Experimental mass excess of ^{49}K and ^{50}K

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The beta decay energy Q_β of the delayed neutron emitters ^{49,50}K produced by fragmentation of a uranium target with a 600 MeV proton beam has been determined. Energies of the beta transitions to well-located neutron emitting levels in the daughter nuclei have been measured by means of a scintillation telescope in coincidence with a large solid angle neutron time of flight spectrometer. The ^{49}K and ^{50}K inferred mass excesses, -30.33 ± 0.07 and -25.5 ± 0.3 MeV, respectively, are compared with mass predictions.

I. INTRODUCTION

The knowledge of the mass excess of nuclei far from stability is of basic interest, providing a sensitive test of nuclear models. As pointed out by Haustein[1] in a critical review of the predictive properties of various theoretical approaches, strong deviations may occur between experimental and calculated mass excesses on both sides of the valley of stability. The mass measurements of ^{49}K and ^{50}K have been performed in the framework of a systematic study[2–5] of the beta decay of the neutron-rich potassium isotopes $^{47-52}$K at the CERN on line mass separator. In the established decay schemes, beta delayed neutron emission occurs with $P_n=0.86$ and $P_n=0.29$ for ^{49}K and ^{50}K, respectively, allowing the measurement of beta spectra in coincidence with delayed neutrons to be made.

II. EXPERIMENTAL PROCEDURE

The isotopes are produced by bombarding a uranium carbide target with a 2 μA proton beam of the CERN 600 MeV synchrocyclotron. Typical production rates were 3×10^4 atoms/s for ^{49}K and 10^3 atoms/s for ^{50}K. The ion beam is mass separated in the ISOLDE facility and directed to a tape transport system with the detector setup, as illustrated in Fig. 1. The beta telescope which subtends a solid angle of 640 msr consists of a 0.5 mm scintillator sheet as an energy loss detector for gamma rejection and a 110 mm diameter, 100 mm long, plastic NE102 counter for energy analysis, with a resolution of 300 keV at 973 keV. A large area NE110 scintillator sheet, 160 cm long, 18 cm high, and 1.25 cm thick, bent in a radius of curvature of 100 cm is used for neutron time-of-flight spectrometry. It is optically coupled to two phototubes associated with a meantimer device yielding a time resolution of 1.1 ns. Neutrons are detected in a solid angle of 270 msr. On line calibration of the beta telescope has been achieved by means of ^{26}Na and ^{46,47}K isotopes collected at the ISOLDE separator in the same experiment and a ^{106}Ru radioactive source.

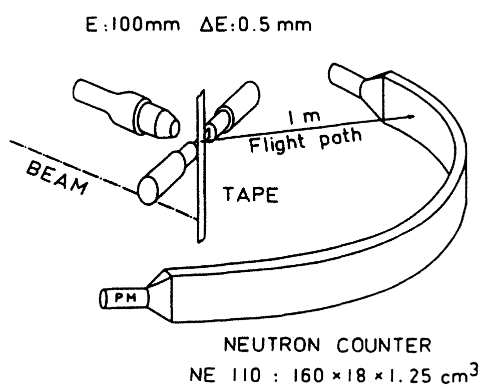

FIG. 1. Experimental setup.

III. BETA SPECTRA ANALYSIS AND RESULTS

The beta spectra are analyzed by the shape fitting technique described by Parks *et al.*[6] The adjusted function is of the form

$$BA_4(A_1-A_2CX+C^2X^2)(CX-A_3)^2 ,$$

where C is the stretch factor, X the channel number, and B the normalization coefficient. The terms A_i are determined by a least squares fit of the analytical expression to a reference beta spectrum with $C=1$ and $B=1$. Another least squares minimization on C and B is used to stretch or compress each calibration spectrum along the energy axis and to normalize the number of events. The stretch factors calculated are then plotted as a function of endpoint energies, and a linear fit is made to the data.

A. The ^{49}K nucleus

The decay scheme of this isotope[5] indicates strong feeding of neutron emitting levels in ^{49}Ca ($P_n=0.86$). In the

