Fine structure of the α-spectrum of ^{241}Am

LEP
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Related topics

Energy level diagram (decay diagram), transition probability, excited nuclear states, γ-emission, connection between the fine structure of the α-spectrum and the accompanying γ-spectrum.

Principle and task

The α-spectrum of an open ^{241}Am-emitter is measured with a semi-conductor α-detector, maximum use being made in this case of the resolution capacity of the pulse height analyzer. Use is made for this purpose of the "Magnifier" function, which is an additional amplification stage having in the effect that only that proportion of the pulses exceeding the threshold voltage of 5 V undergoes further processing. The pulse peaks above this threshold are amplified 6 times and restricted to a maximum of 10 V. Fig. 2 shows the voltage U applied to the magnifier input, as a function of the output voltage U_L delievered by the magnifier amplifier and applied to the window discriminator. This is represented by the expression:

$$U = \frac{1}{5} U_L + 5 \text{ V} \tag{1}$$

To determine the α-energies, it is then necessary from the measured values U_L, corresponding to the individual spectrum peaks, to calculate in a accordance with equation (1) the corresponding voltages U_i as the magnifier input. The energies E_i for the individual lines can be calculated from the voltages U_i assuming an energy E_o = 5.486 MeV for the principal peak. The corresponding expression is

$$E_i = E_o \cdot \frac{U_i}{U_o}, \tag{2}$$

U_o being the pulse height in relation to the magnifier input, determined for the principal peak in accordance with equation (1).

Equipment

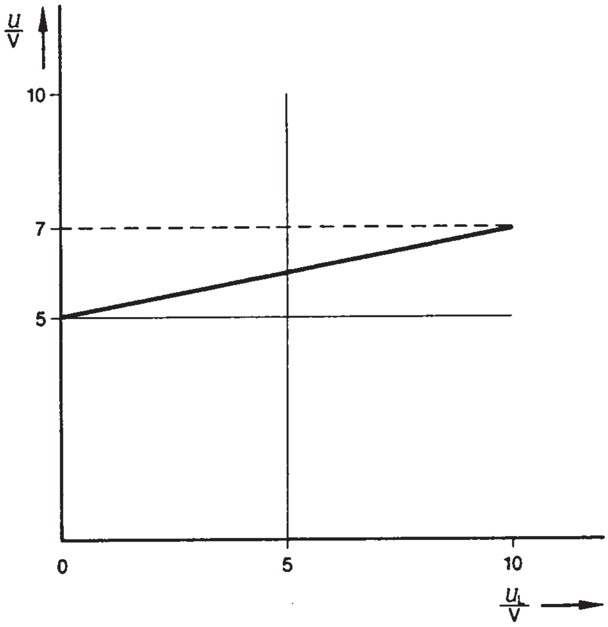
Americium-241 source, 3.7 kBq	09090.03	1
Container f. nuclear phys. expts.	09103.00	1
Alpha detector	09100.00	1
Pre-amplifier f. alpha detector	09100.10	1
Impulse height analyser	13725.93	1
xyt recorder	11416.97	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
Range multiplier, vacuum	11112.93	1
Moving coil instrument	11100.00	1
T-connection NW 10	02668.13	1
Hose nipple NW 10	02668.12	2
Centring and sealing ring NW 10	02668.04	3
Clamping ring NW 10	02668.03	3
Adapter for vacuum pump	02657.00	1
Rubber tubing, vacuum, i.d. 8 mm	39288.00	2
Pinchcock, width 20 mm	43631.20	1
Screened cable, BNC, l 750 mm	07542.11	4
Connecting cord, 750 mm, red	07362.01	2
Connecting cord, 750 mm, blue	07362.04	2

Problems

1. The spectrum of an open ^{241}Am-emitter is recorded with the *xyt*-recorder at the maximum resolution capacity of the measurement layout, using automatic window movement.

Fig. 1: Experimental set-up: Fine structure of the α-spectrum of ^{241}Am.

Fig. 2: Magnifier function of the pulse height analyser.



The energy of the two peaks preceding the principal peak is calculated. The principal peak, corresponding to a particle energy of 5.486 MeV, is used for calibration purposes.

2. The resolution capacity of the measurement layout is measured from the half-life width of the principal peak.

Set-up and procedure

Fig. 1 shows the complete measurement layout with the α-detector located in the measurement vessel. The open ^{241}Am source is screwed to the adjustable source holder in the vessel.

The resolution capacity required for resolution of the fine structure of the α-spectrum necessitates a voltage of -100 V at the α-detector. This voltage is taken by means of a BNC cable from the corresponding socket of the pulse height analyzer to the “Bias” socket of the α-preamplifier. The “Bias” switch on the preamplifier must be in the “Ext” position.

The pulse height analyser is initially disconnected (no voltage at the α-detector).

