

Characteristic X-rays of copper (Item No.: P2540101)

Curricular Relevance



Difficulty



Difficult

Preparation Time



1 Hour

Execution Time



2 Hours

Recommended Group Size



2 Students

Additional Requirements:

- PC

Experiment Variations:

Keywords:

X-ray tubes, bremsstrahlung, characteristic X-radiation, energy levels, crystal structures, lattice constant, absorption of X-rays, absorption edges, interference, Bragg's law

Overview

Short description

Principle

An X-ray tube with a copper anode generates X-radiation that is selected with the aid of a monocrystal as a function of the Bragg angle. A Geiger-Müller counter tube measures the intensity of the radiation. The glancing angles of the characteristic X-ray lines are then used to determine the energy.



Fig. 1:P2540101

Equipment

Position No.	Material	Order No.	Quantity
1	XR 4.0 expert unit, X-ray unit, 35 kV	09057-99	1
2	XR 4.0 X-ray goniometer	09057-10	1
3	XR 4.0 X-ray Plug-in Cu tube	09057-51	1
4	Geiger-Mueller counter tube, 15 mm (type B)	09005-00	1
5	XR 4.0 X-ray LiF crystal, mounted	09056-05	1
6	XR 4.0 potassium bromide (KBr) crystal	09056-01	1
7	XR 4.0 Software measure X-ray	14414-61	1
8	Data cable USB, plug type A/B, 1.8 m	14608-00	1
9	XR 4.0 X-ray Diaphragm tube d = 2 mm	09057-02	1

Tasks

1. Analyse the intensity of the copper X-radiation as a function of the Bragg angle and with the aid of a LiF monocrystal.
2. Analyse the intensity of the copper X-radiation as a function of the Bragg angle and with the aid of a KBr monocrystal.
3. Determine the energy values of the characteristic X-rays of copper and compare them with the values that were determined based on the corresponding energy-level diagram.

Setup and Procedure

Setup

Connect the goniometer and the Geiger-Müller counter tube to their respective sockets in the experiment chamber (see the red markings in Fig. 2). The goniometer block with the analyser crystal should be located at the end position on the right-hand side. Fasten the Geiger-Müller counter tube with its holder to the back stop of the guide rails. Do not forget to install the diaphragm in front of the counter tube (see Fig. 3). Insert a diaphragm tube with a diameter of 2 mm into the beam outlet of the tube plug-in unit.

For calibration: Make sure, that the correct crystal is entered in the goniometer parameters. Then, select "Menu", "Goniometer", "Autocalibration". The device now determines the optimal positions of the crystal and the goniometer to each other and then the positions of the peaks.



Fig. 2: Connectors in the experiment chamber

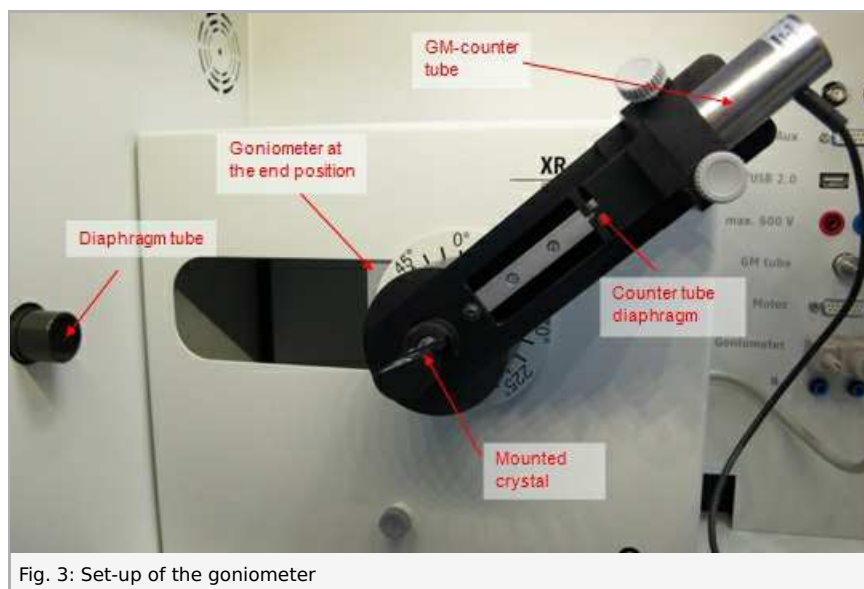


Fig. 3: Set-up of the goniometer

Note

Details concerning the operation of the X-ray unit and goniometer as well as information on how to handle the monocrystals can be found in the respective operating instructions.

