Characteristic X-Radiation of Tungsten (Item No.: P2542801)

Curricular Relevance

Area of Expertise: ILIAS

Education Level: Physik

Topic: Hochschule

Subtopic: Moderne Physik

Experiment: Röntgenphysik

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	1 Hour	2 Hours	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 tungsten 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.

Student's Sheet

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Fig. 1: P2542801

This experiment is included in the upgrade sets “XRP 4.0 X-ray solid-state physics”, “XRC 4.0 X-ray characteristics”, and “XRS 4.0 X-ray structural analysis”.

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 unit W tube	09057-81	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 Software measure X-ray	14414-61	1
7	Data cable USB, plug type A/B, 1.8 m	14608-00	1
8	XR 4.0 X-ray Diaphragm tube d = 2 mm	09057-02	1

Tasks

1. Record the X-ray spectrum that is emitted by the tungsten anode as a function of the Bragg angle and with the aid of the LiF monocrystal that is used as the analyser.
2. Determine the energy values of the characteristic X-rays of tungsten based on the spectra and compare them with the values that were determined based on the corresponding energy-level diagram.

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Setup and Procedure

Setup

Connect the goniometer and the counter tube to the appropriate sockets in the experimenting area (see red marking in Fig 2). Fix a diaphragm tube in the X-ray outlet tube (2 mm tube diameter). Set the goniometer block with mounted analyzing crystal to the right position and the counter tube to the right stop. Do not forget to install the diaphragm of the GM-tube (See Fig. 3).

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.

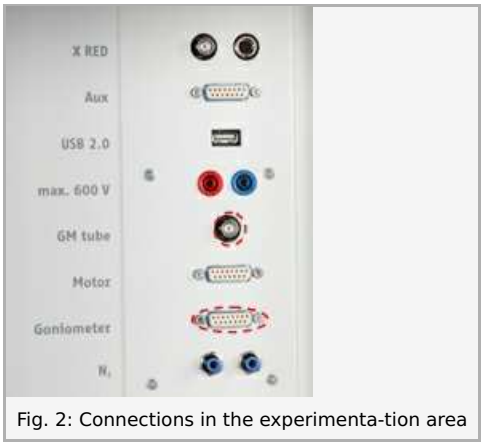

Fig. 2: Connections in the experimenta-tion area

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 data cable to the USB port of your computer.
- 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 to change the parameters for the experiment. Select the parameters as shown in Figure 6.
- If you click the X-ray tube, you can 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 experiment description, you will find a brief introduction to the evaluation of the resulting spectra.

Fig. 4: Connection of the computer

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

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

- 2:1 coupling mode
- Gate time 5-6 s; angle step width 0.1°
- Scanning range 4°-80° (LiF monocrystal)
- Anode voltage U_A = 35 kV; anode current I_A = 1 mA

Fig 6: Measuring parameters of the Goniometer

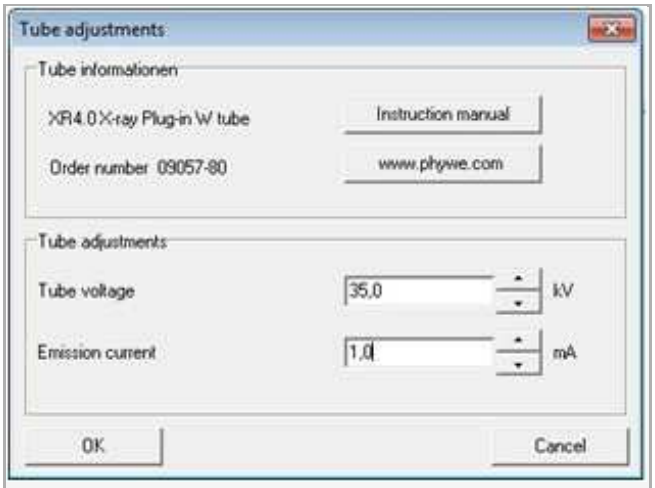

Fig 7: Measuring parameters of anode voltage and current

Note

Never expose the Geiger-Müller counter tube to the primary X-radiation for an extended period of time.

Theory and Evaluation

Theory

When electrons hit the metallic anode of the x-ray tube with a high kinetic energy, x-rays with a continuous energy distribution (bremsstrahlung) are generated. The bremstrahlung is superimposed by additional discrete lines. If an atom of the anode material is ionised, for example, in a deeper shell by an electron impact, an electron from a higher shell can take the now free place while emitting inter alia an x-ray quantum. The energy of this x-ray quantum corresponds to the energy difference of the two levels that are involved in this process. Since the energy difference is atom-specific, the radiation that is generated by this process is also called the characteristic x-radiation.
When an x-ray with the wavelength λ hits the group of lattice planes of a monocrystal at the glancing angle ϑ, the rays that are reflected by the lattice planes only interfere in a constructive manner, if their path difference Δ corresponds to an integer of the wavelength (see Fig. 8). This condition is represented by the socalled Bragg's law:

$2dsin\vartheta = n\lambda$ (1)
(d = interplanar spacing; n = 1, 2, 3,..)

