

Recording and calibrating an X-ray energy spectrum

Objects of the experiment

- Recording the fluorescence spectrum of a calibration target made of galvanized steel.
- Two-point energy calibration of the recorded spectrum.
- Verifying the energy calibration by identifying other lines of the recorded spectrum.

Principles

The X-ray energy detector enables the energy of X-rays to be determined. The central component of the detector is a Si-PIN photodiode, which is cooled by means of a Peltier element in order to reduce the leakage current. In the PIN diode, the incoming X-rays produce electron-hole pairs through interaction with the crystal atoms. These pairs are separated in an electric field and then converted into a voltage pulse. The number of electron-hole pairs and the pulse height are proportional to the X-ray energy. The pulse height analysis is carried out with a multichannel analyzer (MCA), which is connected to a computer (PC).

PIN diode:

The PIN diode consists of a silicon monocrystal with an intrinsic (undoped) layer of approximately 150 μm width between a p-layer and an n-layer. In this layer, part of the incoming X-rays is absorbed. The absorption on an X-ray photon takes place via the photoelectric effect, whereby a fast photoelectron is knocked out. Apart from the portion that corresponds to the binding energy, the X-ray energy is thus transformed into kinetic energy of the photon. The electron loses its energy in collisions with the crystal atoms, whereby the atoms are ionized with consequent formation of electron-hole pairs. The first atom ionized by the photoelectric effect can itself emit a characteristic X-ray photon, whose entire energy is

absorbed in the detector in most cases. Then the total energy absorbed and transformed into electron-hole pairs corresponds to the photon energy E_x . In the electric field present at the PIN diode, the electrons and holes are separated and attracted to the electrodes before they can recombine.

On average, formation of an electron-hole pair in silicon requires the energy $\varepsilon = 3.8 \text{ eV}$. The absorbed X-ray energy E_x , which is considerably greater, is thus transformed into approximately

$$N_x = \frac{E_x}{\varepsilon} \quad (\text{I})$$

electron-hole pairs. That means, the number of electron-hole pairs is proportional to E_x and the charge attracted to the electrodes in

$$Q_x = e \cdot N_x \quad (\text{II}).$$

This charge gets into a charge-sensitive preamplifier and is collected in a feedback capacitor $C_F \approx 1 \text{ pF}$. Hence a voltage signal

$$U_x = \frac{Q_x}{C_F} \quad (\text{III})$$

arises at the output of the preamplifier. This signal is very small and is therefore amplified electronically by a linear low-noise amplifier. Finally the output signal

$$U'_x = A \cdot U_x \quad \text{with } A \approx 1000 \quad (\text{IV})$$

is obtained, which is proportional to the X-ray energy E_x .

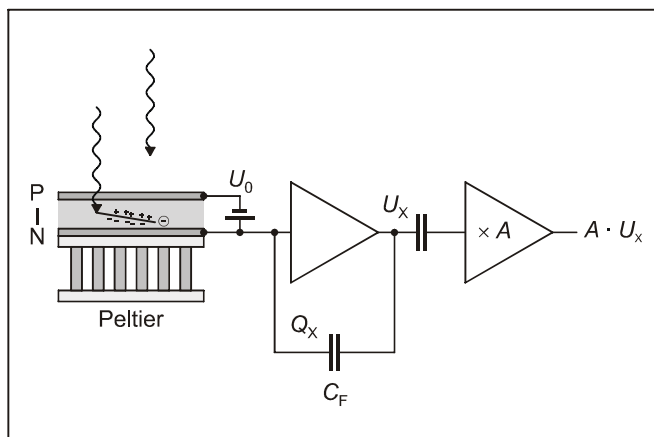


Fig. 1 Schematic illustration of the X-ray energy detector

Apparatus

1 X-ray apparatus with X-ray tube Mo and goniometer or	554 811
1 X-ray apparatus with X-ray tube Cu and goniometer	
1 X-ray energy detector	559 938
1 Sensor-CASSY	524 010
1 MCA box	524 058
1 CASSY Lab	524 200
1 BNC Cable, 1m	501 02
1 PC with Windows 98/NT or higher version	

Multichannel pulse height analysis:

Further processing of the detector signals takes place in a multichannel analyzer (Sensor-CASSY + MCA box), whose central component is an analog-digital converter. This converter measures the pulse height U_X and converts the measured value into a proportional digital value n_X . More precisely, n_X corresponds to a pulse height interval, whose width depends on the resolution of the analog-digital converter. The computer assigns a memory location to each digital value and counts the events in each location. The result is a histogram representing the frequency distribution of the pulse heights.

