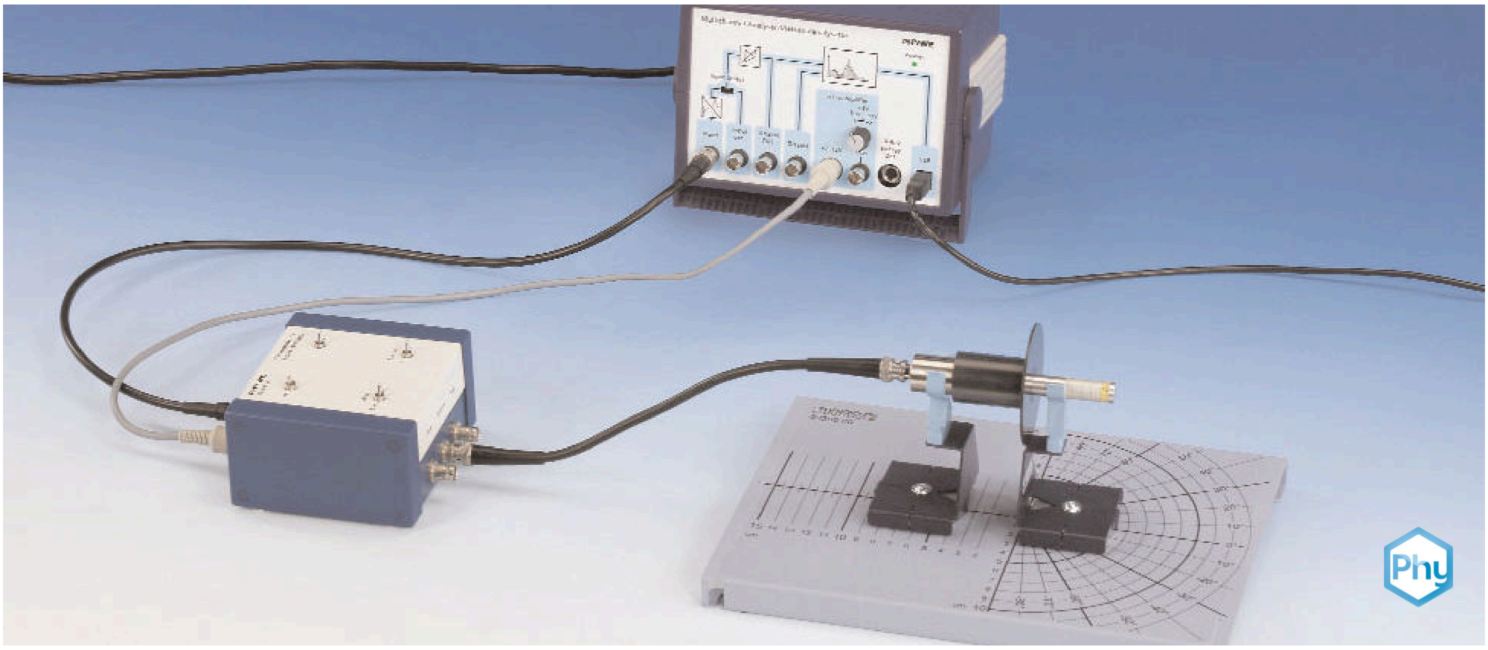
Alpha energies of different sources with MCA



Physics | Modern Physics | Nuclear & particle physics

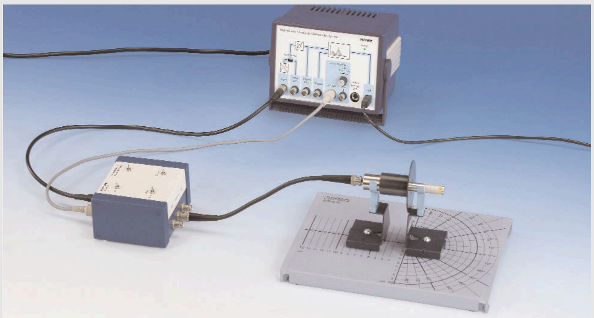
Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/5fb6d29d8d4c7f0003d4930e

General information

Application



Setup

Radioactive materials can be identified by the specific energies of their radiation. As such weakly radiating sources can be used in medicine to identify problems in the metabolism of the patient.

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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

An α-spectrometer, consisting of a photodetector, a preamplifier and a multi channel analyser (MCA) is calibrated with the help of two α-emission lines of a $^{226}\mathrm{Ra}$ source which is in radioactive equilibrium with its decay products. The α-emission energy of a $^{241}\mathrm{Am}$ source and other detectable lines of the $^{226}\mathrm{Ra}$ source are determined. The α-energies found in this way are assigned to the corresponding nuclides of the radium decay series.