Procedure

- Connect the X-ray unit via the USB cable to the USB port of your computer (the correct port of the X-ray unit is marked in Figure 4).
- Start the "measure" program. A virtual X-ray unit will be displayed on the screen.
- You can control the X-ray unit by clicking the various features on and under the virtual X-ray unit. Alternatively, you can also change the parameters at the real X-ray unit. The program will automatically adopt the settings.
- Click the experiment chamber (see the red marking in Figure 5) to change the parameters for the experiment. Select the parameters as shown in Figure 6 for the LiF crystal. If you use the KBr crystal, select a start angle of 3° and a stop angle of 75°.
- If you click the X-ray tube (see the red marking in Figure 5), you can



Fig. 4: Connection of the computer

change the voltage and current of the X-ray tube. Select the parameters as shown in Fig. 7.

- Start the measurement by clicking the red circle:



- After the measurement, the following window appears:



- Select the first item and confirm by clicking OK. The measured values will now be transferred directly to the "measure" software.
- At the end of this manual, you will find a brief introduction to the evaluation of the resulting spectra.

Overview of the settings of the goniometer and X-ray unit:

- 1:2 coupling mode
- Gate time 2 s; angle step width 0.1°
- Scanning range 4°-55° (LiF monocrystal) and 3°-75° (KBr monocrystal)
- Anode voltage $U_A = 35$ kV; anode current $I_A = 1$ mA

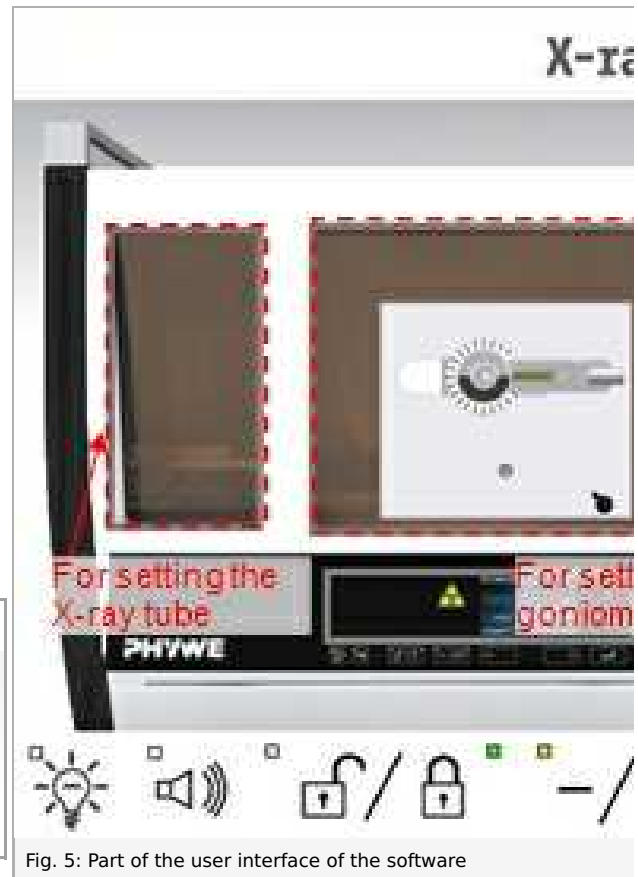


Fig. 5: Part of the user interface of the software



Fig 6: Settings of the goniometer (LiF crystal)

