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Experimental mass excess of ^{40}Cl and ^{42}Cl

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The beta-decay energy Q_β of the neutron-rich chlorine isotopes ^{40,42}Cl produced by fragmentation of a tantalum target with a 2-μA proton beam has been determined. Energies of the beta transitions to bound levels in the daughter nuclei were measured by means of a scintillation telescope in singles or in coincidence with a high-efficiency Ge(Li) gamma counter. The ^{40}Cl and ^{42}Cl inferred experimental mass excesses, -27.72 ± 0.08 and -24.66 ± 0.22 MeV, respectively, are compared to mass predictions.

I. INTRODUCTION

An argument often put forward against mass excess determinations via Q_β measurements is the level scheme dependence of the inferred values. Nevertheless, far from stability this method is sometimes the only way to obtain these fundamental quantities. In a beta decay with several high-intensity β branches, the measurement of different E_β values may check the reliability of the decay scheme and allow independent Q_β evaluations from which a mass estimate with relatively good precision can be inferred. Taking advantage of the gamma-ray spectrometry measurements performed in previous studies,[1,2] the Q_β measurements of ^{40,42}Cl have been undertaken. From this work a new determination of the ^{40}Cl mass excess is achieved and a first experimental value of the ^{42}Cl mass excess is obtained.

II. EXPERIMENTAL PROCEDURE

The heavy chlorine isotopes are produced by bombarding tantalum foils with a 2-μA proton beam from the CERN 600-MeV synchrocyclotron. Typical production rates of 10^5 atoms/s for ^{40}Cl and 2.10^3 atoms/s for ^{42}Cl have been obtained with a negative-ion source.[3] The ion beam is mass separated in the ISOLDE-2 facility and directed to a tape transport system, the counting station of which is equipped with a beta telescope[4] and a 33% relative efficiency Ge(Li) counter. The emitted electrons are detected in a 640-msr solid angle with an energy resolution of 300 keV at 973 keV. On-line calibration of the telescope is achieved by means of the ^{86,88}Br isotopes supplied by the ISOLDE-2 separator during the same experiment and a ^{106}Ru radioactive source. Direct beta spectra are registered and beta-gamma coincidences are event-mode recorded for subsequent playback. The beta distributions in coincidence with selected gamma transitions are obtained by appropriate gating conditions, each gate on a gamma line undergoing background subtraction by means of a second gate of the same width set close to the first one. The energy distributions are analyzed by the shape-fitting method described in Ref. 4; as low-energy beta branches to higher-located levels—connected to the state of interest by gamma transitions—are present in the spectrum, only the high-energy part free from their contribution is considered for the end-point determination.

III. RESULTS

A. The ^{40}Cl nucleus

According to the study of Klotz *et al.*,[1] the ^{40}Cl beta decay proceeds essentially to the ground state and to three excited levels in ^{40}Ar, as shown in the partial scheme of Fig. 1(a). In the present work, the ground-state transition and the β spectra registered in coincidence with the γ rays deexciting the levels at 4.1, 4.3, and 4.6 MeV have been analyzed. An example of the data reduction is given in Fig. 2(a), and the results obtained for the different distributions are summarized in Table I. The stretch factors deduced from the shape fitting of the β spectra are reported on the suitable calibration curve [Figs. 3(a) and 3(b)] yielding the end-point energies E_β of the different transitions. These quantities combined with the excitation energy of the corresponding final states provide four experimental values of Q_β for the $^{40}\text{Cl}\rightarrow{}^{40}\text{Ar}$ decay. For each, the quoted error takes into account uncertainties related to statistics, excitation energy, and calibration.

From the weighted mean of these independently determined values, a Q_β of 7.32 ± 0.08 MeV is obtained; in the

