

# X-ray fluorescense and Moseley's law with MCA

LEP 5.2.47 -15

## **Related Topics**

Binding energy, photoelectric effect, structure of electron shells, characteristic X-rays,  $\gamma$ -spectrometry, X-ray spectrometry.

## Principle

Photons originating from nuclear transitions are called  $\gamma$ -quanta and photons originating from electron transitions of high energy are called X-rays. If matter is irradiated with photons of high energy, part of them are absorbed by electrons transferring the energy and momentum of the photon to the electron which is called photoelectric effect. If the energy is sufficient, also the innermost i.e. strongest bound electrons of an atom can be removed from the atom by this process. The states of the missing electrons are filled with other electrons under emission of characteristic X-rays or Auger-electrons. The emission of characteristic X-rays caused by irradiation with photons of high energy is called X-ray fluorescence. The binding energy of the innermost electrons increases with atomic number and so does the energy of the characteristic X-rays which is measured in this experiment. The energy resolution of a scintillation counter is sufficient for such examinations. The dependence of X-ray energy on atomic number was examined by Moseley.

## Equipment

Americium-241 source, 370 kBg	09090.11	1
Source Cs-137, 37 kBg	09096.01	1
Absorption material, lead	09029.01	1
Support rod -PASS-, square, <i>l</i> = 250 mm	02025.55	З
Right angle clamp -PASS-	02040.55	3
Support base -PASS-	02005.55	1
Universal clamp	37715.00	1
Source holder, swivel-type	18461.88	1
Barium sulfate, 500 g	30035.50	1
Tin rods, 100 g	31991.25	1
Silver plate, 25 g	31839.04	1
Cer (IV) sulfate, 25 g	31194.04	1
lodine resublimed, 25 g	30093.04	1
Crocodile clips, pack of 10	07274.03	1
Plastic bags, DIN A5, pack of 100	46444.01	1
Screened cable, BNC, $l = 750 \text{ mm}$	07542.11	1
Gamma detector	09101.00	1
Operating unit f. gamma detector	09101.93	1
High-voltage connecting cable	09101.10	1
Multi Channel Analyzer (MCA)	13726.99	1
MCA Software	14524.61	1
RS232 data cable	14602.00	1
PC. Windows <sup>®</sup> 95 or higher		

#### Fig. 1: Experimental set-up





## Tasks

- Perform an energy calibration of the setup using the 59.5 keV line of <sup>241</sup>Am and the 32.2 keV line of <sup>137</sup>Cs.
- Record spectra of the fluorescence radiation exited with the radiation of the <sup>241</sup>Am source for different specimen.
- 3. Plot the energy of the fluorescence peak vs. the function  $(Z 1)^2$  of the specimen's nuclear mass number Z and calculate the Rydberg constant from the slope of the obtained graph.



Fig. 2: Start window of the MCA



Fig. 3: Window for spectrum recording – here the spectrum of <sup>241</sup>Am with gain level 4.

#### Set-up and Procedure

Set up the equipment as seen in Fig. 1. Before turning on the operating unit for the scintillation counter, connect the high voltage cable correctly to operating unit and photomultiplier and read the instructions in the manual of the gamma-detector. Set the multiturn potentiometer of the operating unit to 2.00. Connect the MCA to the computer's USB port or a RS232 serial interface and start the "measure" program. Select the Gauge "Multi Channel Analyzer" (MCA).

 First adjust the detector: Start with the <sup>241</sup>Am source. Select "Spectra recording", use the "Continue" button and in the spectra recording window (see Fig. 3) set the "Gain" to "Level 4" and the "Offset" to 1 % and choose "Channel number" as x-Data. Place the source in a distance to the detector such that the counting rate is slightly below 1000 cts/s. Adjust the multiturn potentiometer on the detector's operating unit so that the 59.5 keV peak moves to the right end of the spectrum (around channel 3500). Leave this setting unchanged throughout the measurement – for low drift turn on the detector some time before measurement. "Cancel" the measurement.

Detector calibratio	on
Detector / Calibrati	ion: 2-point calibration 137Cs, 241Am
Comment:	none
Mode:	2-point calibration
Gain:	Level 4, Offset 0%
Equation:	0,1· <channel> keV + 5,2 keV</channel>
Calibrate	Save Delete
Port:	COM3
Device version:	1.02-2
Perform hardv	vare adjustment





Fig. 5: Performing the calibration – here with <sup>241</sup>Am



Now calibrate the MCA so that the corresponding energy of each channel is known: Start the MCA gauge of "measure" again and select "Settings and Calibration". The window as seen in Fig.4 appears – use the "Calibrate" button. Set the "Gain" to "Level 4", the "Offset" to 1 % and select "2-point calibration". Move one bar to the 59.5 keV peak, then remove the <sup>241</sup>Am and bring the <sup>137</sup>Cs in direct vicinity to the detector. Use the "Clear diagram" button and move the other bar to the then appearing 32.2 keV peak and type the energy values in the appropriate fields and finally use the "Apply" button and then the "Save" button of the window seen on Fig. 4 and enter a name for your calibration.