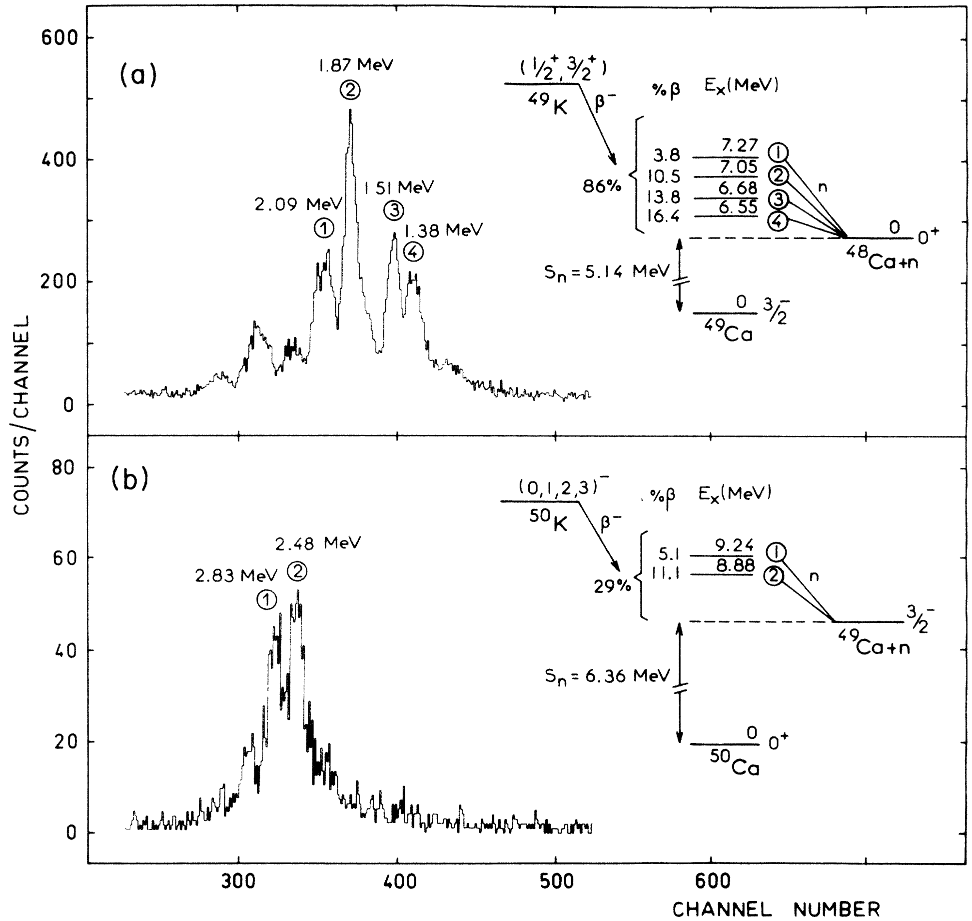

FIG. 2. Delayed neutron time of flight spectra registered (a) for ^{49}K and (b) for ^{50}K.

neutron time of flight spectrum [Fig. 2(a)] four lines corresponding to neutron energies $E_n = 2.09$, 1.87, 1.51, and 1.38 MeV were selected in order to obtain the coincident beta spectra feeding the excited levels in ^{49}Ca. From our previous studies of neutron spectra and neutron gamma coincidences, these neutron emissions are known to populate the ground state of ^{48}Ca. The collected data were analyzed in different ways: changing the region of fit, the channel width, and taking different spectra as a calibration reference. An example of the shape fitting analysis is given in Fig. 3(a). A typical set of results is listed in Table I. The stretch factors extracted from the beta shape

TABLE I. Typical stretch fit results for ^{49}K.

E_n (MeV)	E_x ^{49}Ca (MeV)	Stretch factor C	Reduced χ^2	E_β (keV)	Q_β (keV)
2.09	7.28(5)	0.706(20)	1.17	3906(113)	11 186(123)
1.87	7.05(4)	0.660(13)	0.65	4047(52)	11 097(65)
1.51	6.69(3)	0.616(15)	0.68	4183(59)	10 873(66)
1.38	6.55(3)	0.619(27)	1.40	4174(95)	10 724(100)

TABLE II. Typical stretch fit results for ^{50}K.

E_n (MeV)	E_x ^{50}Ca (MeV)	Stretch factor C	Reduced χ^2	E_β (keV)	Q_β (keV)
2.83	9.24(10)	1.387(145)	1.24	4802(600)	14 042(608)
2.48	8.88(7)	1.273(80)	1.07	5286(400)	14 166(406)

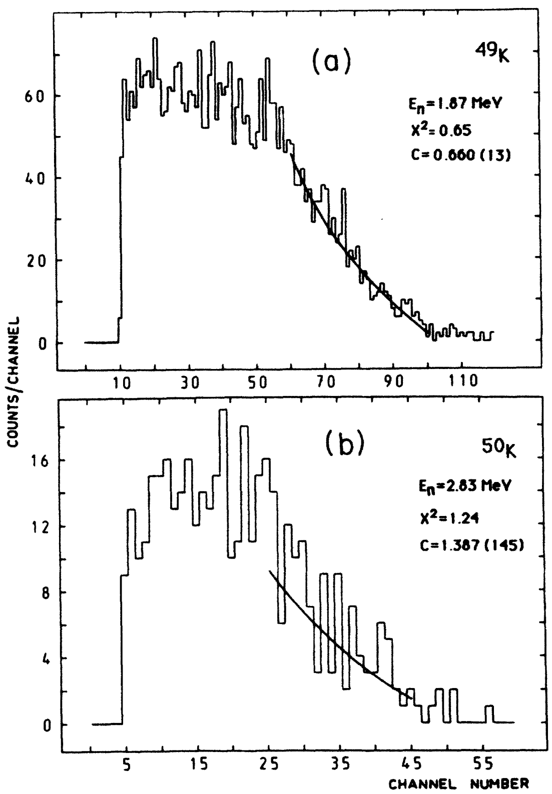

FIG. 3. The shape fitting analysis for (a) the ^{49}K beta spectrum in coincidence with the $E_n = 1.87$ MeV neutron line and (b) the ^{50}K beta spectrum in coincidence with the $E_n = 2.83$ MeV neutron line.