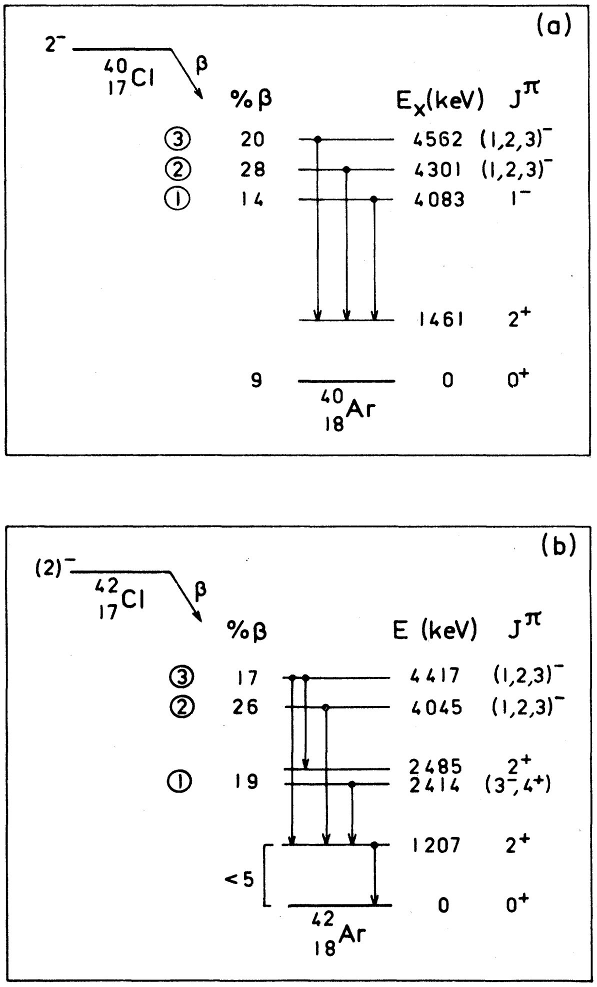

FIG. 1. Partial decay scheme (a) for ^{40}Cl and (b) for ^{42}Cl.

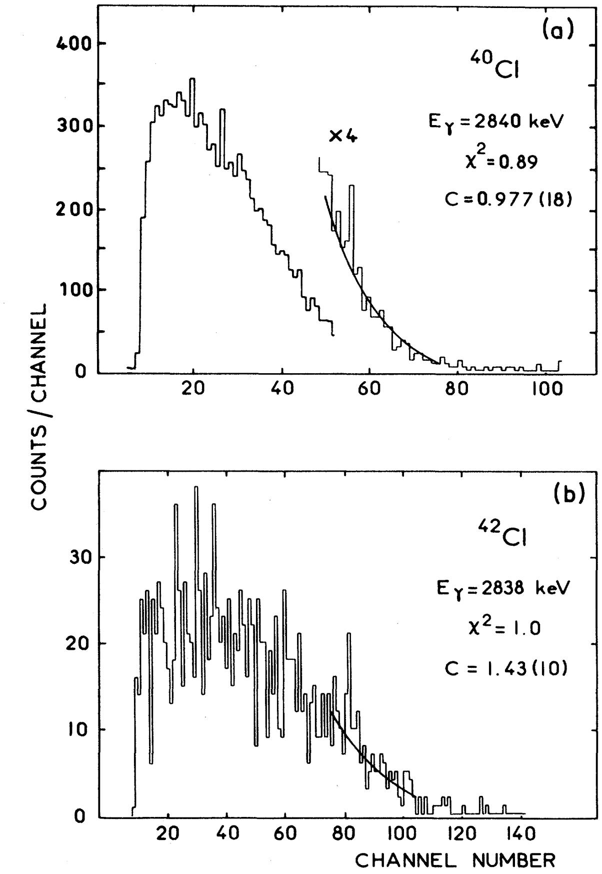

FIG. 2. The shape-fitting analysis for (a) the ^{40}Cl beta spectrum in coincidence with the $E_\gamma = 2840$-keV line and (b) the ^{42}Cl beta spectrum in coincidence with the $E_\gamma = 2838$-keV line.

final error a 50-keV systematic uncertainty for the shape-fitting procedure has been folded in. This result is significantly more precise than the earlier one ($Q_\beta = 7.5 \pm 0.5$ MeV) reported by Gurach *et al.*[5]

B. The ^{42}Cl nucleus

In a preliminary work[2] on the $^{42}\text{Cl} \rightarrow {}^{42}\text{Ar}$ beta decay, the feeding of the states in ^{42}Ar had been established, and strong transitions to the ground state and to the first excited state had been indicated as well as no beta branch to the second excited level located at 2414 keV.

The first evidence in our E_β measurements is that no significant ground-state transition $^{42}\text{Cl}[(2)^-]_{\text{g.s.}} \rightarrow {}^{42}\text{Ar}[0^+]_{\text{g.s.}}$ occurs, as the values of the beta end points yielded by the analysis of the direct distribution and the spectrum in coincidence with the 1207-keV line (Table II) are compatible within their error bars. The earlier reported ground-state beta feeding (20%) had been inferred from the comparison of the measured beta and

TABLE I. Stretch fit results for the direct beta spectrum and the beta distributions in coincidence with selected gamma rays for ^{40}Cl.

