X-ray fluorescence and Moseley's law

Physics > Modern Physics > Atomic & Molecular Physics

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/5fbad4c965f94e0003ca8cd2

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General information

Application

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Setup

Some materials can be used in fields like medicine due to their fluoresent properties to make differences in radiation intensity visible.

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Other information (1/2)

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Prior knowledge

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

Main principle

Photons originating from nuclear transitions are called γ-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.

Other information (2/2)

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Learning objective

The goal of this experiment is to investigate X-ray fluorescence.

Tasks

1. Perform an energy calibration of the setup using the 59.5 keV line of $^{241}\mathrm{Am}$ and the 59.5 keV line of $^{137}\mathrm{Cs}$.
2. Record spectra of the fluorescence radiation exited with the radiation of the $^{241}\mathrm{Am}$ source for different specimen.
3. Plot the energy of the fluorescence peak vs. the function $(\mathrm{Z}-1)^2$ of the specimen'snuclear mass number Z and calculate the Rydberg constant from the slope of theobtained graph.

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Theory

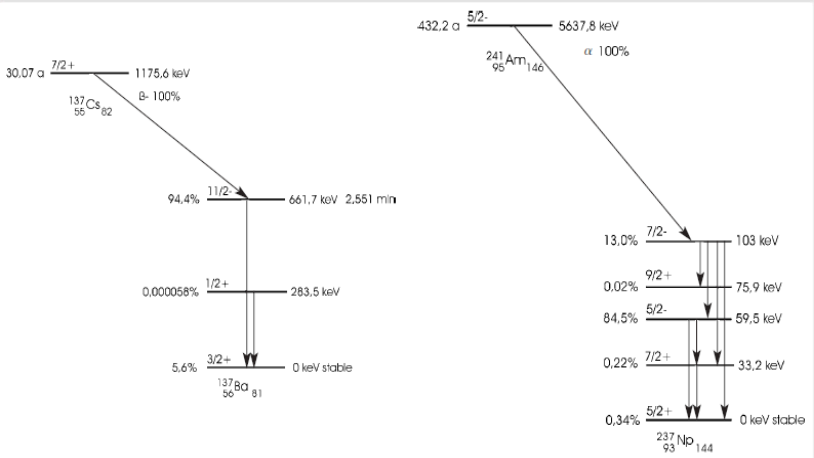

Fig. 1: Decay schemes of Cs-137 and Am-241

Fig. 1 shows the decay schemes of the used nuclids. The proportions of the energy scale are not displayed correctly and the term scheme of $^{237}\mathrm{Np}$ is strongly simplified – in the experiment only the 59.5 keV of $^{237}\mathrm{Np}$ is of importance. It is to be kept in mind, that the exited states of the daughter nuclides can also disintegrate by inner conversion in the case of $^{137}\mathrm{Ba}$ leading to a strong 32 keV X-ray line.

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Equipment

Position	Material	Item No.	Quantity
1	Gamma detector	09101-00	1
2	PHYWE high precision power supply 1.5 kV DC	09107-99	1
3	PHYWE Multichannel Analyser (MCA)	13727-99	1
4	measure Software multi channel analyser	14452-61	1
5	Support base DEMO	02007-55	1
6	Right angle clamp expert	02054-00	3
7	Universal clamp	37715-01	1
8	Spring balance holder	03065-20	1
9	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	3
10	Support rod with hole, stainless steel, 10 cm	02036-01	1
11	Absorption material, lead	09029-01	1
12	Silver foil, 150 x150 x 0.1 mm, 25 g	31839-04	1
13	Tin-II chloride 250 g	31991-25	1
14	Barium sulphate 500 g	30035-50	1
15	Iodine resublimed 25 g	30093-04	1
16	Radioactive source Cs-137, 37 kBq	09096-01	1
17	Radioactive source Am-241, 370 kBq	09090-11	1
18	Plastic sack, flat, DIN A5, 100pc	46444-01	1
19	Alligator clips, bare, 10 pcs	07274-03	1
20	High-voltage connecting cable	09101-10	1
21	Screened cable, BNC, l = 750 mm	07542-11	1

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Setup and Procedure

Setup

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Set up the experiment as shown in Fig. 2. 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 voltage of the operating unit to 1.0 kV. Connect the MCA to the computer's USB port and start the "measure" program. Select the Gauge "Multi Channel Analyzer" and you will receive the start window, as shown in Fig. 3.

