Internal conversion in Ba-137m (Item No.: P2524515)

Curricular Relevance

Area of Expertise: ILIAS

Education Level: Physik

Topic: Hochschule

Subtopic: Moderne Physik

Experiment: Kernphysik - Radioaktivität

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

Additional Requirements:

- PC

Experiment Variations:

Keywords:

Gamma- and X-radiation, nuclear transitions, transition probability, half life, metastable states, isotopic spin quantum numbers, selection rules for transitions, multipole radiation, isomeric nuclei, conversion electrons, characteristic X-rays, scintillation detectors

Overview

Short desciption

Principle

An energy spectrum of the -radiation of a $^{137}\mathrm{Cs}$ source is recorded with a scintillation counter and a multi channel analyser (MCA). The total number of incidents is compared with the number of incidents that belong to the $32\,\mathrm{keV}$ X-ray peak yielding an estimation of the rate of inner conversion of the decay of $^{137m}\mathrm{Ba}$.

Fig. 1: Experimental set-up

Student's Sheet

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Equipment

Position No.	Material	Order No.	Quantity
1	Radioactive source Cs-137, 37 kBq	09096-01	1
2	Multichannel analyser	13727-99	1
3	Gamma detector	09101-00	1
4	PHYWE High Precision Power Supply 1.5 kV DC	09107-99	1
5	High-voltage connecting cable	09101-10	1
6	measure Software multi channel analyser	14452-61	1
7	Support rod, stainless steel, 500 mm	02032-00	1
8	Right angle clamp expert	02054-00	1
9	Tripod base PHYWE	02002-55	1
10	Screened cable, BNC, l = 750 mm	07542-11	1

Tasks

1. Record a spectrum of the photon emissions of a $^{137}\mathrm{Cs}$ source.
2. Determine the conversion factor of the decay of $^{137m}\mathrm{Ba}$ from the spectrum.

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Set-up and procedure

Set up the experiment as shown 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 voltage of the operating unit to $1.0\,\mathrm{kV}$. 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. 2.

Select "Spectra recording" (see Fig. 2), set the "Gain" to "Level 1", set the "Offset" to 0 %, choose "Channel number" as x-Data (see Fig. 3) and start data recording. Put the Cs pellet directly on top of the detector, or, if the impulse rate exeeds $800\,\mathrm{cts/s}$, one or two centimeters away into the universal clamp. Increase the high voltage on the detector operating unit, until the $662\,\mathrm{keV}$ peak gets to about channel 3500. If you are not sure about the high voltage setting, start with low settings and increase the high voltage, until the $662\,\mathrm{keV}$ peak wanders to the right end of the spectrum. Reset (clear the counts) and record a spectrum for some minutes. Use the "Accept data" button to save the data for further processing.