Preparation

- Evacuate the vessel to about 0.8 hPa.
- Close the vacuum tube with a pinch cock.
- Disconnect the pump (the pressure will rise to about 1 hPa; the vacuum will be sufficient provided that the pressure remains clearly below 5 hPa).
- Switch on the pulse height analyzer.
- Note: A voltage of -100 V is now applied to the detector; the pressure range between 10^{-2} hPa and 1 hPa should be avoided, since at this voltage under unfavourable conditions the detector can be damaged by the formation of a microplasma (gas discharge).
- Move the source to a distance of 4 mm from the detector.
- Note the pulse height on the oscilloscope (time factor: 20 μs/cm) and adjust the amplification of the pulse height analyzer so as to obtain a pulse height of about 5.5 V.
- Press the “Magnifier” key and select an amplification setting so as to obtain an optimal compromise between resolution capacity and the statistical errors resulting from the counting rate. The greater the amplification, the lower will be the resolution capacity of the discriminator with a simultaneous increase in the counting rate. The optimal setting must be determined from a series of measurements.
- It is recommended that the pulse height on the oscilloscope should be initially adjusted to about 3 V.
- Note: The horizontal line behind the pulse does not correspond to the zero line but to a voltage of about -0.5 V. The zero line is obtained by a temporary short-circuiting of the oscillsocope input (input switch in the “GND” position); the pulse heights are measured from this line.

Setting of the *xyt*-recorder

- Adjust the zero-point setting in such a way that with no input voltages (i.e. with the zero key pressed on the recorder) the recording stylus is located in the lower left-hand corner of the recording surface.
- Set the pulse height analyzer on “Manual” operation.
- Search for the intensity peak of the spectrum, i.e. set the pulse height analyzer on the maximum pulse rate with the “Base” adjusting knob and select the γ-sensitivity of the recorder in such a way that proper use can be made of the height of the recording surface with a 1 % window setting.
- Set the “Base” adjusting knob on 0.5 V (corresponding to 50 scale divisions) and select the *x*-sensitivity of the recorder in such a way that the recording carriage is located immediately adjacent to the right-hand limit of the recording surface.
- Lower the recording stylus briefly, marking the point on the *x*-axis corresponding to this pulse height.

Recording the spectrum

The following settings are made on the pulse height analyzer:

Window: 1 %
Base: corresponding to the maximum pulse height +0.5 V
Timing cycle: 3.2 s

- Press the Auto/Man key (for “automatic scanning” operation).
- Press the “Zero” key.
- Lower the recording stylus.
- Press the “Start/Stop” key and record the spectrum.

Theory and evaluation

Fig. 3 shows a simplified energy level diagram for the α-decay of ^{241}Am. Five different transition possibilities are apparent from the basic state of the ^{241}Am into different excited states of the ^{237}Np isotope. The energy differences are sufficiently great for the resolution capacity of the measuring equipment to ensure separation of the anticipated five emission lines. It is however evident from the transition probabilities given in the tabel below that detection of α-transitions 4 and 5 may give rise to problems.

Transition No.	E_α (value from the literature)	Transition probability (%)
1	5.389	1.3
2	5.443	12.7
3	5.486	86
4	5.513	0.12
5	5.545	0.25

Fig. 4 shows a ^{241}Am spectrum, in which the two peaks 1 and 2 preceding the principal peak are clearly apparent. A slight shoulder at the bottom of the heigh-energy arm of the principal peak is also apparent.

The α-energies corresponding to lines 1 and 2, obtained from this spectrum, are shown in the table below. The known value of 5.486 MeV has been assumed in this case for the α-energy of line 3 (the principal peak).

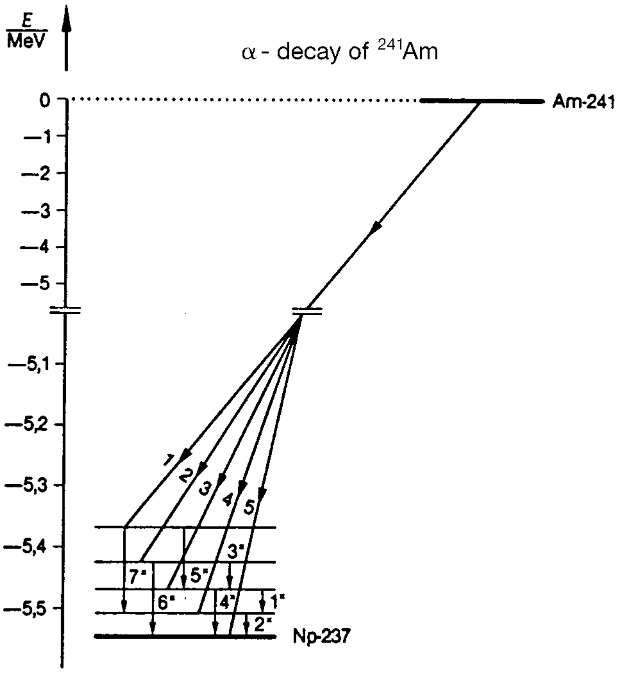
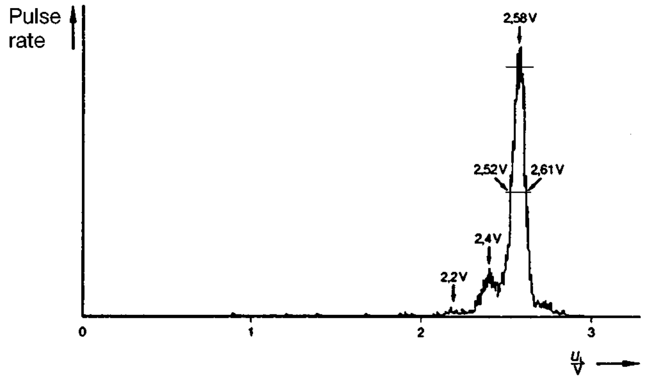


Fig. 3: Energy level diagram for the α-decay of ^{241}Am.