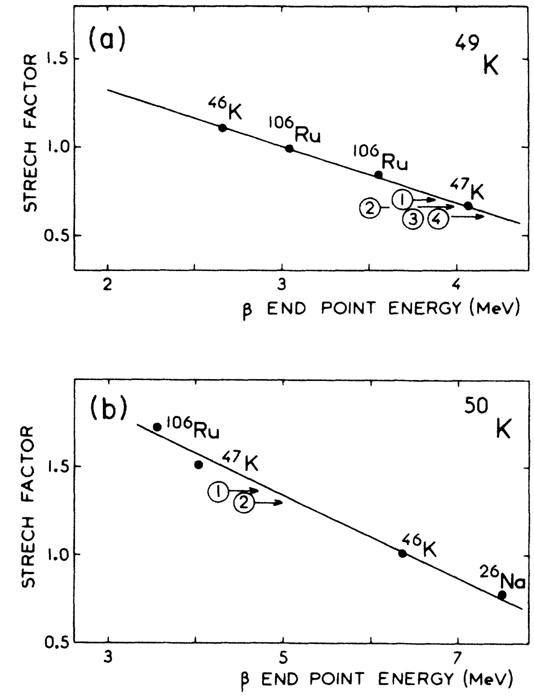

FIG. 4. Beta end-point energy calibration as a function of the stretch factor (a) ^{49}K and (b) ^{50}K.

fitting and injected on the corresponding calibration curve [Fig. 4(a)] yield the energy values E_β for the individual transitions from which four independent Q_β determinations are obtained. For each result the error takes into account the statistics and the energy uncertainty on the neutron emitting level. The weighted mean value of the overall analysis of the data (Table I plus other values) yields a Q_β of 10.97±0.07 MeV. In the final quoted error a 50 keV systematic uncertainty for the shape fitting procedure has been folded in.

B. The ^{50}K nucleus

Spectroscopic information on the beta decay of ^{50}K ($P_n = 0.29$) is known from previous work.[3] As shown in Fig. 2(b), only two neutron lines, at 2.83 and 2.48 MeV, could be considered for the beta neutron coincidence spectra. A fit of the beta spectrum in coincidence with the 2.83 MeV line is shown in Fig. 3(b). As in the preceding section, we report, in Table II and Fig. 4(a), a typical set of results for the Q_β determination. Again, the quoted errors include the contributions from statistics and level excitation energy errors. From the weighted mean value of all our results, a Q_β of 14.05±0.30 MeV is obtained. As for ^{49}K, a 50 keV systematic uncertainty for the method has been folded in.

IV. DISCUSSION

The experimental mass excesses of ^{49}K and ^{50}K listed in Table III are obtained from our Q_β measurements and the mass excess of ^{49}Ca and ^{50}Ca reported by Wapstra and Audi.[7] They are in rather good agreement with various mass estimates.[8,9] Predicted values are moderately dispersed for ^{49}K and close to the measured one. For the nucleus ^{50}K the calculated quantities are spread out between −22.22 and −26.0 MeV bracketing the experimental value.

TABLE III. Comparison of the experimental mass excess of ^{49}K and ^{50}K with various predictions.

Isotope	$(M-A)$ experimental (MeV)	$(M-A)$ calculated[a] (MeV)
		−30.89 Myers-Swiatecki
		−28.67 Myers
^{49}K	−30.33±0.07	−30.93 Groote
		−30.59 Jänecke
		−30.69 Comay-Kelson
		−30.67 Takahashi[b]
		−22.22 Möller-Nix
		−23.17 Myers
^{50}K	−25.5 ±0.3	−25.35 Groote
		−25.89 Jänecke
		−26.00 Comay
		−25.70 Takahashi[b]

[a]Reference 8, unless otherwise quoted.
[b]Reference 9.

Measurement of the beta spectra in coincidence with neutrons in order to determine the Q_β value of delayed neutron emitters is shown to be a powerful method to obtain mass excesses of neutron-rich isotopes far from stability. As the neutron emission occurs from a level for which gamma cascade feeding does not exist, a pure beta spectrum is obtained in coincidence with each neutron line.

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