

Study of the Alpha-energies of Ra-226 with MCA

(Item No.: P2522315)

Curricular Relevance



Difficulty



Difficult

Preparation Time



1 Hour

Execution Time



2 Hours

Recommended Group Size



2 Students

Additional Requirements:

- PC

Experiment Variations:

Keywords:

Decay series, radioactive equilibrium, isotopic properties, decay energy, particle energy, energy loss of alpha-particles in matter, semiconductor barrier layer

Overview

Short description

Principle

An α -particle striking the barrier layer of a detector diode generates a number of charge carriers proportional to the energy deposited in the barrier layer by the α -particle. The charge carriers are collected by the electrodes of the reversely biased diode and a current pulse results in the diode circuit. A preamplifier converts the current pulse to a voltage pulse, the multi channel analyser (MCA) processes the pulses by shaping their form such that the pulse height is proportional to amount of charge. The pulse is registered then by adding one count to a specific channel if its pulse height fits the pulse height interval of that channel or else rejecting it if the height does not fit any channel. The pulse height intervals of the channels strung together form a larger interval without overlap. The counts per channel plotted over channel number represent the pulse height spectrum which in turn corresponds to the energy spectrum of the α -particles reaching the detector, if all the pulse forming processes are completely linear plus if all the α -particle's energy is deposited in the barrier layer.

α -particles coming from an open ^{241}Am -emitter in a vacuum are used for calibrating the set-up. It is assumed that they have no energy losses before reaching the detector. The remaining peak width is assigned to limited detector resolution and assumed to be only little asymmetric around the peak centre due to detector front covering.



Equipment

Position No.	Material	Order No.	Quantity
1	Multichannel analyser	13727-99	1
2	measure Software multi channel analyser	14452-61	1
3	Alpha and Photodetector	09099-00	1
4	Radioactive source Am-241, 3.7 kBq	09090-03	1
5	Radioactive source Ra-226, max. 4 kBq	09041-00	1
6	Container for nuclear physics exp.	09103-00	1
7	Pre-amplifier f.alpha detector	09100-10	1
8	Vacuum gauge DVR 2, 1 ... 1000 hPa	34171-00	1
9	Diaphragm pump, two stage, 220V	08163-93	1
10	Vacuum tube, NBR, 6/14mm, 1 m	39289-00	2
11	Tubing connector, Y-shape, ID 8-9mm	47518-03	1
12	Pinchcock, width 20 mm	43631-20	1
13	Screened cable, BNC, l = 750 mm	07542-11	3

Tasks

1. The spectrum of an uncovered ^{241}Am emitter is recorded with the MCA. The energy of the principal peak, corresponding to a particle energy of 5.486 MeV , is used for calibration.
2. Some air is used to slow down the α -particles of known energy resulting in a mean energy shift and a peak broadening. The mean energy loss to peak broadening relation is measured and assumed to be linear in a range above 2.8 MeV .
3. The energy spectrum of the α -particles emitted from the covered ^{226}Ra source is recorded and evaluated.

Set-up and procedure

Set-up and evaluation

Set-up

Fig. 1 shows the experimental set-up.

The black shielding is mounted on the detector and the detector is attached to the flange cover. The uncovered ^{241}Am source is put into the black detector shielding up to the bedstop so the source is as near to the detector as possible. The sliding rod is retracted and secured with the milled screw. The flange cover is mounted to the experimental container.

The upper two switches of the preamplifier have to be set to " α " and "Inv.". The "Bias" switch has to be set to "Ext." and the polarity switch for the internal bias should be kept to "-" to avoid accidental wrong polarisation of the detector diode.

The short BNC cable is used to connect the experimental vessel to the "Detector" socket of the α -preamplifier. One of the other BNC cables connects the "Bias" socket of the α -preamplifier with the "Bias" socket of the MCA. The bias selector switch of the MCA is to be set to " -33 V ". The other BNC cable connects the "Output" socket of the α -preamplifier with the "Input" socket of the MCA. The 5-pole cable connects the " $\pm 12\text{ V}$ " jack of the MCA with the corresponding socket of the α -preamplifier.