Fig. 4: Measured α-spectrum of ^{241} Am.



Line	U_L/V	U/V	E/MeV	E/MeV (value from the literatur)
2	2.2	5.44	5.410	5.389
2	2.4	5.48	5.450	5.443
3	2.58	5.516	(5.486)	5.486

Out of the five anticipated α-transitions, transitions 1, 2 and 3 can be clearly detected. Transitions 4 and 5 are responsible for the shoulder on the right side of the principal peak. Determination of the corresponding α-energies and separation of these two lines are not possible with the present method of measurement. The interaction of a wide range of error parameters has to be taken into account when assessing the accuracy of the energy measurements recorded here. The accuracy of the energy measurement in the present case is governed both by the uncertainty in determining the central points of the line in Fig. 4 (measurements U_L for lines 1, 2 and 3) and by the instrumental uncertainty of the amplification factor (+5 %) and of the amplification factor $\lambda = 5$ (±2 %) of the magnifier amplifier.

The instrumental errors only affect the measurement results to a very slight extent (about ±1.0 %), however, since the lines for measurement are very closely adjacent to the 5.486 MeV line used for calibration.

The α-energies E_1 and E_2 can be calculated from the pulse height U_{L1} and U_{L2} measured with the magnifier, using the formula

$$E_{1,2} = E_3 \frac{U_s + \frac{U_{L1,2}}{f}}{U_s + \frac{U_{L3}}{f}}$$

in which $E_3 = 5.486$ MeV (the error beeing less than 0.001 MeV can be disregarded),

$U_s = (5 \pm 0.25)$ V
$f = 5 \pm 0.1$
$U_{L1} = (2.20 \pm 0.05)$ V
$U_{L2} = (2.40 \pm 0.03)$ V
$U_{L3} = (2.58 \pm 0.01)$ V

The maximum anticipated errors can be easily estimated by calculating the α-energies from formula (1) and introducing the extreme values of the above parameters; it is legitimate in this case to combine errors with signs which affect the final result in the same direction.

The relevant values are summarized in the table below:

Line No.	$\frac{U_{L1,2}}{V}$	$\frac{U_s}{V}$	λ	$\frac{U_{L3}}{V}$	$\frac{E_{1,2}}{MeV}$
1	2.15	4.75	4.9	2.59	5.393
1	2.25	5.25	5.1	2.57	5.426
2	2.37	4.75	4.9	2.59	5.439
2	2.43	5.25	5.1	2.57	5.460

This yields the following result:

E_1 = 5.410 MeV ± 17 keV (± 0.3 %)
E_2 = 5.450 MeV ± 11 keV (± 0.2 %)

The literature value for line 1 is very slightly outside the calculated limits of error. One possible reason for this may be that the displacement of the peak of this very weak line toward larger pulse heights as a result of the rising arms of lines 2 and 3 was not taken into account.

The limited resolution capacity of the measuring equipment due to instrumental reasons is apparent from Fig. 4. The principal line has a half-life width which is obtained from the voltage values U_L = 2.52 V, U = 5.504 V and U_L = 2.61 V, U = 5.522 V.

The half-life width is:

5.49 MeV – 5.47 MeV = 20 keV.

Two α-energies can only be reliable separated if the distance between them is not less than this value. The resolution capacity in this energy range is therefore better than 0.4 %.

Comments

1. The resolution capacity is mainly determined by the quality of the detector. Impurities on its surface (oil film) and ageing (“radiation damage”) due to high radiation doses reduce the resolution capacity. Since a reduction in the resolution capacity is detectable even on exposure to 10^8 α-particles the source should be withdrawn from the detector as far as the stop at the end of the measurement. If the measurement apparatus is not to be used for a fairly long period, the vessel should be ventilated with operating voltage of the detector disconnected.

Particle rates in excess of 200/s at the detector (measured during “Integral” operation; threshold voltage about 0.4 V) are inadvisable, since the resolution capacity will in this case be reduced by the increased frequency of particles striking the detector during the recovery period. When working with more active sources, the optimal distance between the source and the detector should always be determined by an integral measurement of the pulse rate. Particles striking the edge of the detector crystal give rise to low pulse heights and again reduce the resolution capacity; this can be corrected by carefully centring the source by means of the lateral adjustment screws on the plate of the source holder.

2. If a digital counter is available, the α-transition 5 can be clearly detected by recording a few measurements manually in the corresponding pulse height range and counting the pulses. To reduce the statistical error, sufficiently large counting times should be selected to enesure that about 100 pulses are recorded per measurement.