For a quantitative evaluation, a two-point energy calibration is required

$$E_X = a \cdot n_X + b \quad (V)$$

because the proportionality factors of the relations $E_X \sim Q_X \sim U_X \sim n_X$ are not known and the zero of the analog-digital converter cannot be adjusted exactly.

The X-ray apparatus fulfils all regulations on the design of 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 protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 $\mu\text{Sv/h}$, which is of the order of magnitude of the natural background radiation.

■ Before putting the X-ray apparatus into operation, inspect it for damage and check whether the high voltage is switched off when the sliding doors are opened (see instruction sheet of the X-ray apparatus).

■ Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the X-ray tube.

■ When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

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

■ Do not block the target arm and sensor arm and do not use force to move them.

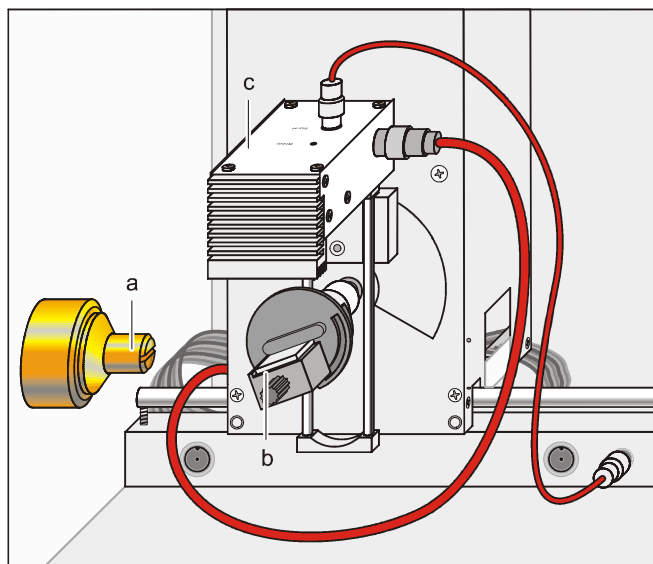


Fig. 2 Experimental setup for recording and calibrating an X-ray energy spectrum

Collimator (a), Calibration target (b), X-ray energy detector (c)


Setup

The experimental setup is illustrated in Fig. 2.

- Guide the connection cable of the table power supply through the empty duct of the X-ray apparatus, and connect it to the Mini-DIN socket of the X-ray energy detector.
- Fasten the assembly of the X-ray energy detector and the sensor holder in the sensor arm of the goniometer.
- Use the BNC cable supplied with the X-ray energy detector to connect the signal output of the detector to the BNC socket SIGNAL IN of the X-ray apparatus.
- Push a sufficient length of the connection cable into the duct so that the sensor arm can perform a complete rotation.
- Press the SENSOR key and, using the ADJUST knob, adjust a sensor angle of 90° manually.
- Connect the Sensor-CASSY to the computer, and plug in the MCA box.
- Use a BNC cable to connect the output SIGNAL OUT on the terminal panel of the X-ray apparatus to the MCA box.
- Adjust the distances between the slit of the collimator and the axis of rotation and between the axis of rotation and the entrance aperture of the X-ray energy detector each to 5-6 cm.
- Lay the calibration target from the scope of delivery of the X-ray energy detector on the target stage.
- Press the TARGET pushbutton, and, using the ADJUST knob, adjust target of 45° angle manually.

Carrying out the experiment

- Connect the table power supply to the mains (after approx. 2 minutes the LED shines green and the X-ray energy detector is ready for operation).

- Call CASSY Lab, and select the measuring parameters “Multichannel Measurement, 256 Channels, Negative Pulses, Gain -6, Measuring Time 300 s”.
- Select the tube high voltage $U = 35$ kV and the emission current $I = 1.00$ mA, and switch the high voltage on.
- Start recording the spectrum with  or with the F9 key.
- When the measuring time is over, store the spectrum with an appropriate name.

Measuring example

In the spectrum several lines are found (see Fig. 3). The two lines with the highest counting rate are the Fe $K\alpha$ and the Zn $K\alpha$ lines. They are used for the energy calibration.

Evaluation

Energy calibration:

- Open the “Energy Calibration” dialog window with the shortcut Alt+E, and select “Global Energy Calibration”.
- Enter the energies of the Fe $K\alpha$ line (6.40 keV [1]) and the Zn $K\alpha$ line (8.63 keV [1]).
- Select the menu item “Other Evaluations” → “Calculate Peak Center” in the pop-up menu of the diagram window, and mark the region of the Fe $K\alpha$ line (excluding the neighbouring line with a smaller counting rate).
- Enter the result in the “Energy Calibration” dialog window.
- Then determine and enter the peak center of the Zn $K\alpha$ line.
- Close the “Energy Calibration” dialog window with OK.