Turn MCA and preamplifier on right at the beginning so they have time to thermalise before starting the measurement. But complete the electrical connections and the preamplifier settings prior to turning on the MCA.

The MCA is connected by USB to a computer with "measure"-software installed on it. It may be necessary to remove a by "Windows" automatically installed USB driver and to install the correct USB driver for the MCA manually if the MCA is used with the computer the first time.

Procedure

Close the venting screw of the flange cover and evacuate the experimental vessel. When the final pressure achievable with the pump is reached, close the pinch cock and then turn off the vacuum pump. Start the "measure" program, select "Gauge" > "Multi Channel Analyser". Select "Spectra recording" and use the "Continue" button (Fig. 2).

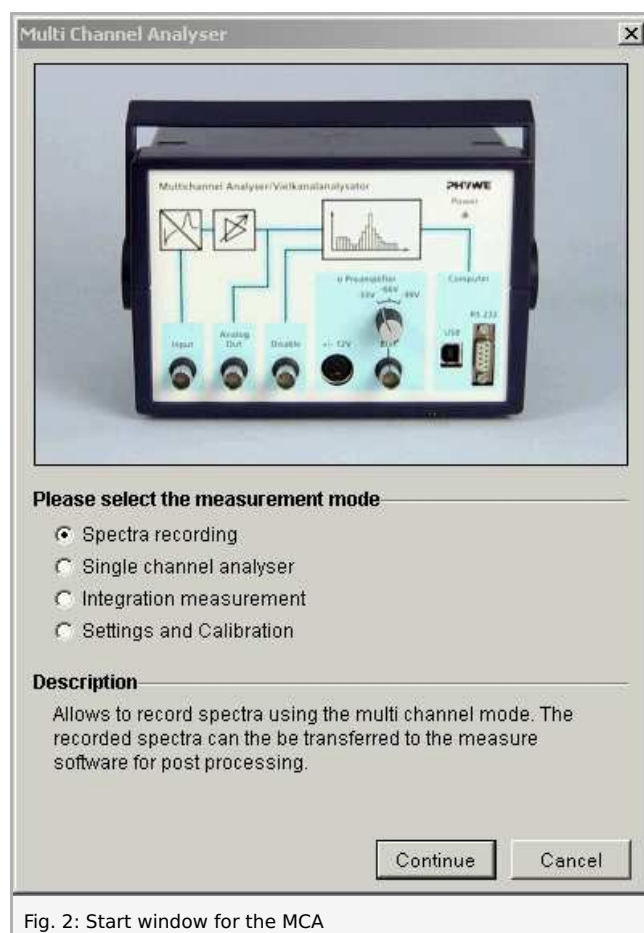


Fig. 2: Start window for the MCA

Set "Gain" to "Level 2" and "Offset [%]" to 5. The counting rate should be between 50 and 60 per second.

Select "Channel number" as "X-Data" and "1" as "Interval width [channels]".

Stop the measurement with the "Accept data" button, when the position of the main ^{241}Am -peak is clearly visible for evaluation. 5000 impulses should be sufficient for this purpose.

Student's Sheet

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The recorded data appear now in a window in the "measure" main program. Denote the measurement parameters using the "Display options" dialog and save the measurement data.

Vent the vessel until the pressure is 500 hPa and record a spectrum at this pressure collecting about 10000 impulses. "Accept data" and save the resulting spectrum.

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Fully vent the experimental vessel and record a spectrum at ambient pressure (about 1000 hPa) the source still right in front of the detector collecting again about 10000 incidents.

Exchange the ^{241}Am source with the ^{226}Ra source: Push the ^{226}Ra source up to the bedstop into the black detector shielding. Evacuate the vessel again and record a spectrum of the radiation with the same settings as before. The counting rate should be between 200 and 250 per second. Record about a quarter of a million impulses. Finally use the "Accept data" button.