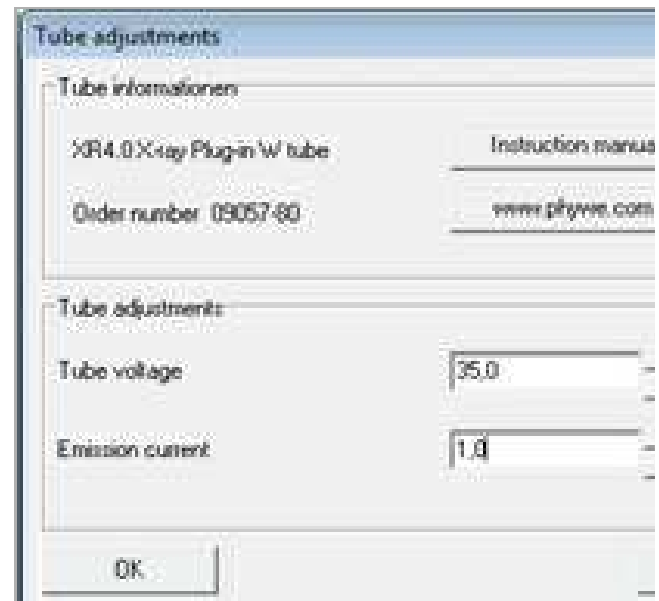


Fig 7: Voltage and current settings

Theory and Evaluation

Theory

Neue Seite

Task 1

Analyse the intensity of the copper X-radiation as a function of the Bragg angle and with the aid of a LiF monocrystal.

Figure 10 shows the X-ray spectrum of copper that was analysed with a LiF monocrystal. Well-defined lines are superimposed on the continuous bremsstrahlung spectrum. The glancing angles of these lines remain unaltered when the anode voltage is varied. This indicates that these lines are characteristic X-ray lines. The two line pairs can be assigned to first-order and second-order interferences ($n = 1$ and $n = 2$). Table 1 shows the glancing angles ϑ that were determined with the aid of Figure 10 and also the energy values for the K_{α} and K_{β} line of copper that were calculated with the aid of equation (4).