2. Now choose the program part "Spectra recording" again with "Gain" "Level 4" and 1 % "Offset". Put 3 cm of lead shielding between the 340 kBq 241Am source and the detector with the source close to the detector. Check the spectrum that gets recorded now and the counting rate the detector should "see" as few of the source's radiation as possible - the presence of the source shouldn't increase the background rate a lot. Then put the fluorescenting specimen in the vicinity of the detector so that it is exposed to the source's radiation and so that the fluorescence radiation can reach the detector. Move it until the counting rate gets maximal. The counting rate should be distinctly higher with specimen than without. Reset the spectrum and in the now recorded spectrum the fluorescence peak should be clearly visible and much lower than the 60 keV peak. Save the recorded spectra with the "Accept data" button. If the specimen is powder and is packed in a plastic bottle, simply the whole package can be used. Glass packages absorb too strongly and show a broad fluorescence spectrum themselves - specimen in glass bottles have to be removed from the bottle and may be put into e.g.plastic bags. Metal pieces need no packaging.



Fig. 7: Fluorescence peaks

#### Theory and evaluation

Fig. 6 shows the decay scemes of the used nuclids. The proportions of the energy scale are not displayed correctly and the term sceme of  $^{237}$ Np is strongly simplified – in the experiment only the 59.5 keV of  $^{237}$ Np is of importance. It is to be kept in mind, that the exited states of the daugther nuclids can also disintegrate by inner conversion in the case of  $^{137}$ Ba leading to a strong 32 keV X-ray line.

In the recorded spectra use "Display options" to change the displayed area to 10 to 60 keV and on the "Channels" chart change the "Interpolation" from "Bars" to "Straight lines". Then use the "Smooth" tool to generate a new diagram where the position of the fluorescence peak is more clearly visible. With the "Survey" function read out the corresponding energy of the peak. Fig. 7 shows results combined into one graph with "Measurement" > "Assume channel".











Fig. 8: Window for creating measurements



Fig. 9: Window for channel modification

Create a measurement with "Measurement" > "Enter data manually..." as seen in Fig. 8. Then change the x-channel with "Analysis" > "Channel modification..." to  $(Z-1)^2$  as seen in Fig. 9. The number of digits beyond the point can be changed with the "Information" button. The slope of the graph can be evaluated with the "Regression" tool.



Fig. 10: Plot of Moseley's law

The fluorescence peak that dominates here is from  $K_{\alpha}$  radiation. The corresponding energy is the energy difference between the state of the innermost electron in the atom, the lowest energy state, and the energy of an electron state one shell above that.  $K_{\alpha}$  radiation is thus the radiation emitted when an innermost electron is lost by photo effect and it's state is filled up with an electron of the next shell and the energy difference is emitted as photon. Moseley's law now states that this energy is connected to the ionization energy of atomar hydrogen, the Rydberg constant  $R_{\alpha}$  in a simple manner:

$$E_{\mathrm{K}_{lpha}}=rac{3}{4}~hR_{\infty}\cdot(Z-1)^2$$
 .

with atomic number Z and Planck's quantum h.

Fig. 10 shows that this approximation is astonishingly well valid – though one would expect strong deviations because of the complicated shell structure of heavy atoms – e.g. Cer is a lanthanoid and has an electron in the f-shell and Barium belongs to the second main column of the table of elements and has none.

The slope in Fig. 10 reads 0.0107 keV and with  $h = 6.626 \cdot 10^{-34} \, \rm{Js} = 4.136 \cdot 10^{-18} \, \rm{keVs}$  is then

$$R_{\infty} = (3.45 \pm 0.3) \cdot 10^{15} \frac{1}{s}$$
.

Literature values for  $R_{\infty}$ :  $R_{\infty}/c_0 = 1.097 \cdot 10^7 \text{ 1/m}$   $R_{\infty} = 3.290 \cdot 10^{15} \text{ 1/s}$   $h \cdot R_{\infty} = 13.6 \text{ eV}$  $h \cdot R_{\infty} = 2.178 \cdot 10^{-18} \text{ J}$