Theory and evaluation

Theory

For a short sketch of α -decay theory refer to LEP 5.2.20-15. α -particles interact strongly with matter because of their electric charge and are stopped by some cm of air or some tens of μm of condensed matter. At the beginning of their path the energy loss in matter is nearly proportional to the path length or the electron density. This holds in case the α -energy is still higher than 2.8 MeV.

Here in the experiment the ^{226}Ra source in use is covered so all α -particles originating from it have to pass some material when leaving the source before they reach the detector. The source covering leads to a specific peak broadening and since the energy loss is proportional to layer thickness and all α -particles have to cross the same covering, the mean energy loss in the cover may be assumed to be equal for all of them.

Another effect can broaden the peak and shift the mean energy: The emitting nuclides may not sit in an indefinitely thin layer underneath the source cover but may be dispersed in some metal of some layer thickness so α -particles coming from different depth undergo different energy losses and peak broadenings.

The effects of peak energy shift and energy distribution broadening due to source cover and depth distribution of the nuclides can be discerned by comparing actual peak form to peak form caused by a layer of matter resulting in a specific energy loss.

The ^{226}Ra source can be considered to be in radioactive equilibrium with its decay products up to ^{210}Pb , which has 22.3 years of half-life. All branches of the decay series cross this nuclide and your source may not be old enough to be in equilibrium with the products following this nuclide. So the fraction of ^{210}Po may be significantly lower depending on the production date of your source and the related peak may not be present. Actually you can calculate the source's age by comparing the ^{210}Po peak height with neighbouring peaks. So the peaks to be expected in an intensity that can be registered in this experiment are:

4784 keV	^{226}Ra
5304 keV	^{210}Po
5489 keV	^{222}Rn
6002 keV	^{218}Po
7687 keV	^{214}Po

nuclide	decay mode	half-life	E / MeV	product of decay
^{238}U	α	$4.468 \cdot 10^9 \text{ a}$	4.270	^{234}Th
^{234}Th	β^-	24.10 d	0.273	^{234}Pa
^{234}Pa	β^-	6.70 h	2.197	^{234}U
^{234}U	α	245500 a	4.859	^{230}Th
^{230}Th	α	75380 a	4.770	^{226}Ra
^{226}Ra	α	1602 a	4.871	^{222}Rn
^{222}Rn	α	3.8235d	5.590	^{218}Po
^{218}Po	α 99.98 % β^- 0.02 %	3.10 min	6.115 0.265	^{214}Pb ^{218}At
^{218}At	α 99.90 % β^- 0.10 %	1.5 s	6.874 2.883	^{214}Bi ^{218}Rn
^{218}Rn	α	35 ms	7.263	^{214}Po
^{214}Pb	β^-	26.8 min	1.024	^{214}Bi
^{214}Bi	β^- 99.98 % α 0.02 %	19.9 min	3.272 5.617	^{214}Po ^{210}Tl
^{214}Po	α	0.1643 ms	7.833	^{210}Pb
^{210}Tl	β^-	1.30 min	5.484	^{210}Pb
^{210}Pb	β^-	22.3 a	0.064	^{210}Bi
^{210}Bi	β^- 99.99987% α 0.00013%	5.013 d	1.426 5.982	^{210}Po ^{206}Tl
^{210}Po	α	138.376 d	5.408	^{206}Pb
^{206}Tl	β^-	4.199 min	1.533	^{206}Pb
^{206}Pb		stable		

Table 1: Radium decay series

nuclide	fraction produced per atom ^{226}Ra	E / keV	main α -emission line /keV	fraction of α -particles
^{226}Ra	100 %	4871	4784.34	94.45 %
^{222}Rn	100 %	5590	5489.48	99.920 %
^{218}Po	100 %	6115	6002.35	99.9789 %
^{218}At	0.02 %	6874	6693	89.91 %
^{214}Bi	99.9 %	5617	5452	0.0113 %
^{218}Rn	0.10 %	7263	7129.2	99.870 %
^{214}Po	99.98 %	7833	7686.82	99.9895 %
^{210}Po	99.99987 %	5408	5304.33	99.9988 %

Table 2: Expected α -radiation from the ^{226}Ra source

^{241}Am decays to 100 % to stable ^{237}Np and in 85 % of the decays an α -particle of 5486 keV is emitted which contributes to the main peak.