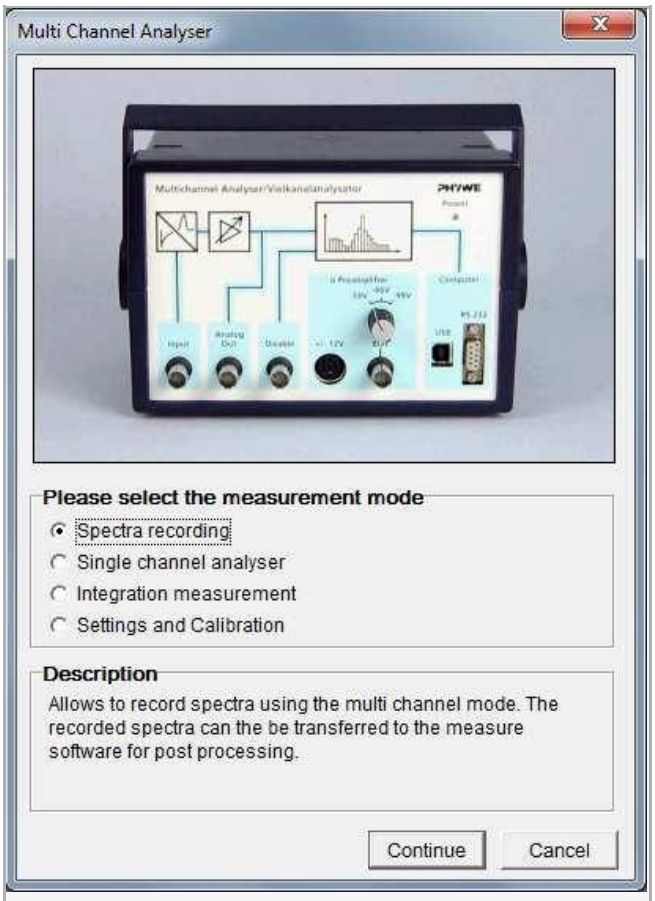

Fig. 2: Start window of the MCA

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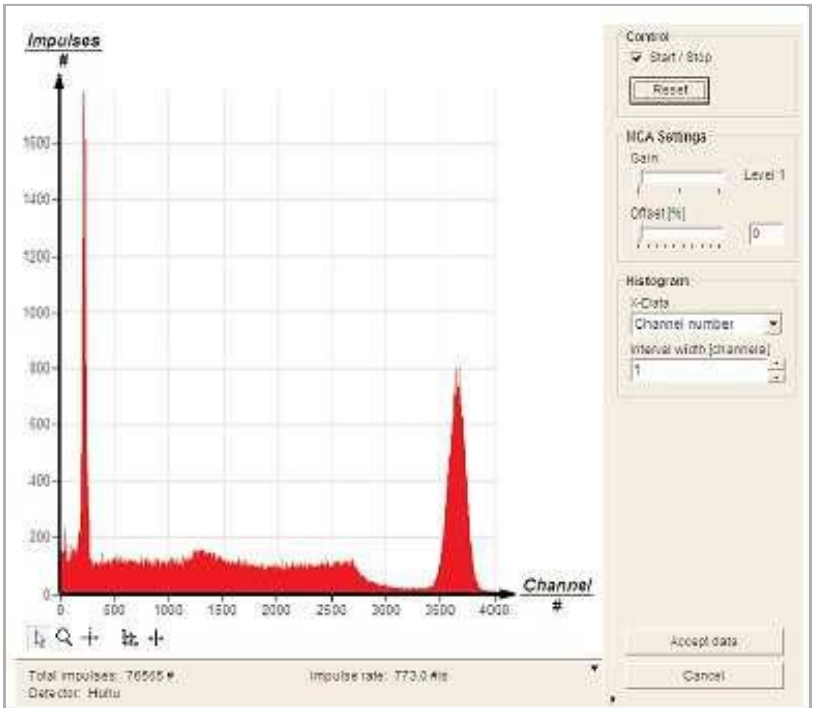

Fig. 3: Window for spectrum recording – here the spectrum of Cs-137 with gain level 1

Theory and evaluation

Fig. 4 shows the decay scheme of the used nuclid $^{137}\mathrm{Cs}$. The proportions of the energy scale are not displayed correctly.

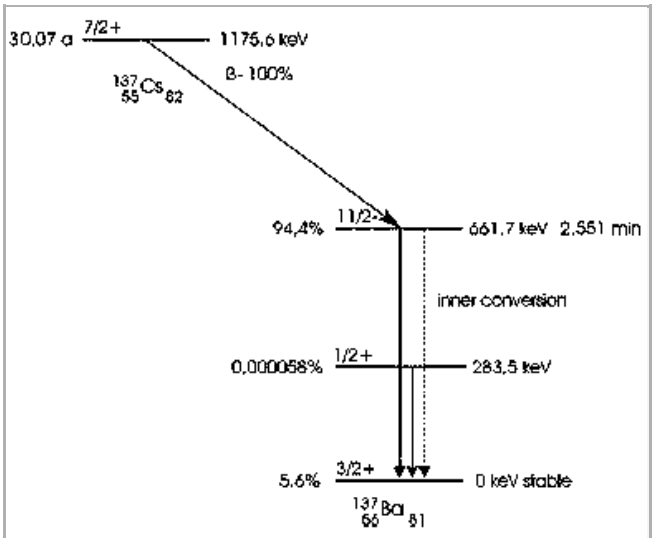

Fig. 4: Decay scheme of Cs-137

The decay of $^{137}\mathrm{Cs}$ leaves 94.4% of the daughter nuclid atoms $^{137}\mathrm{Ba}$ in an exited state called metastable $^{137m}\mathrm{Ba}$ with a half life of 2.551 minutes and an energy exess of $662\,\mathrm{keV}$ compared to the ground state. The decay of this state by photon emission is of high multipolarity. The difference in spin quantum number is 4, i.e. the photon is to carry the angular momentum $4\hbar = 4h/2\pi$ which has a very low probability compared to "normal" transitions where the photon carries an angular momentum of only one $\hbar$. So the half life of the exited state is that long that another possible decay process gets a remarkable probability: inner conversion. Inner conversion means, that energy, angular momentum and parity of the exited state don't get transferred to a photon but to an electron. So a transfer process of these physical quantities from the nucleus of the atom to the electron shell of the atom takes place. Since the innermost electrons have the highset probability to be found near the atomic nucleus, it is generally them that take part in this reaction. When the $662\,\mathrm{keV}$ of the exited state are transferred to one of them, it flies away leaving an ionized atom with unoccupied state in the inner shell. The unoccupied state is then filled by an electron of an outer shell leading to emission of characteristic X-rays or Auger electrons. In the case of the dominating inner conversion to Kshell electrons, 10% of such reactions result in Auger electrons and the rest in K_α–X-radiation. The Auger electrons are not detected in this experiment.