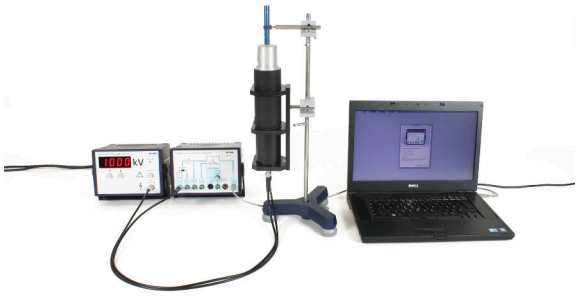

Fig. 2

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Procedure (1/5)

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First adjust the detector: Start with the $^{241}\mathrm{Am}$ source. Select "Spectra recording" (see Fig. 3), click the "Continue" button and in the spectra recording window (see Fig. 4) 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 voltage 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.

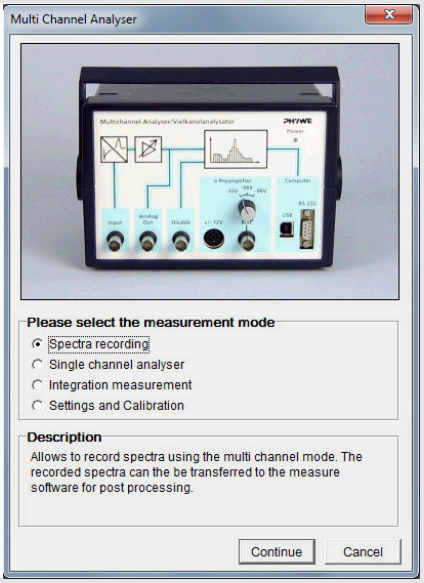

Fig. 3: Start window of the MCA

Procedure (2/5)

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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" (see Fig. 3). The window shown in Fig.5 will appear – click on 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 and type the energy value in the appropriate field, as shown in Fig. 6. Then remove the $^{241}\mathrm{Am}$ and bring the $^{137}\mathrm{Cs}$ in direct vicinity to the detector.

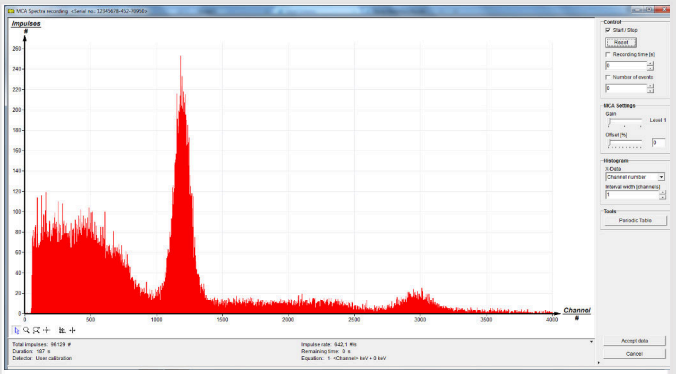

Fig. 4: Window for spectrum recording - here the spectrum of Na-22 with gain level 1.

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Procedure (3/5)

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Click on the "Clear diagram" button and move the other bar to the then appearing 32.2 keV peak of the ^{137}Cs and type the energy value in the appropriate field and finally click on the "Apply" button and then the "Save" button of the window seen in Fig. 5 and enter a name for your calibration.

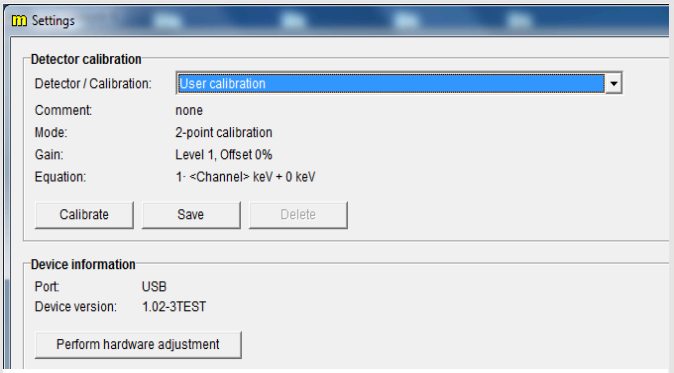

Fig. 5: Calibration window

Procedure (4/5)