Fig. 4 shows a decay scheme and Table 1 lists decay data for ^{241}Am . The 5.486 MeV line is used here for calibrating the setup.

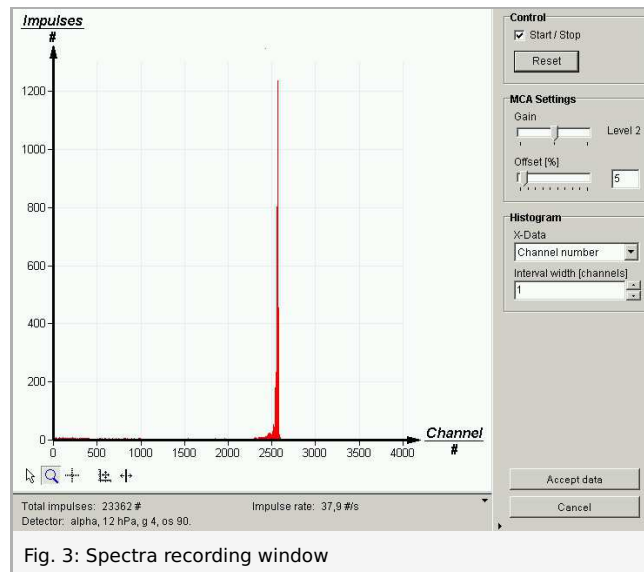


Fig. 3: Spectra recording window

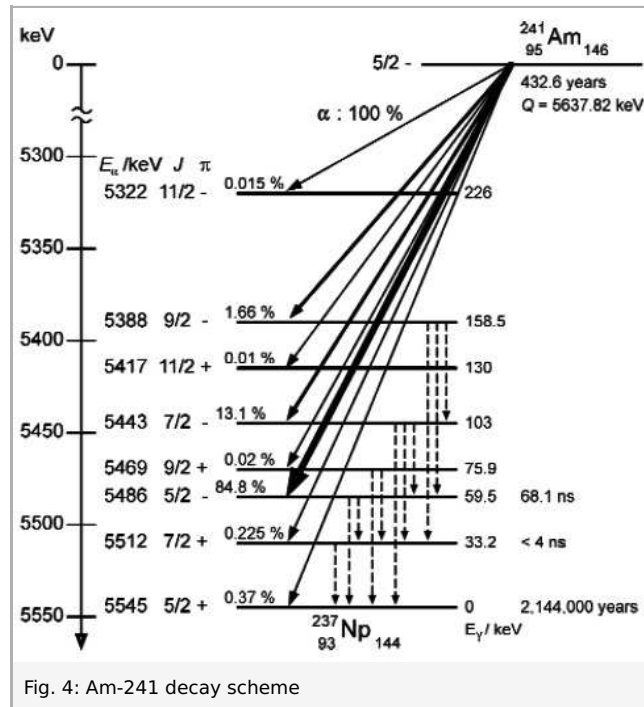


Fig. 4: Am-241 decay scheme

Reaction: ${}^{241}_{95}\text{Am}_{146} \rightarrow {}^{237}_{93}\text{Np}_{144} + {}^4_2\text{He}_2 + \Delta E$			
α -Energy/keV	Fraction/%	${}^{237}\text{Np}$ state/ $J\pi$	γ -Energy/keV
5544.5	0.37	5/2 +	-
5511.5	0.225	7/2 +	33.2
5485.6	84.8	5/2 -	59.5, 26.3
5469	0.02	9/2 +	75.8, 42.7
5442.8	13.1	7/2 -	103, 69.8, 43.4
5416.5	0.01	11/2 +	
5388	1.66	9/2 -	125.3, 99, 55.6
5322	0.015	11/2 -	

Table 3: ${}^{241}\text{Am}$ decay radiation

Evaluation

Results for the ${}^{241}\text{Am}$ -radiation may look like Fig. 5.

