X-ray energy spectroscopy - calibration of the X-ray energy detector

Physics › Modern Physics › Production & use of X-rays

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/5f7ad24c692dbb00031eea40

General information

Application

Setup

Most applications of X rays are based on their ability to pass through matter. Since this ability is dependent on the density of the matter, imaging of the interior of objects and even peaple becomes possible. This has wide usage in fields such as medicine or security.

Other information (1/2)

Prior knowledge

The prior knowledge required for this experiment is found in the Theory section.

Main principle

Various metal samples are subjected to polychromatic X-rays. The resulting fluorescence radiation is analysed with the aid of a semiconductor detector and a multi-channel analyser. The maxima of intensity of the corresponding characteristic X-ray lines are determined. The predefined energy values of the characteristic lines and channels of the multi-channel analyser that must be assigned in turn result in a calibration of the semiconductor energy detector.

Other information (2/2)

Learning objective

The goal of this experiment is to get to investigate the spectra of fluorescence radiation.

Tasks

- Record the spectra of the fluorescence radiation that is generated by the metal samples.
- Determine the channel numbers of the intensity maxima of the characteristic lines of the corresponding fluorescence radiation.
- Represent the predefined line energies as a function of the channel numbers in a graphical form for two different gain factors of the multi-channel analyser.

Theory

The energy analysis of X-rays with the aid of semiconductor detectors is described briefly based on the example of a Si-pin-detector (p-contact - intrinsic - n-contact). Incident X-ray quanta with a sufficient level of energy create free electrons in the Si crystal due to the photoelectric effect. The kinetic energy of these electrons correlates with the energy of the X-ray quanta. Apart from the phonon excitation, the electrons also create electron-hole pairs on their way through the depletion layer of the semiconductor. The number of these electron-hole pairs is a measure of the energy of the incident quantum. Holes and electrons are withdrawn by voltage that is applied externally and, thereby, create a charge pulse. The magnitude of the charge pulse, on the other hand, is a measure of the energy of the incident X-ray quantum.

The resulting pulse height spectrum will then be analysed by a multi-channel analyser, in which various pulse heights are assigned to different channels. Pulses of the same voltage level will be added up in the same channel.

In a last step, an energy value must also be assigned to the pulse height (= channel number).

This energy calibration can be performed – as it is done here – with the aid of the characteristic lines and the known energy levels of the X-ray fluorescence radiation.

Equipment

Position	Material	Item No.	Quantity
1	XR 4.0 expert unit, 35 kV	09057-99	1
2	XR 4.0 X-ray goniometer	09057-10	1
3	XR4 X-ray Plug-in Cu tube	09057-51	1
4	XR 4.0 X-ray material upgrade set	09165-88	1

Setup and Procedure

Setup

- Screw the adapter ring onto the inlet tube of the energy detector and connect the signal and supply cables to the corresponding ports of the detector with the aid of the right-angle plugs.
- Connect the signal and supply cables to the corresponding ports in the experiment chamber of the X-ray unit. In Figure 1, the port for the signal cable is marked in red and the port for the supply cable is marked in green. Connect the external X RED ports of the x-ray unit (see Fig. 2) to the multi-channel analyser (MCA). Connect the signal cable to the “Input” port and the supply cable to the “X-Ray Energy Det.” port of the MCA.
- Secure the energy detector in the holder of the swivel arm of the goniometer. Lay the two cables with sufficient length so that the goniometer can be swivelled freely over the entire range. Connect the multi-channel analyser and computer with the aid of the USB cable.

Fig. 1: Connectors in the experiment chamber

Fig. 2: Connection of the multi-channel analyser

Procedure (1/2)

- Insert the diaphragm tube with the 2-mm-aperture.
- Bring the goniometer block and the detector to their respective end positions on the left. Bring the detector to the 90° position in the 1:2 coupling mode
- Insert the metal sample with the universal crystal holder (sample is at 45°).
- Operating data of the copper X-ray tube: Set an anode voltage U_A = 35 kV and the anode current so that the counting rate for each of the samples is $\leq$ 300 c/s (select the maximum anode current for the tin and silver samples).
  Confirm the operating data by pressing the “ENTER” button.

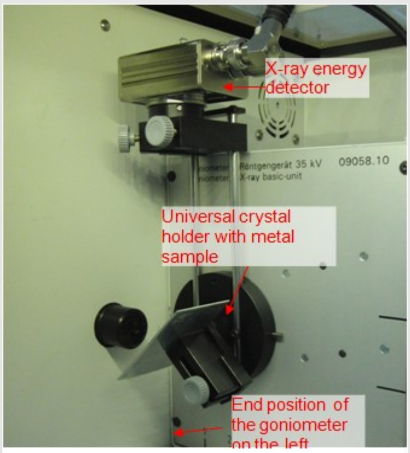

Fig. 3: Goniometer set-up

Procedure (2/2)

- Lock the sliding door of the X-ray unit.
- In the “measure” program, select “Multi-channel analyser” under “Gauge”. Then, select “Spectra recording”. Set “XData = channel number” and “Interval width [channels] = 1 channel”. Set the offset so that low-energy noise signals will be suppressed (usually 5% are sufficient).
- Gain = 2 (select gain level 4 for the second measurement series).
- Measuring time: 3 minutes (5 minutes for the Ag sample). Use the timer of the X-ray unit for this purpose.

Evaluation

Task 1

Record the spectra of the fluorescence radiation that is generated by the metal samples.

As an example of measurements with gain level 4 of the multichannel analyser, Figure 4 shows the fluorescence spectrum of a copper sample.