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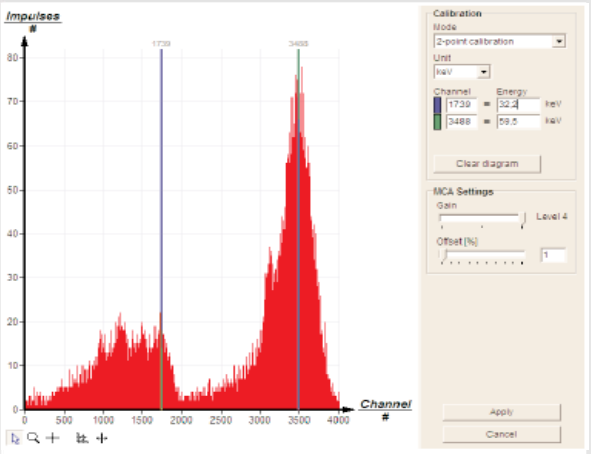

Fig. 6: Performing the calibration – here with Am-241

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 ^{241}Am 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 fluorescent 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.

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Procedure (5/5)

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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.

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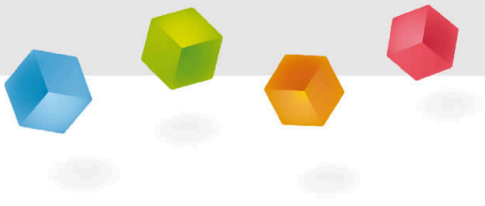

Evaluation

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Evaluation

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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".

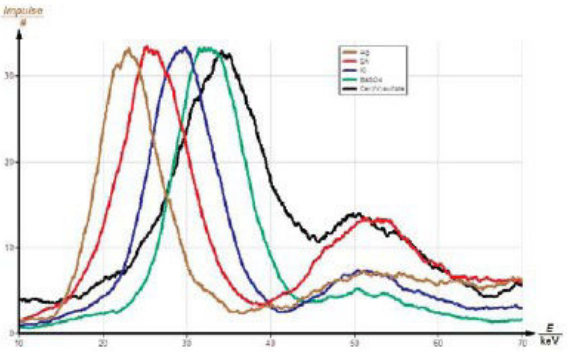

Fig. 7: Fluorescence peaks

Evaluation (part 2)

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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.

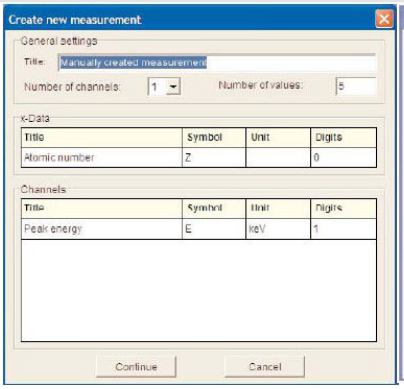

Fig. 8: Window for creating measurements

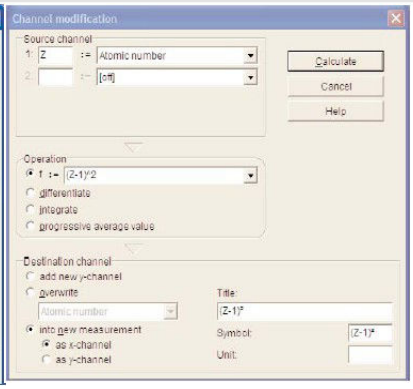

Fig. 9: Window for channel modification

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Evaluation (part 3)

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The fluorescence peak that dominates here is from K_α 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_α radiation is thus the radiation emitted when an innermost electron is lost by photo effect and its 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_∞, in a simple manner:

$E_{K_\alpha} = \frac{3}{4} h R_\infty \cdot (Z-1)^2$ 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.

Evaluation (part 4)

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The slope in Fig. 10 reads 0.0107 keV and thus

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

Literature values for R_∞:

$R_\infty / c_0 = 1.097 \cdot 10^7\ 1/s$

$R_\infty = 3.200 \cdot 10^{15}\ 1/s$

$h \cdot R_\infty = 13.6\,eV = 2.178 \cdot 10^{-18}\ J$

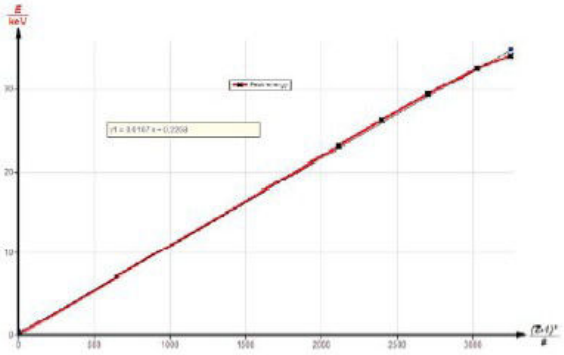

Fig. 10: Plot of Moseley's law

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