If the interplanar spacing d is known, the wavelength λ can be determined based on the glancing angle ϑ. The energy E of the radiation then results from:

$E = h \cdot f = \frac{hc}{\lambda}$ (2)

(1) and (2) finally leads to:

$E = \frac{n \cdot h \cdot c}{2dsin\vartheta}$ (3)

Planck's constant h = 6.6256 $\cdot 10^{-34}$ Js
Speed of light c = 2.9979 $\cdot 10^{8}$ m/s
Interplanar spacing LiF (200) d = 2.014 $\cdot 10^{-10}$ m
Equivalent 1 eV = 1.6021 $\cdot 10^{-19}$ J

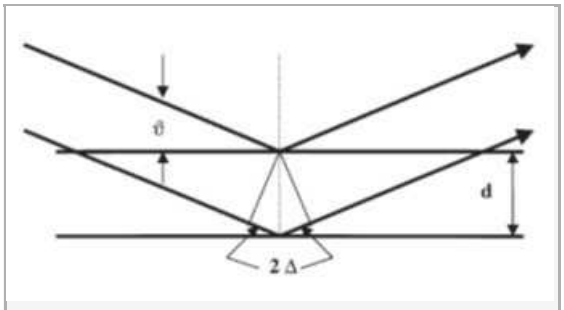

Fig. 8: Bragg scattering on the lattice planes

Figure 9 shows the energy level diagram of the tungsten atom. Since the energy of the K-shell is approximately 70 keV, the maximum available energy of the primary beam of the x-ray unit of 35 keV is insufficient for exciting the K-shell. An ionization is only possible for the L-level.
For clarity, Figure 9 shows the L-transitions for the dipole radition (see 4) that are possible in accordance with the quantummechanical selection rules only up to the N-shell. The quadrupole radiation with a much lower intensity can be neglected.

$\Delta l = \pm$ and $\Delta j = 0, \pm 1$ selection rules for the dipole radiation (4)

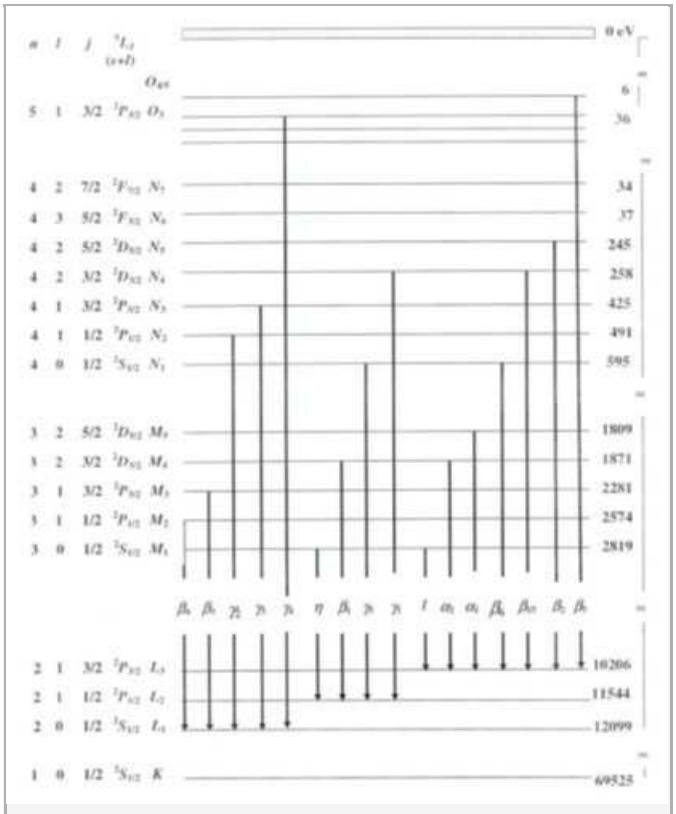

Fig. 9: Schematic representation of the energy level of tungsten (Z = 74)

(l = orbital angular momentum, j = total angular momentum)

Task 1

Task 1: Record the X-ray spectrum that is emitted by the tungsten anode as a function of the Bragg angle and with the aid of the LiF monocrystal that is used as the analyser.

