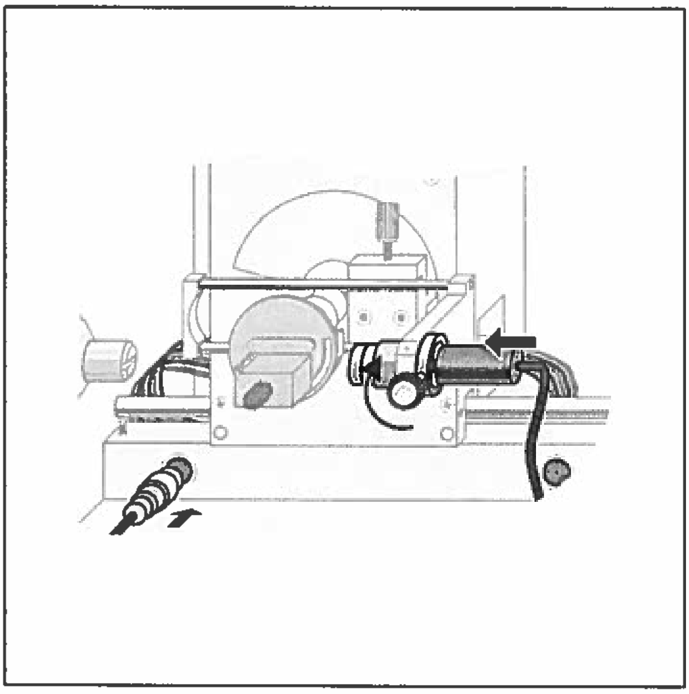
Demounting:

- Remove the sensor.
- Remove the target holder.
- Loosen the knurled screw on the sensor arm.
- Lift the top guide rail of the sensor holder out of the top groove of the sensor arm and lower the sensor holder.

Adjusting the sensor arm:

- Loosen the knurled screw on the sensor arm.
- Set the desired distance between the target and the sensor and then fix the sensor holder in position with the corresponding knurled screw.

6 Inserting a sensor



- Slide the goniometer to the left in the experiment chamber as necessary.
- Loosen the knurled screw at the sensor seat.
- Remove the cover cap from the end-window counter, carefully insert the counter in the sensor seat from the rear as far as it will go and then tighten the knurled screw.
- Press the SENSOR key and use the ADJUST knob to check that the sensor holder can move freely in the angular range you wish to investigate.

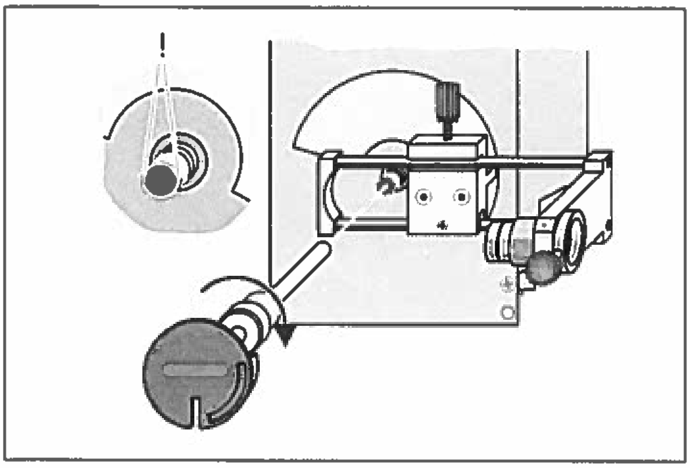
When using the internal rate meter:

- Connect the lead of the counter tube to the socket marked GM TUBE in the experiment chamber.

When using an external counter:

- Connect the counter tube lead to the socket marked HV OUT in the experiment chamber and connect the socket HV IN on the connector panel of the X-ray apparatus to the external counter.

7 Mounting/ demounting the target holder



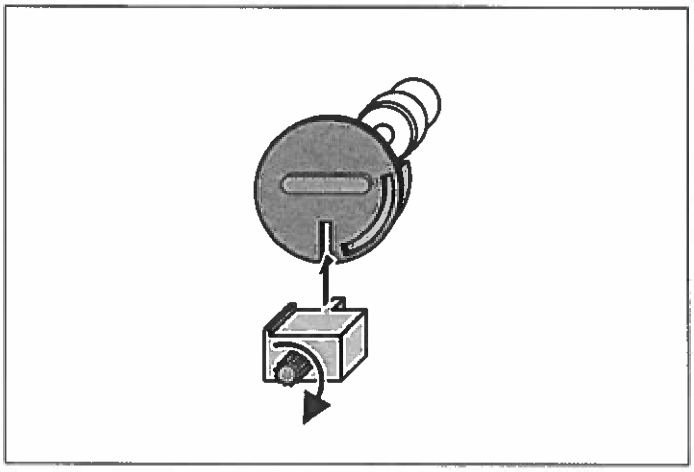
Mounting:

- Mount the goniometer and position the target arm of the goniometer horizontally with the ZERO key (the V-shaped groove in the bushing of the target arm must be vertical).
- Insert the axle of the target holder into the bushing of the target arm so that the cotter pin of the axle slides into the V-shaped groove of the bushing.
- Tighten the union nut of the target holder finger-tight.

Demounting:

- First remove the target, e.g. monocrystal, if one has been set up (see below).
- Loosen the union nut of the target holder.
- Pull the axle of the target holder forward out of the bushing of the target arm.

8 Mounting/ demounting the target stage



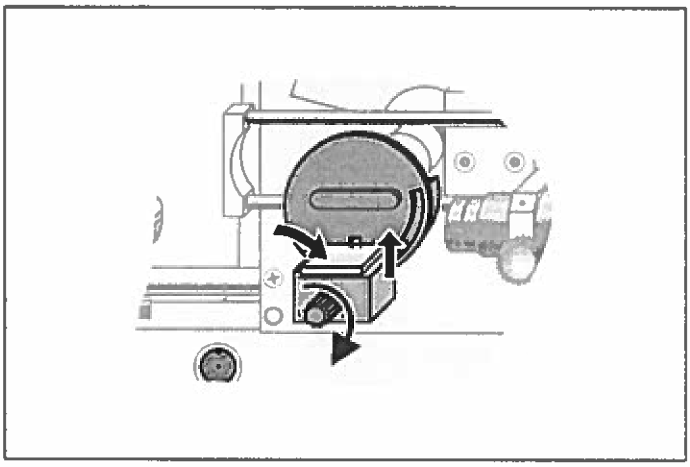
Mounting:

- Loosen the knurled screw on the target stage.
- Insert the plastic guide in the groove of the target holder from below and raise the target stage as far as it will go.
- Tighten the knurled screw finger-tight.

Demounting:

- First remove the target (see section below).
- Loosen the knurled screw on the target stage and pull the target stage downward out of the groove of the target holder.

9 Setting up a target



- Position the target and sensor arms of the goniometer horizontally using the ZERO key.
- Loosen the knurled screw of the target stage and lower the platform slightly.
- Lay the target (e.g. NaCl crystal or aluminum scattering body) flat on the target stage and push it backwards against the back stop.
- Raise the target stage with the target up against the stop edge and tighten the knurled screw finger-tight.
- Carefully check that the target is held firmly.