The incoming photons from the $^{137}\mathrm{Cs}$ pellet generates with help of the detector and the MCA the energy spectrum displayed in Fig. 3. Two structures inside the spectrum are due to the $662\,\mathrm{keV}$ γ-photons: The$662\,\mathrm{keV}$ full energy photo peak and the according Compton continuum reaching from the first channel up to the so called Compton edge. The line at $32\,\mathrm{keV}$ (on the top of the Compton continuum caused by the $662\,\mathrm{keV}$ γ-photons) is due to the X-ray photons. As Compton scattering inside the detector is negligible at $32\,\mathrm{keV}$ there is no Compton continuum belonging to the X-ray line in the spectrum.

This means the areas under the $662\,\mathrm{keV}$ full energy photo peak and the Compton continuum and the $32\,\mathrm{keV}$ X-ray line must be separated and determined. We also have to take into account the energy dependence of the intrinsic efficiency. For the used Gamma detector the intrinsic efficiency is 95% at $32\,\mathrm{keV}$ and decreases to 72% at $662\,\mathrm{keV}$. Last but not least we have to take care of the concurrence process to the emission of a X-ray photon, the Auger process. After an excitation of the electron shell due to internal conversion an Auger process takes places in 10% and a X-ray emission in 90% of all cases.

So for evaluation the number of $662\,\mathrm{keV}$ photons is measured by integration over the $662\,\mathrm{keV}$ photo peak and integration over the Compton spectrum and the number of $32\,\mathrm{keV}$ photons is measured by integration over the $32\,\mathrm{keV}$ peak minus the Compton background of the $662\,\mathrm{keV}$ line it sits on top of. In "measure" use "Analysis" > "Show integral..." as seen in Fig. 5. Then use the "Survey" tool to determine the height of the Compton spectrum to be subtracted from the $32\,\mathrm{keV}$ photo peak as seen in Fig. 6. Use "Analysis" > "Channel modification..." to subtract the height of the Compton background from all channels as seen in Fig. 7. Mark the $32\,\mathrm{keV}$ peak with the "Mark" tool that looks like a cross and use "Analysis" > "Show integral..." for evaluation of the number of incidents that belong to the peak.