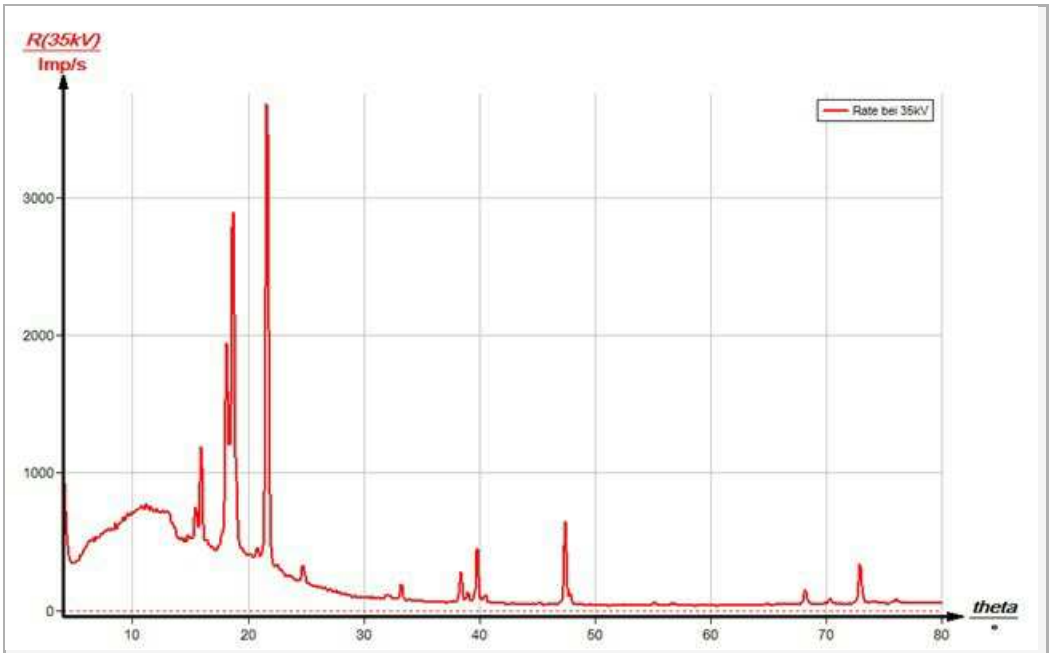

Fig. 10: X-ray spectrum of tungsten

Figure 10 shows the x-ray spectrum of tungsten that was analysed with a LiF monocrystal. Well-defined lines are superimposed on the continuous bremsspectrum. The glancing angles of these lines remain unaltered when the anode voltage is varied. This indicates that these lines are characteristic X-ray lines.
Figures 11 and 12 show certain sections of the spectrum that were created with the aid of the zoom function of the “measure” software. This enables closely neighbouring and less intensive lines to be distinguished more clearly. A total of 27 lines can be distinguished.
The evaluation (see the table) shows that there are only first-order lines in the angular range of $10° < \vartheta < 30°$. They reach the highest intensity level. The range of $30° < \vartheta < 80°$ includes the lines with $n = 2$ and $n = 3$. The separation of lines number 2 and 10 into α_1 and α_2 or γ_2 and γ_3 can only be observed in the range with $n = 2$. Line number 11 can be clearly assigned to the K_α line of copper. The small circular tungsten anode is actually embedded in a cylindrical copper rod that is also partly hit by the electrons.

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Task 2

Task 2: Determine the energy values of the characteristic X-rays of tungsten based on the spectra and compare them with the values that were determined based on the corresponding energy-level diagram.

Column B of the table shows the glancing angles ϑ that were determined with the aid of Figures 10 to 12 and also the energy values for the characteristic X-ray lines of tungsten that were calculated with the aid of equation (4). The wavelength λ and the corresponding energies E_{exp} that were calculated with (1) and (3) are shown in columns D and E. Column H shows the energy values E_{Lit} that were calculated with the aid of Figure 9. The correspondence between the two energy values provides evidence concerning the assignment of the lines to the various transitions. As expected, there are only those lines that comply with the selection rules. It is not possible to discern all of the possible transition, since for some of them the intensity is too low.