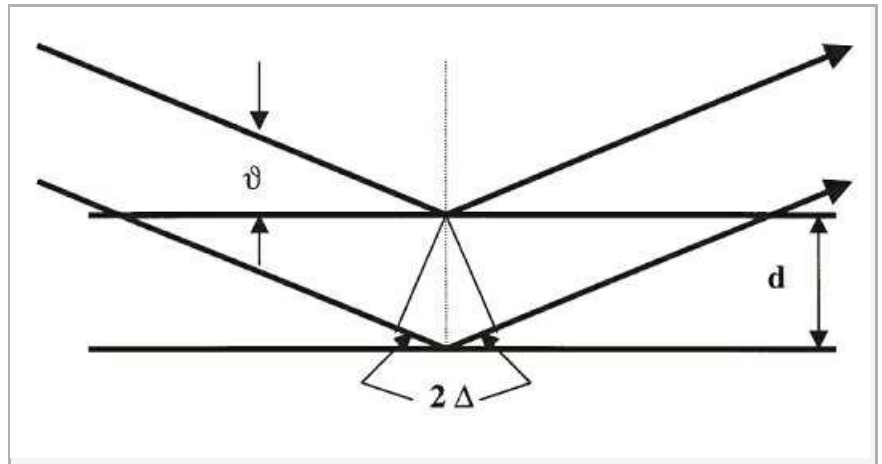


Fig. 9: Bragg scattering on a pair of lattice planes

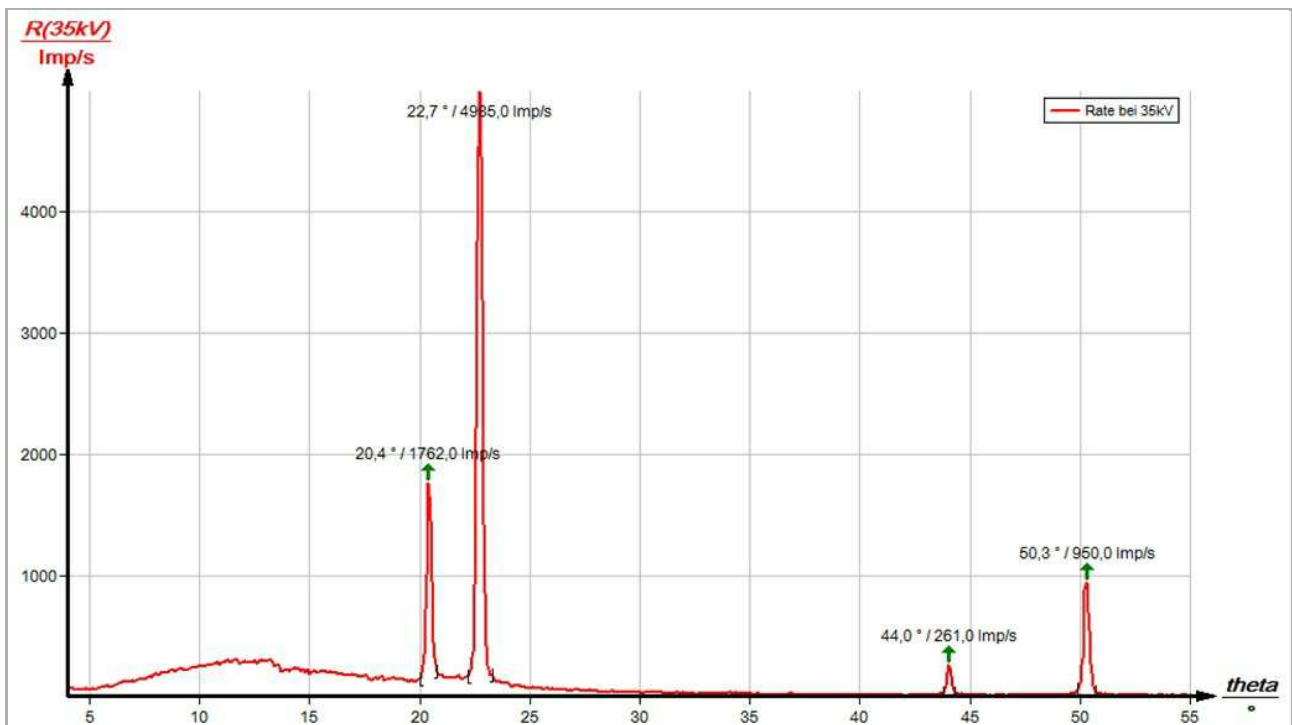


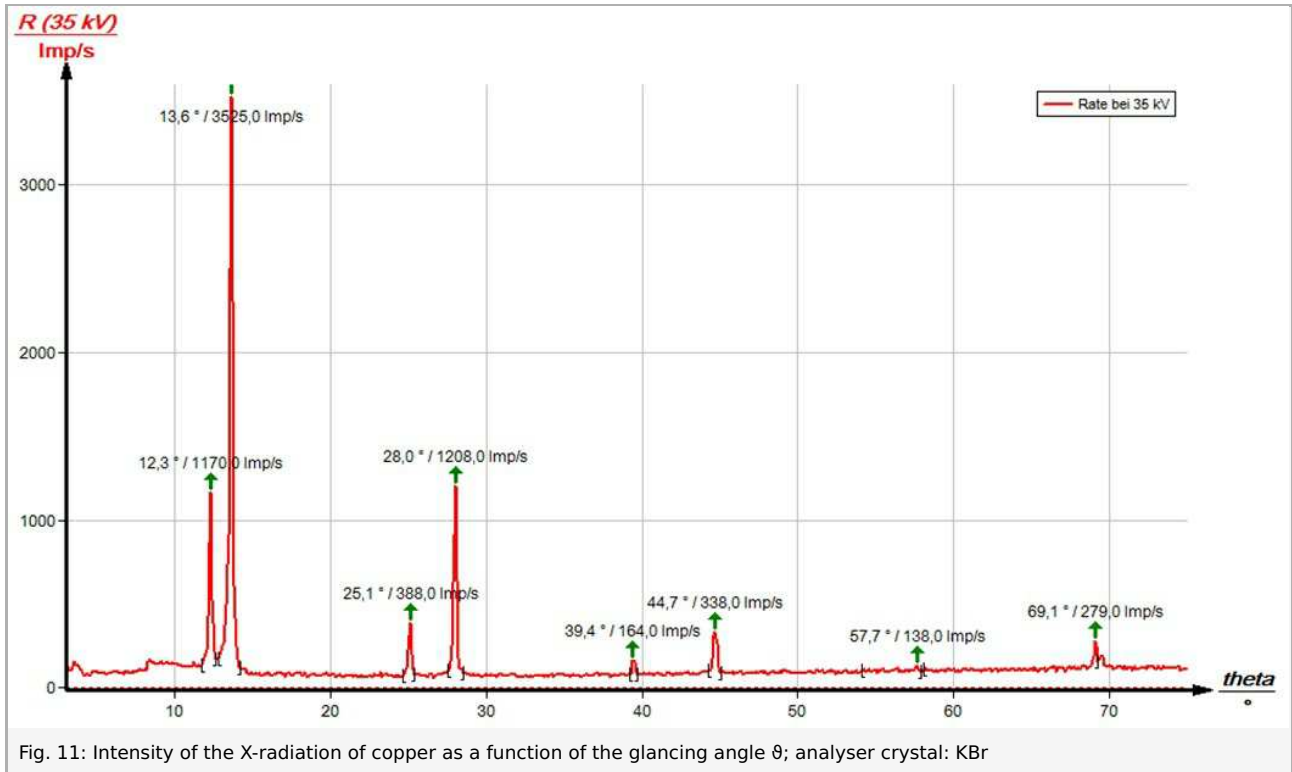
Fig. 10: Intensity of the X-radiation of copper as a function of the glancing angle ϑ ; analyser crystal: LiF