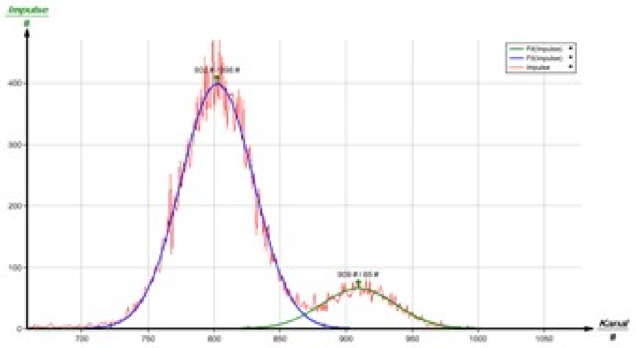

Fig. 4: Fluorescence lines of copper with a fitted nor-mal distribution, gain level 4.

Task 2

A	B	C	D	E
			Gain level 2	Gain level 4
Element	Line	E [keV]	Channel number	Channel number
Fe	K_α	6.40	596	1402
Fe	K_{β_1}	7.06	680	1564
Ni	K_α	7.47	731	1671
Cu	K_α	8.04	802	1813
Ni	K_{β_1}	8.26	828	1857
Zn	K_α	8.63	877	1973
Cu	K_{β_1}	8.90	909	2027
Zn	K_β	9.57	995	2208
Ag	K_α	22.08	2595	
Ag	K_{β_1}	24.94	2958	

Determine the channel numbers of the intensity maxima of the characteristic lines of the corresponding fluorescence radiation.

The following table shows the results of various spectra for two different gain levels of the analyser. The values that are stated for the K_α lines are the mean energy values of the K_{α_1} and K_{α_2} lines.

Since the X-ray unit can only supply radiation with a maximum energy of 35 keV, analyses with gain level 1 of the multi-channel analyser are not useful in this case.

Task 3

Represent the predefined line energies as a function of the channel numbers in a graphical form for two gain factors of the multi-channel analyser.

The table values of the energy of the fluorescence lines are shown in Figure 5 (gain level 4) and Figure 6 (gain level 2) as a function of the associated channel numbers that were determined during the experiment. In their mathematical form, the regression lines that are added help in precisely determining the energy level of an unknown radiation based on the associated channel number.

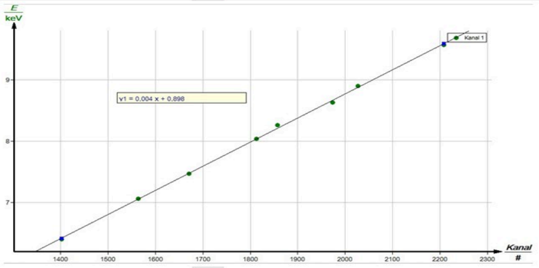

Fig. 5: Gain level 4

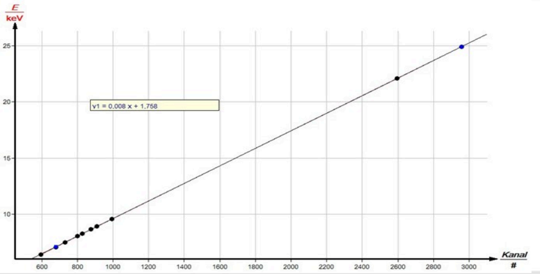

Fig. 6: Gain level 2

Note

- In order to determine the line position, switch from the bar display to the curve display. To do so, click “Display options” and then “Interpolation and straight lines”. Figure 7a shows the result concerning the spectrum of the zinc sample.
- Extend the relevant line section with the aid of the zoom function
- Then, select the various curve sections with

open the window “Function fitting"

Then, select “Scaled normal distribution“ (see Fig. 7b).

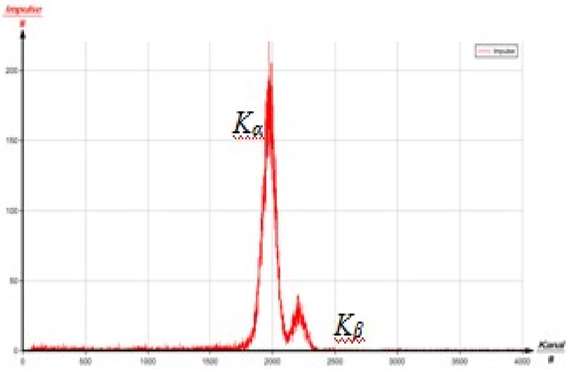

Fig. 7a: Fluorescence spectrum of zinc, gain level 2

Note (part 2)

- Hide the original measurement curve and reselect the sections of the normal distributions. Find the line centroids of the normal distributions with “Peak analysis”

(see Fig. 7c) or determine them with the function “Survey”

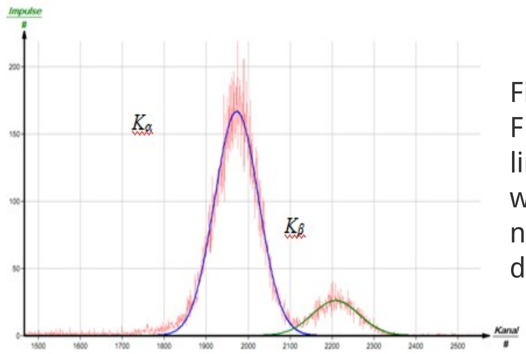

Fig. 7b: Fluorescence lines of zinc with a fitted normal distribution

Fig. 7c: Normal distribution of the zinc fluorescence lines for determining their channel position (original measurement curve not shown)