Other information (2/2)

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Learning objective

The goal of this experiment is to learn the principle behind α-spectroscopy.

Tasks

1. Perform a two-point calibration of the set-up with the $^{226}\mathrm{Ra}$ source.
2. Record the a-spectrum of $^{226}\mathrm{Ra}$ with the same settings as in the calibration.
3. Record the α-spectrum of the $^{241}\mathrm{Am}$ source.
4. The α-energies corresponding to the individual peaks of the α-spectrum of the radium decay series and the main $^{241}\mathrm{Am}$ source α-energy are determined and compared to literature values.

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Theory (1/5)

The α-decay is a special form of nuclear fission, where a nucleus splits into an α-particle, which is the helium nucleus ${}^{4}_{2}\mathrm{He}^{2+}_{2}$, and a nucleus with mass number 4 less, atomic number 2 less and neutron number 2 less than the initial nucleus. An example is the reaction

$$^{226}_{88}\mathrm{Ra}_{138} \rightarrow \ ^{222}_{86}\mathrm{Ra}^{2-}_{136} + \ ^{4}_{2}\mathrm{He}^{2+}_{2} + \Delta\mathrm{E}$$

alternatively written as

$$^{226}_{88}\mathrm{Ra}_{138} \rightarrow \ ^{222}_{86}\mathrm{Ra}^{2-}_{136} + \alpha + \Delta\mathrm{E}$$

According to the liquid drop model of the atomic nucleus, an \alpha-decay sets energy free for all nuclei heavier than 165 atomic mass units while proton emission does not yield net energy. The \alpha-particle has to overcome the short-range attracting force of strong nuclear interaction to be set free and to gain energy from the relatively long-ranged repelling force of Coulomb interaction.

Theory (2/5)

So an α-particle inside a heavy nucleus is in a metastable state and has to cross a potential barrier to be emitted which can only happen by tunnel effect. The tunnel effect favoures the emission of smaller particles over heavier ones so the rate of other spontaneous fission incidents is always lower than the rate of α-decay incidents.

In case of higher energy gain by α-decay the potential barrier is thinner and the decay more likely, that is the half-life is shorter. On the other hand potential wall curvature is less for heavy nuclei so α-particles from high Z nuclei may have higher energy, which is both stated by the Geiger-Nuttall law.

Because the emission of α-particles is favoured over emission of bigger nuclear fragments, heavy nuclei may have to undergo several decays until they get sufficiently small to be stable.

The neutron fraction of nucleons needed for stability has to be larger in heavy nuclides than in light nuclei. An β-particle carries away the same numbers of neutrons and protons. It lowers thus the neutron excess. So α-decays transforming protons to neutrons need to occur in the resulting decay series (or-chain), too. Table 1 lists such a decay series.

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Theory (3/5)

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Typical α-decay energies are around 5 MeV, so the a-particles gain a speed of 15,000 km/s or 5% of the speed of light. Decay momentum is split evenly between both reaction partners but the lighter α-particle gains the main fraction of the reaction energy. Still the recoil energy of the decaying heavy nucleus is in the range of 100 keV, thus much higher than binding energy of the outer electrons or chemical or lattice binding, and may not be neglected. α-particles interact strongly with matter because of their electric charge. They 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.

nuclide	decay mode	half-life	E / MeV	product of decay
^{238}U	α	$4.468 \cdot 10^9$ 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	3.8235 d	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

Theory (4/5)

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Here in this experiment the sources in use are covered so all α-particles have to pass some material before leaving the source and some millimetres of air before they reach the detector. The effect of the source covering prevails over the effect of the air and leads to a peak broadening. This limits the energy resolution to greater extent than the limited resolution of the detector.

The energy loss in the source cover and air is unknown but can be assumed to be roughly constant for all α-particles so in case of assumed detector linearity (at least) two calibration lines are necessary to calibrate the set-up.