Task 2

Analyse the intensity of the copper X-radiation as a function of the Bragg angle and with the aid of a KBr monocrystal.

If the LiF monocrystal is replaced by the KBr monocrystal (Fig. 11), interferences up to the fourth order can be observed due the larger interplanar spacing of the crystal.

The spectrum of the bremsstrahlung in Figure 11 shows a clear intensity step at $\vartheta = 8.0^\circ$. This corresponds to the K -edge absorption value of bromine ($E_K = 13.474$ keV) with $n = 1$ that can be expected in theory. The K -edge absorptions of potassium, lithium, and fluorine cannot be observed in this area of the bremspectrum, since the intensity is too low (for K - and L -edge absorption experiments, please refer to experiment P2541201).



Task 3

Determine the energy values of the characteristic X-rays of copper and compare them with the values that were determined based on the corresponding energy-level diagram.

Table 1 shows the glancing angles ϑ that were determined with the aid of Figures 10 and 11 and also the energy values for the characteristic X-ray lines of copper that were calculated with the aid of equation (4).

Based on the energy values of the characteristic lines of Tasks 1 and 2, the following mean values result: $E_{K\alpha} = 8.010$ keV and $E_{K\beta} = 8.862$ keV. A comparison with the corresponding values of (1) shows good correspondence.

Table 1: Results



LiF crystal			
$n=1$	22.7	K_{α}	7.974
	20.4	K_{β}	8.830
$n=2$	50.3	K_{α}	8.005
	44.0	K_{β}	8.857
KBr crystal			
$n=1$	13.6	K_{α}	8.018
	12.3	K_{β}	8.831
$n=2$	28.0	K_{α}	8.015
	25.1	K_{β}	8.870
$n=3$	44.7	K_{α}	8.041
	39.4	K_{β}	8.902
$n=4$	69.1	K_{α}	8.069
	57.7	K_{β}	8.919

Note

The evaluation of the two spectra can be varied as follows: Use the energy values of the characteristic lines that were determined for one of the spectra in order to determine the interplanar spacing of the analyser crystal that was used for the other spectrum.

"measure" software

With the "measure" software, the peaks in the spectrum can be determined rather easily:

- Click the button  "Mark" and select the area for the peak determination.
- Click the button  "Peak analysis".
- The window "Peak analysis" appears (see Fig. 12).
- Then, click "Calculate".
- If not all of the desired peaks (or too many of them) are calculated, readjust the error tolerance accordingly.
- Select "Visualise results" in order to display the peak data directly in the spectrum.