The result of the energy calibration is displayed in Fig. 4.

Identifying the $K\beta$ lines:

- Call the menu item “X-Ray Energies” in the pop-up menu of the diagram window, and click on the element symbol Fe.
- Close the window with the “OK” button, and erase the marking of the Fe L lines by pressing the keys Alt + ← several times.
- Call the menu item “X-Ray Energies” anew, click on the element symbol Zn, and erase the marking of the Zn L lines.

It turns out that the four measured peaks can be attributed to the fluorescence of the two main constituents of the galvanized steel sheet, namely Fe and Zn (see Fig. 5).

Results

The X-ray energy detector can be used to measure the energy of X-rays.

For this an energy calibration is required, which can be performed as a two-point calibration.

Literature

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

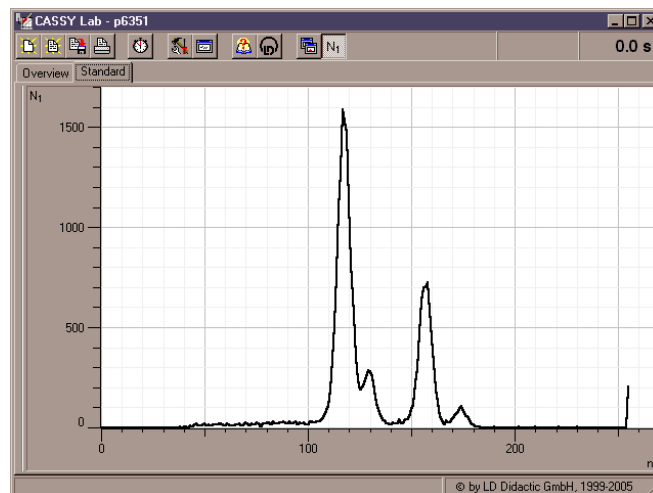


Fig. 3 Uncalibrated fluorescence spectrum of the calibration target.

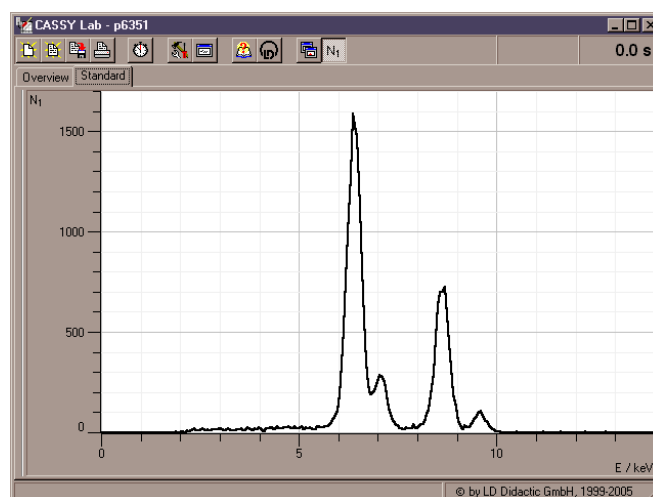


Fig. 4 Energy calibrated fluorescence spectrum of the calibration target

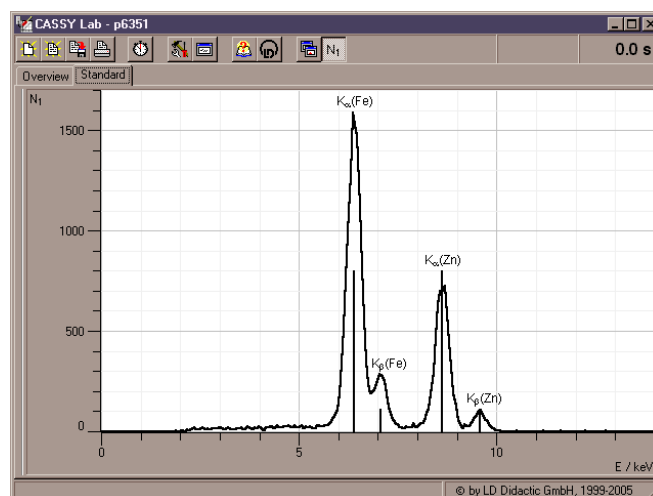


Fig. 5 Fluorescence spectrum of the calibration target with identified lines