The $^{226}\mathrm{Ra}$-source can be considered to be in radioactive equilibrium with it's decay products up to $^{210}\mathrm{Po}$, 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 $^{210}\mathrm{Po}$ 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 $^{210}\mathrm{Po}$ peak height with neighbouring peaks. So the peaks to be expected in an intensity that can be registered in this experiment are:

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Theory (5/5)

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

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 $^{226}\mathrm{Ra}$ source

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

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Equipment

Position	Material	Item No.	Quantity
1	Alpha and Photodetector	09099-00	1
2	Pre-amplifier for alpha detector	09100-10	1
3	PHYWE Multichannel Analyser (MCA)	13727-99	1
4	measure Software multi channel analyser	14452-61	1
5	Radioactive source Am-241, 3.7 kBq	09090-03	1
6	Radioactive source Ra-226, max. 4 kBq	09041-00	1
7	Base plate for radioactivity	09200-00	1
8	Source holder on fixing magnet	09202-00	1
9	Counter tube holder on fixating magnet	09201-00	1
10	Screened cable, BNC, l 250 mm	07542-10	1
11	Screened cable, BNC, l = 750 mm	07542-11	1

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Setup and Procedure

Setup

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The upper two preamplifier switches have to be set to "α"and "Inv.". The "Bias" switch has to be set to "Int." and the polarity switch for the internal bias must be kept to "–". Wrong polarisation of the detector diode is to be avoided. The short BNC cable is used to connect the detector to the "Detector" socket of the α-preamplifier. The other BNC cable connects the "Output" socket of the -preamplifier with the "Input" socket of the MCA. The 5-pole cable connects the "+/-12 V" jack of the MCA with the corresponding socket of the α-preamplifier. Complete the electrical connections and preamplifier settings prior to turning on the MCA. You may allow some minutes warm up time for the preamplifier before starting the measurement. The MCA is connected by USB to a computer with "measure"- software installed on it. It may be necessary to remove a USB driver that "Windows" installs automatically and to install the correct USB driver for the MCA manually if the MCA is used with the computer for the first time. The black shielding is mounted on the detector and the detector is attached to the counter tube holder on fixing magnet. The $^{226}\mathrm{Ra}$ source is put into the source holder and inserted into the black detector shielding up to the bedstop – so the source is as near to the detector as possible.

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Procedure (1/4)

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Start the program "measure", select "Gauge" > "Multi Channel Analyser". Select "Settings and Calibration" and press the "Continue" button (Fig. 1).

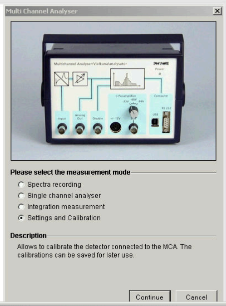
The "Settings" window appears as in Fig. 2. Use the "Calibrate" button. Then the window of Fig. 3 appears.

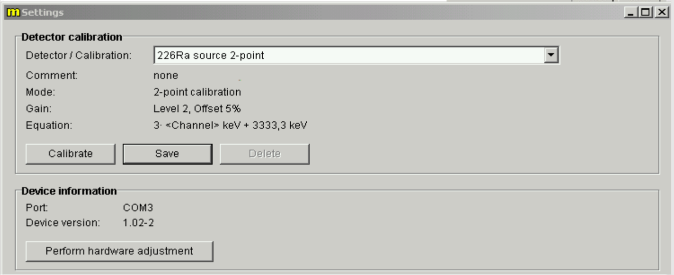
Set the "Calibration mode" to "2-point calibration", "Unit" to "keV" and type "4784" and "7687" into the fields for the calibration energies.

Set "Gain" to "Level 2" and "Offset [%]" to 5.

Fig. 1: Start window for the MCA →

Fig. 2: Calibration settings window ↓





Procedure (2/4)

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Set the "Calibration mode" to "2-point calibration", "Unit" to "keV" and type "4784" and "7687" into the fields for the calibration energies.

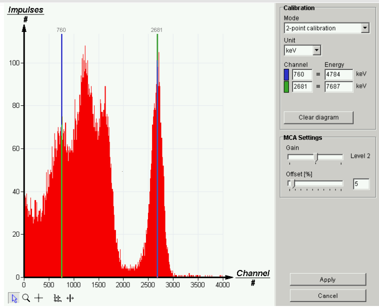
Set "Gain" to "Level 2" and "Offset [%]" to 5.

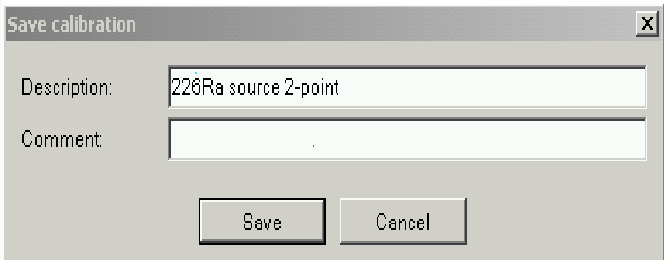
Move the bars to the corresponding peaks as seen in Fig. 3. Use the "Apply" button, then click the "Save" button in the window of Fig. 2 that appears again.