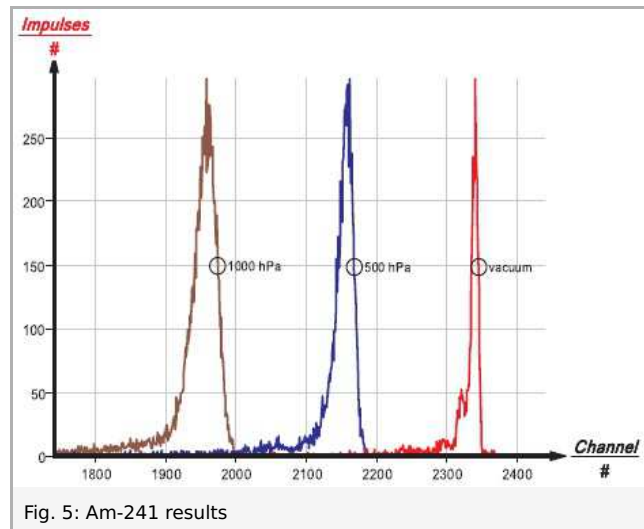
You may use "Measurement" > "Adopt channel..." to display several measurement results in a single plot.

In the "measure" main program zoom in on the interesting region of your measurement curve either using the -tool (magnifying glass) or using the mouse - clicking and holding while moving the mouse on the x- or y-scale will move the graph if left mouse button is used or will alter the magnification if the right mouse button is used.

Use the "Survey" function (-button) to determine the positions of the peaks to be evaluated: Determine the full width at half maximum (FWHM) of the main peak. Assume the peak centre to be the mean value of the positions of both peak sides at half maximum. Alter the scaling if necessary.

hPa, air	peak/height/counts	FWHM	x_1 /ch. #	x_2 /ch. #	$(x_1+x_2)/2$ /ch.
11	260	11	2335	2346	2340.5
500	266	25	2144	2169	2156.5
1000	366	39	1937	1976	1956.5

Table 4: "Survey" read-outs for ^{241}Am with x_1 position of left side of peak at half maximum and x_2 position of right side of peak at half maximum



The MCA cuts an interval from 0 V to 4 V into 4000 equal intervals each assigned to a single channel, so each channel represents an interval of one mV . The offset function shifts the whole 4-V -interval about the specified percentage of 4 V . For example the offset 5% means that the measuring interval begins at $0.050 \cdot 4.000\text{ V} = 0.200\text{ V}$. Then the zero channel counts pulses between 0.1995 V and 0.2005 V and the 3999th channel counts pulses between $4.1935\text{ V} \dots 4.2005\text{ V}$.

Here the offset setting was 5% and the main peak is at channel $\# n = 2340.5$, then the original pulse height P was:

$$P = 0.05 \cdot 4\text{ V} + 2340.5 \cdot 0.001\text{ V} = 2.5405\text{ V}$$

or

$$P = (n + 200) \cdot 1\text{ mV},$$

the number 200 is 5% of 4000 channels.

With the α -energy of 5486 keV given this yields a sensitivity s of the detector set-up of

$$s = \frac{2.5405\text{ mV}}{5486\text{ keV}} = 0.4631 \frac{\text{mV}}{\text{keV}}$$

as calibration factor. The energy E corresponding to a channel number n is then

$$E = \frac{(n+200)}{s}$$

The dependence of the peak width σ on mean energy loss ΔE shows Table 5 and Fig. 7 is a graphic plot of these data.

peak ch. #	Δ ch.	ΔE /keV	σ /ch.	σ /keV
2340.5	0	0	11	23.8
2156.5	-184	397.3	25	54.0
1956.5	-384	829.2	39	84.2