E_γ (keV)	E_x (^{40}Ar) (keV)	Stretch factor C	Reduced χ^2	E_β (keV)	Q_β (keV)
	0	1.019(7)	0.89	7390(118)	7390(118)
2622	4083	0.983(25)	0.84	3070(100)	7153(100)
2840	4301	0.977(18)	0.89	3086(75)	7387(75)
3101	4562	1.102(36)	1.08	2729(145)	7291(145)

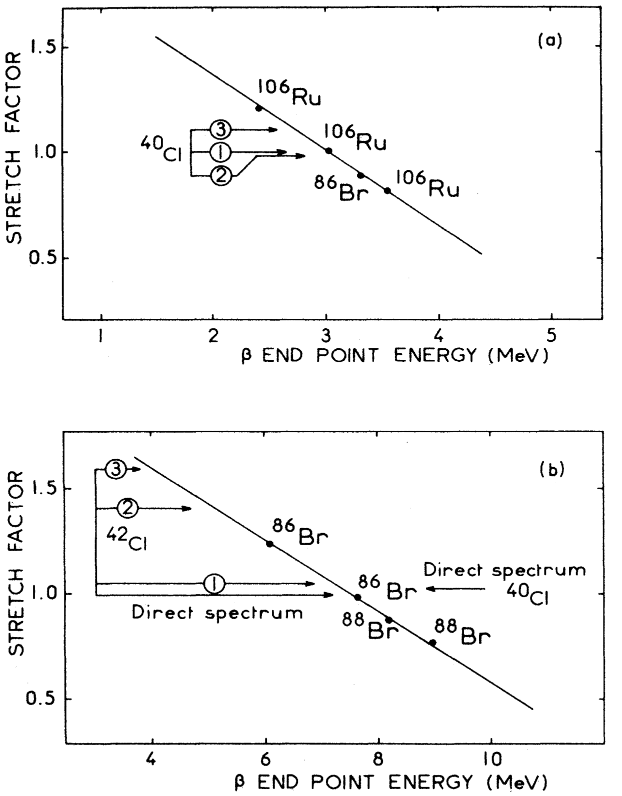

FIG. 3. Beta end-point energy calibrations as a function of the stretch factor.

gamma activities. At that time the noted overestimate presumably was due to a contamination of the mass-separated beam.

Additional information on the decay of ^{42}Cl being available from the present work, this opportunity has been seized to reconsider the earlier recorded gamma-ray spectrometry data. A revised decay scheme has been obtained which supersedes the previous one. As the quantitative analysis of the gamma-gamma coincidence data indicates strong beta feeding of the level at 2414 keV which deexcites by two coincident 1207-keV rays (2414→1207→0 keV), new beta-branching ratios are deduced from the gamma-in gamma-out imbalance for the levels in ^{42}Ar. A partial view of the decay scheme, indicating the gamma lines selected for the E_γ, E_β coincidence measurements is shown in Fig. 1(b). The relative intensity of the registered beta distributions feeding the 2.41-, 4.05-, and 4.42-MeV levels are in agreement with what is expected from the reported beta-branching ratios. For the state at 2414 keV, a $J^\pi = 4^+$ assignment had been preferred by Flynn *et al.*[6] as a result of the angular distribution of the ^{40}Ar(t,p) reaction; nevertheless, from their DWBA analysis, spin and parity 3^- could not be excluded, and such an attribution is now supported by the beta feeding of this state ($\log f_0 t = 6.2 \pm 0.1$) from the negative parity ^{42}Cl ground state. The direct beta spectrum and the distribution in coincidence with the 1207-keV line—showing one main component corresponding to the feeding of the 2414-keV level—have been quantitatively compared after suitable corrections for collection time and detection efficiency, in three energy windows respectively set at 6.15–7.35, 7.35–8.55, and 8.55–9.76 MeV. From this, an upper limit of 5% has been inferred for the beta feeding of the ground and first excited states in ^{42}Ar. As a consequence, in what follows, the E_β value obtained for the direct spectrum has to be associated to the energy of the second excited state for the Q_β value estimate.

The results of the analysis of the beta spectra are detailed in Table II. As an illustration, the shape fitting of the beta spectrum registered in coincidence with the 2838-keV line is shown in Fig. 2(b). The data reduction yields four independent Q_β values for which the quoted errors include the contributions from statistics, level excitation energy, and calibration uncertainties. A resulting Q_β value of 9.76 ± 0.22 MeV is deduced from the weighted mean of the four measured quantities. In the final error, as in the case of ^{40}Cl, a 50-keV systematic uncertainty for the shape-fitting method has been folded in.

IV. DISCUSSION

The experimental mass excess of ^{40}Cl and ^{42}Cl quoted in Table III are inferred from our Q_β measurements, and the mass excesses of ^{40}Ar and ^{42}Ar reported by Wapstra and Audi.[7] The obtained values are, respectively, $\Delta(^{40}\mathrm{Cl}) = -27.72 \pm 0.08$ MeV and $\Delta(^{42}\mathrm{Cl}) = -24.66 \pm 0.22$ MeV. For ^{40}Cl, the result can be compared (Fig. 4) to those deduced from the beta end-point measurement by Gurach and co-workers,[5] and from the transfer-

TABLE II. Stretch fit results for the direct beta spectrum and the beta distributions in coincidence with selected gamma rays for ^{42}Cl.