Enter an appropriate name for the calibration and use the "Save" button of Fig. 4. Use the "Close" button in the window of Fig. 2. Select "Spectra recording" in the window seen in Fig. 1 and use the "Continue" button.

Fig. 3: Calibration window with Ra-226 →

Fig. 4: Naming the calibration ↓





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Procedure (3/4)

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The "MCA spectra recording" window opens. See Fig. 5. Set "Gain" to "Level 2" and "Offset [%]" to 5. Select "Energy" as "X-Data" and "1" as "Interval width [channels]". Counting rate is now around 160 per second. Record data until the peak positions are well visible, approx. 15 minutes.

Stop the measurement with the "Accept data" button. 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.

Fig. 5: Spectra recording window with Ra-226

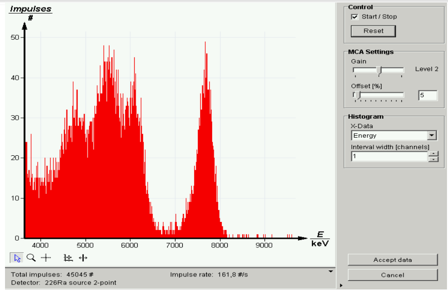
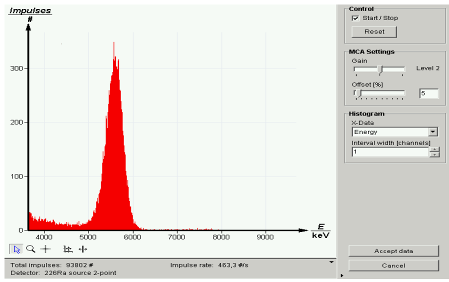


Fig. 6: Spectra recording window with Am-241



Procedure (4/4)

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Replace the $^{226}\mathrm{Ra}$ source with the $^{241}\mathrm{Am}$ source, again the source as close to the detector as possible. Start a measurement with all other settings unchanged. The counting rate should be around 450 per second. See Fig. 6.

Record 120.000 impulses or 5 minutes.

Use the "Accept data" button to end measurement and save the data after denoting the measurement parameters.

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Evaluation

Evaluation (1/2)

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For better visibility of the maximum of the peaks and reduced noise apply the "Smooth" function of "measure" using the -button. See Fig. 7. You may alter the appearance of the curve with the "Display options" function (-button) for example by choosing on the "Channels" chart of the "Display options" dialogue "Straight lines" for "Interpolation:".

Fig. 7: "Smooth" dialog box

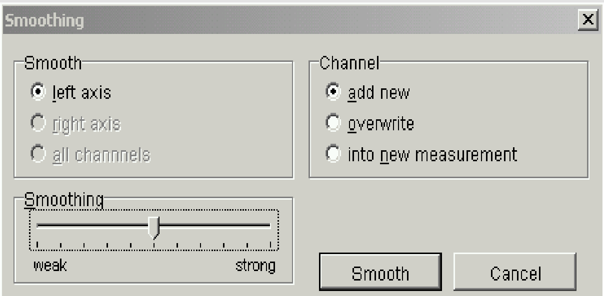

Table 3: Measurement results

measured energy / keV	literature value / keV	deviation
5498	5489	0.16 %
6065	6002	1.05 %
5582	5486	1.75 %

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Evaluation (2/2)

Then use the "Survey" function (button) to determine the position of the -peaks to be evaluated and read out the energies in keV. See Figs. 8 and 9. Also read out with help of the "Survey" function a full width at half maximum (FWHM) energy value to asses the measurement accuracy.

FWHM of the $^{241}\mathrm{Am}$-peak is 424 keV at 5486 keV centre or 7.7%. So the literature values could be reproduced well though the presence of source cover and air broadened the energy distribution of the a-particles reaching the detector.

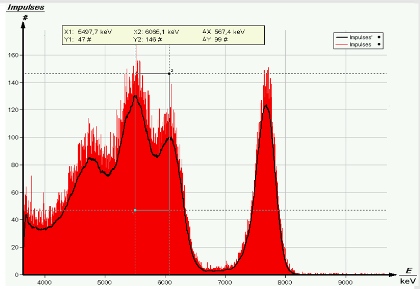

Fig. 8: Ra-226 measurement data

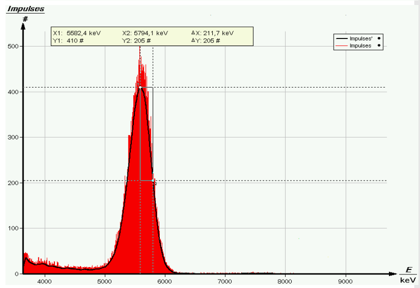

Fig. 9: Am-241 measurement data

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