Table 5: Peak width in dependence on energy loss

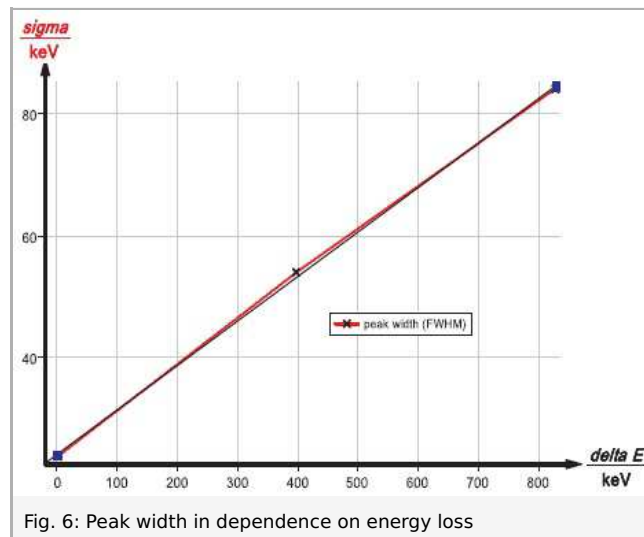


Fig. 6: Peak width in dependence on energy loss

The line of best fit is

$$\sigma = 0.073 \cdot \Delta E + 24.2 \text{ keV}$$

where the 24.2 keV are due to the limiting resolution of the detector.

Fig. 7 shows a spectrum of the α -emissions of the ^{226}Ra source combined with the ^{241}Am results. Use the "measure" function "Analysis" > "Smooth..." to obtain a curve where you can evaluate the peak positions and peak width more ease. Four lines can be evaluated. The whole line profile is visible as one line. Table 6 summarises the results.

n/ Ch. #	E/keV	Literature value/keV	energy loss ΔE /keV	peak displacement/ channels
2897	6688	7687	999	463
2027	4809	6002	1193	552
1744	41988	5489	1291	598
1407	3470	4784	1314	608

Table 6: Example of measurement results

The peak width FWHM of the peak with the highest energy was 211 channels or 456 keV. On the other side if the mean energy loss of 999 keV was equal for all α -particles, this would result in a peak width according to (*) of 97 keV or 45 channels.

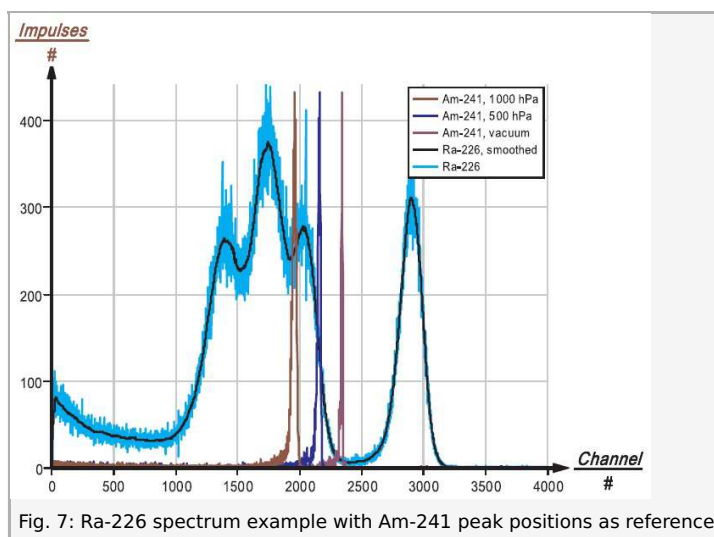


Fig. 7: Ra-226 spectrum example with Am-241 peak positions as reference

A peak width of about 166 channels or 358 keV is due to layer thickness of the layer containing the nuclides. So if same density of material is assumed for nuclide containing metal and cover, the layer containing the nuclides has about 36% the thickness of

the cover.

As the values for the energy loss show, the assumption of linearity of energy loss with layer thickness or the energy independence of energy loss rate is only very roughly fulfilled. A deviation of 30 % is observed over the energy range of the measurement. A displacement of the daughter nuclides by recoil inside the source can be excluded because the α -particles from the daughter nuclides show less loss.