E_γ (keV)	E_x (^{42}Ar) (keV)	Stretch factor C	Reduced χ^2	E_β (keV)	Q_β (keV)
	2414[a]	1.000(23)	1.1	7479(230)	9893(230)
1207	2414	1.070(80)	1.1	7021(640)	9435(640)
2838	4045	1.430(100)	1.0	4676(1052)	8721(1052)
1932 3210	4417	1.540(140)	3.8	3959(1400)	8376(1400)

[a] The high-energy part of the direct spectrum is considered to correspond to the feeding of the 2414-keV level (see the text).

TABLE III. Comparison of the experimental mass excesses of ^{40}Cl and ^{42}Cl with various theoretical predictions.

Isotope	$(M-A)$ experimental (MeV)	$(M-A)$ calculated[a] (MeV)
^{40}Cl	-27.72 ± 0.08	-27.79 Myers[b]
		-28.04 Groote[b]
		-28.55 Möller-Nix
		-29.07 Möller *et al.*
		-27.64 (0.28) Comay-Kelson-Zidon
		-26.84 (0.20) Satpathy-Nayak
		-27.99 Tachibana *et al.*
		-27.62 Jänecke-Masson
		-27.48 Masson-Jänecke
^{42}Cl	-24.66 ± 0.22	-25.68 Myers[b]
		-25.74 Groote[b]
		-25.18 Möller-Nix
		-25.92 Möller *et al.*
		-24.56 (0.33) Comay-Kelson-Zidon
		-23.98 (0.27) Satpathy-Nayak
		-25.42 Tachibana *et al.*
		-24.59 Jänecke-Masson
		-24.18 Masson-Jänecke

[a] Reference 10, unless otherwise quoted.

[b] Reference 9.

reaction ^{40}Ar(^{7}Li, ^{7}Be)^{40}Cl study performed by Fifield *et al.*[8] The latter value is in slight disagreement with our determination (about 2.1 standard deviations), but the three experimental quantities are nevertheless compatible with various predictions.[9,10] For the nucleus ^{42}Cl, our measurement yields the first experimental value of the mass excess. Its comparison with the available predictions (Fig. 5) shows an excellent agreement with the Comay-Kelson-Zidon and the Jänecke-Masson calculations and with what is expected from the systematics.[7] More generally, it can be noticed that for the chlorine isotopes ($A = 35-44$) the theoretical estimates of these authors are the closest ones to the experimental mass excesses.

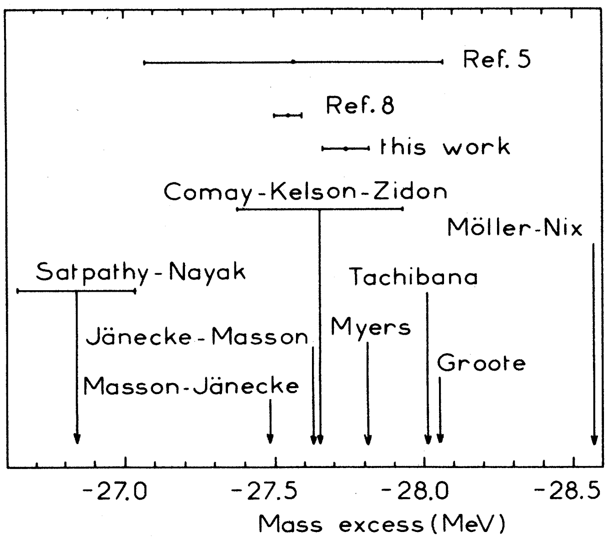

FIG. 4. Experimental and theoretical mass excesses for ^{40}Cl.

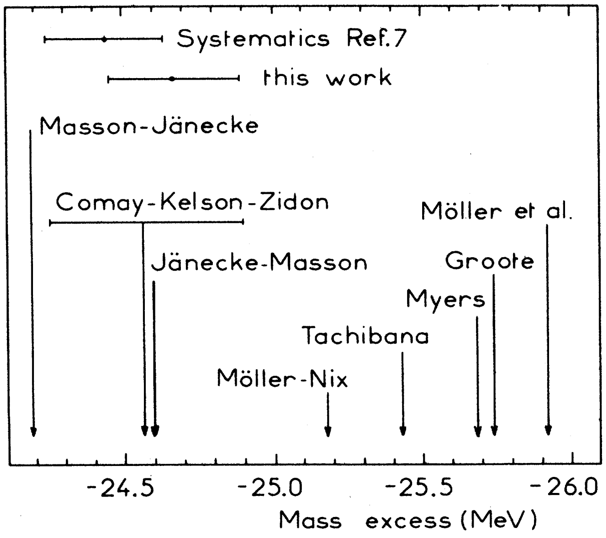

FIG. 5. Experimental and theoretical mass excesses for ^{42}Cl.

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