Table 1

A	B	C	D	E	F	G	H
Line	ϑ / °	n	λ / pm	$E_{exp.}$ / eV	Line	Transition	$E_{Lit.}$ / eV
1	14.69	1	102.15	12138	γ_4	L_1O_3	12063
2	15.23	1	105.81	11717	11294 $\gamma_{3/2}$	$L_1N_3\,/L_1N_2$	
2	15.23	1	105.81	11717	$\gamma_{3/2}$	$L_1N_3\,/L_1N_2$	
3	15.74	1	109.27	11346	γ_1	L_2N_4	11286
4	16.28	1	112.92	10980	γ_5	L_2N_1	10949
5	17.92	1	123.94	10003	β_2	L_3N_5	9961
6	18.21	1	125.87	9849	β_3	L_1M_3	9818
7	18.47	1	127.61	9716	β_1	L_2M_4	9673
8	18.79	1	129.74	9556	β_4	L_1M_2	9525
9	20.60	1	141.72	8748	η	L_2M_1	8725
10	21.47	1	147.43	8409	$\alpha_{1/2}$	L_3M_5/L_3M_4	
11	22.51	1	154.21	8040	Cu-$K_{\alpha1/2}$		
12	24.57	1	167.49	7402	l	L_3M_1	7387
13	31.80	2	106.13	11682	γ_3	L_1N_3	11674
14	32.01	2	106.76	11613	γ_2	L_1N_2	11608
15	33.03	2	109.79		γ_1	L_2N_4	11286
16	38.12	2	124.33	9972	β_2	L_3N_5	9961
17	38.80	2	126.20	9824	β_3	L_1M_3	9818
18	39.52	2	128.16	9674	β_1	L_2M_4	9673
19	40.24	2	130.10	9529	β_4	L_1M_2	9525
20	47.12	2	147.58	8401	α_1	L_3M_5	8397
21	47.58	2	148.68	8339	α_2	L_3M_4	8335
22	54.88	3	109.71	11300	γ_1	L_2N_4	11286
23	56.47	2	167.88	7385	l	L_3M_1	7387
24	67.90	3	124.28	9976	β_2	L_3N_5	9961
25	70.09	3	126.12	9831	β_3	L_1M_3	9818
26	72.66	3	128.04	9683	β_1	L_2M_4	9673
27	75.79	3	130.03	9535	β_4	L_1M_2	9525

Appendix

“measure” software

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

- Click the button

and select the area for the peak determination.

- Click the button

“Peak analysis”.

- The window “Peak analysis” appears (see Fig. 13).
- Then, click “Calculate”.
- If not all of the desired peaks (or too many) are calculated, readjust the error tolerance accordingly.
- Select “Visualise results” in order to display the peak data directly in the spectrum.

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

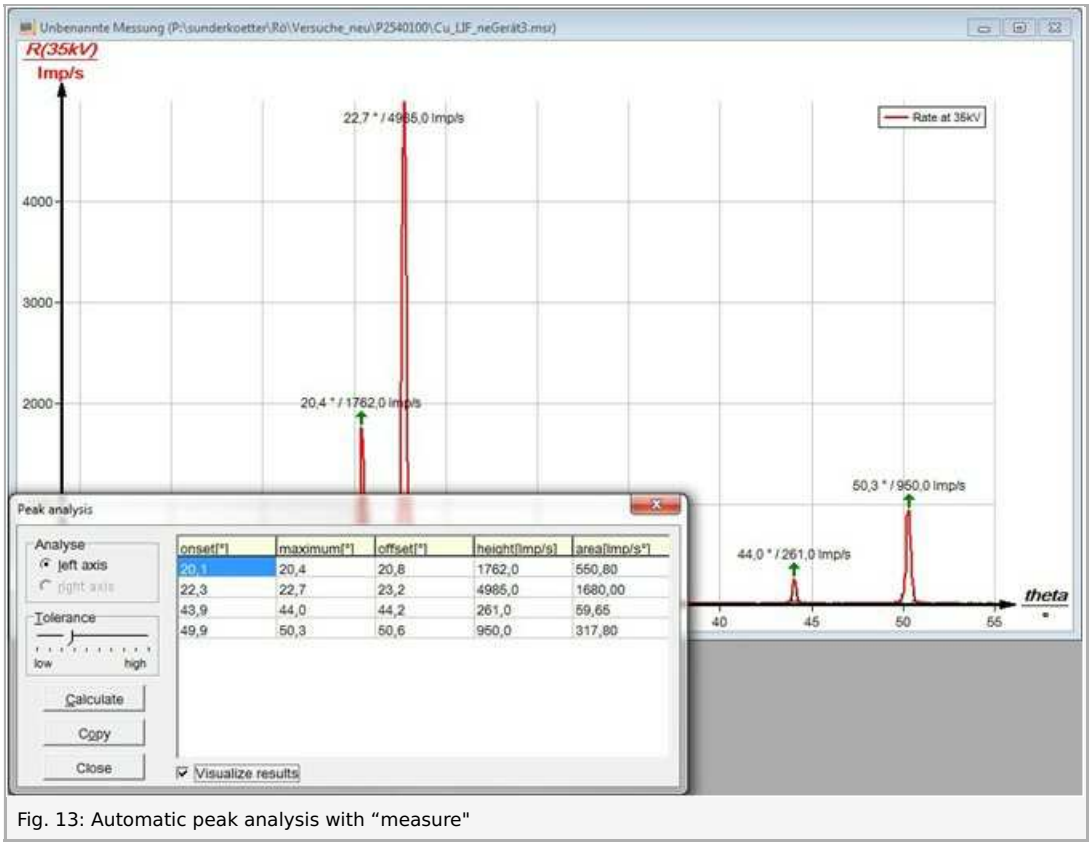

Fig. 13: Automatic peak analysis with “measure"