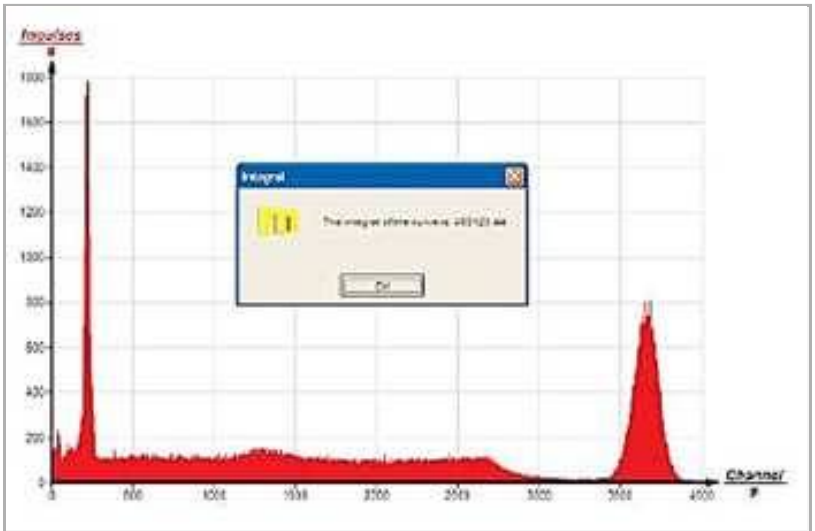

Fig. 5: Integration over the whole spectrum

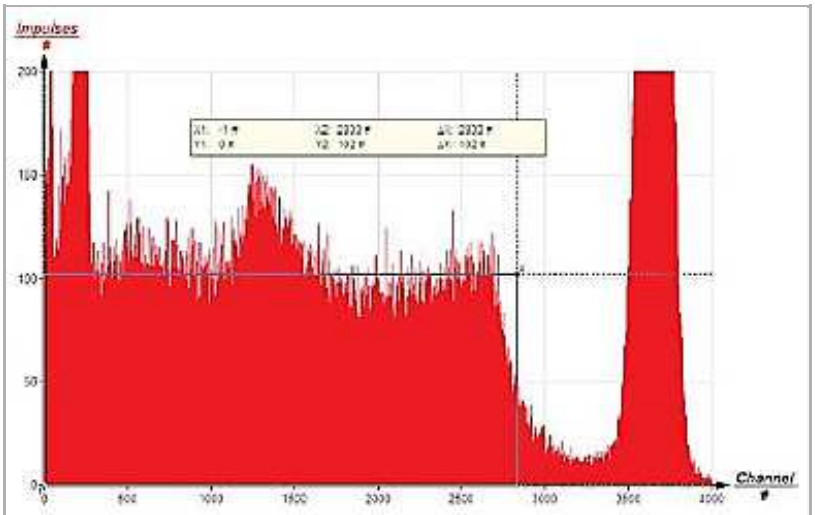

Fig. 6: Evaluating the number of Compton incidents belonging to 662 keV photons

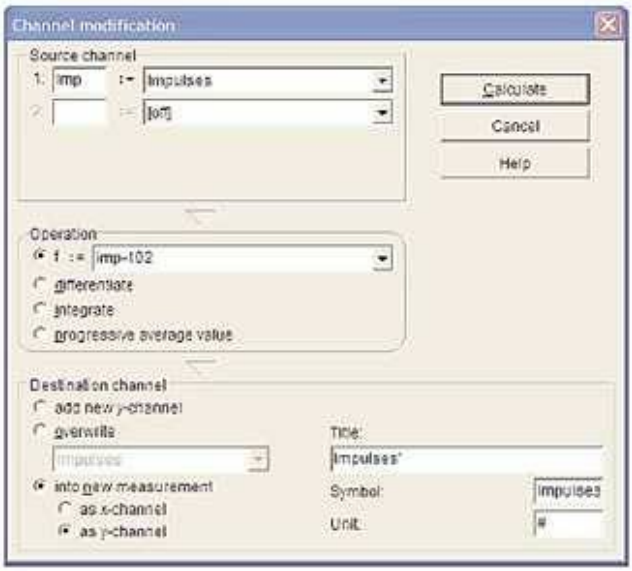

Fig. 7: Channel modification

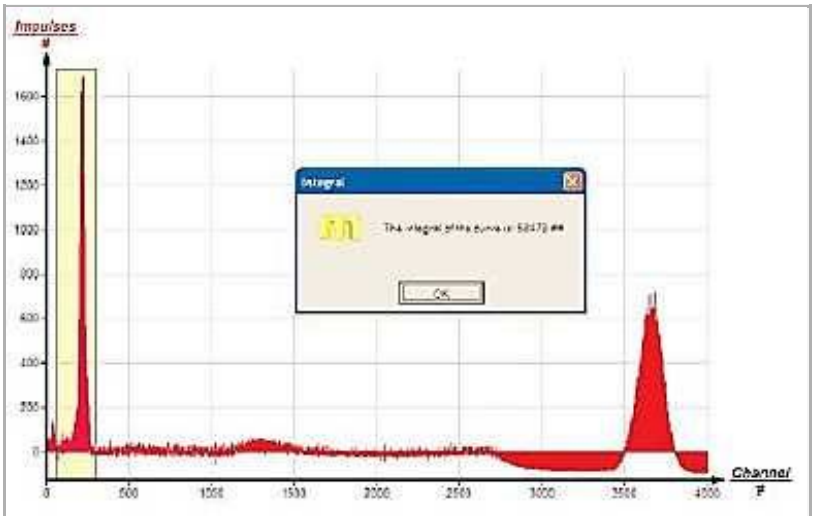

Fig. 8: Integration over 32 keV photo peak

The total number of $662\,\mathrm{keV}$ counts is the integral over the whole spectrum minus the $32\,\mathrm{keV}$ counts:

$$463123 - 58478 = 404645.$$

With intrinsic efficiency of 72% were that $562006 = n_{\mathrm{phot}}$ incoming photons of $662\,\mathrm{keV}$ of $^{137m}\mathrm{Ba}$ decay.

The $32\,\mathrm{keV}$ peak contained 58478 incidents, that means with intrinsic efficiency of 95% were that 61556 incoming photons of $32\,\mathrm{keV}$ of K_{α} X-rays that were the result of inner conversion of $^{137m}\mathrm{Ba}$. If 10% of the inner conversions resulted in Auger electrons that had no detection probability, the number of inner conversions had to be $68395 = n_{\mathrm{ic}}$. The total number of $^{137m}\mathrm{Ba}$ decays was then

$$n_{\mathrm{phot}} + n_{\mathrm{ic}} = 0.108.$$

The literature value is 0.095.

The detection probabilities are of course not 95% and 72% because the solid angle of the detector volume seen from the source is much smaller, so the number of decays was in fact higher, but this does not alter the fraction unless geometric effects are energy dependent. But there are effects like backscattering from the source holder or detector housing and geometric sensitivity effects of the detector because of penetration depth that are energy dependent falsifying the result. Furthermore, there is a rate of inner conversion with L-shell electrons that result to a higher degree in Auger electrons also not taken in account.