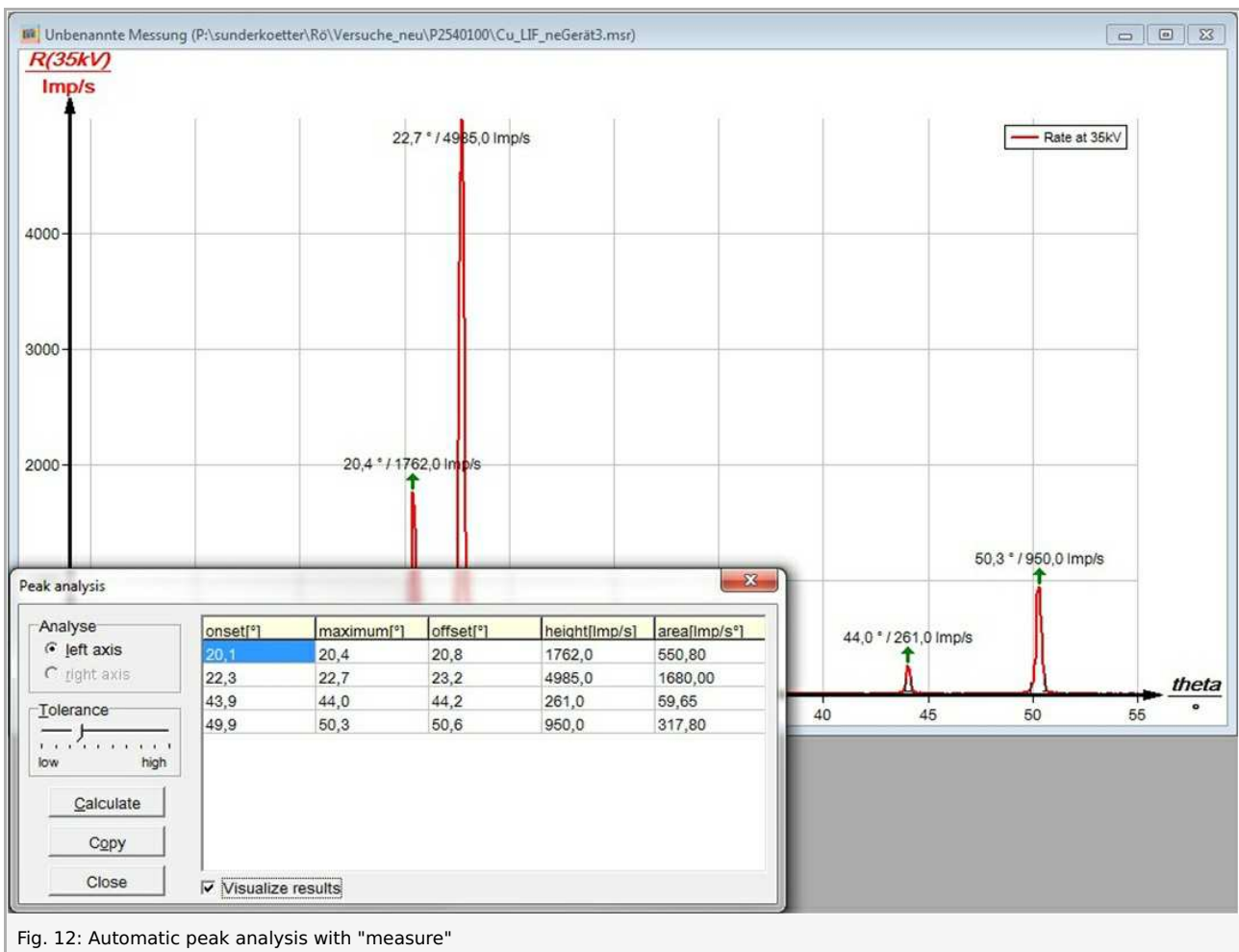


Fig. 12: Automatic peak analysis with "measure"

Refer to the Help of the "measure" software for additional, more detailed explanations concerning the program features.