RELATIVE K-CAPTURE PROBABILITY IN THE UNIQUE FIRST-FORBIDDEN DECAY OF $^{145}_{62}$Sm

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The relative K-capture probability, P_K, for the unique first forbidden decay of ^{145}Sm to the 492.3 keV level in ^{145}Pm was measured by the coincidence method to be $P_K = 0.27 \pm 0.03$. This is compared with the theoretical values P_K(allowed) $= 0.70 \pm 0.03$ and P_K(unique forb.) $= 0.19^{+0.06}_{-0.05}$ calculated using the experimental decay energy $Q = 115 \pm 10$ keV.

1. *Introduction*

A comprehensive review of the experimental data as well as the theoretical estimations of the relative electron capture probabilities for various electron shells has been presented in 1968 at the Debrecen conference [1]. The increase in experimental accuracy and the need for more sophisticated calculations was emphasized. The importance of the corrections of the exchange and overlap type and of the contributions from the outer electron shells to the total capture rates were pointed out. While rather a large volume of data for the allowed and first-forbidden non-unique transitions has been presented there and elsewhere, there is almost no relevant information for the unique first-forbidden transitions not to mention the more strongly forbidden ones.

The aim of the present work is to furnish a piece of experimental data for the relative K-capture probability, P_K (the K-to-total capture ratio), for the unique first-forbidden decay of ^{145}Sm to the 492.3 keV level in ^{145}Pm (*cf.* Fig. 1). This can be done by measuring the ratio of the X-ray-492 γ coincidence counting rate, N^C_{X-492}, to the 492 γ singles counting rate, N^S_{492}. One obtains

$$P_K = \frac{N^C_{X-492}}{N^S_{492}\omega_K(\varepsilon\Omega)_X\varepsilon_C} \tag{1}$$

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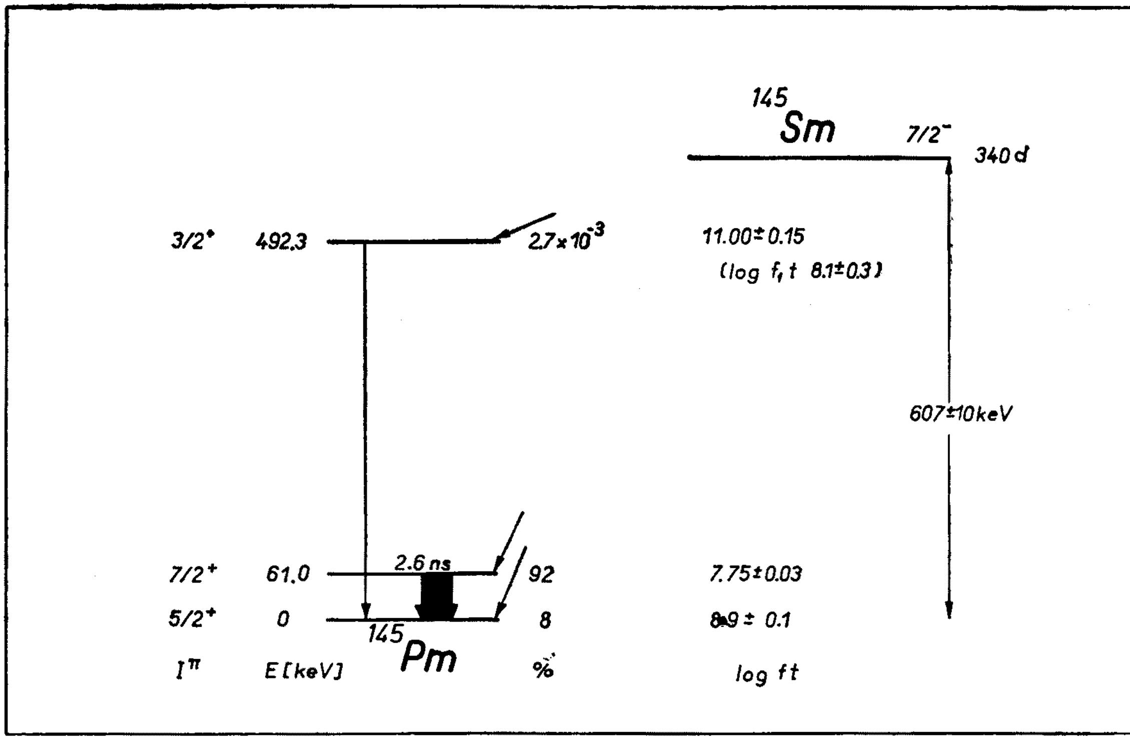


Fig. 1. Decay scheme of ^{145}Sm based on Refs [2, 3]. The 492.3±0.1 keV value for the 3/2$^+$ level in ^{145}Pm is re-determined here

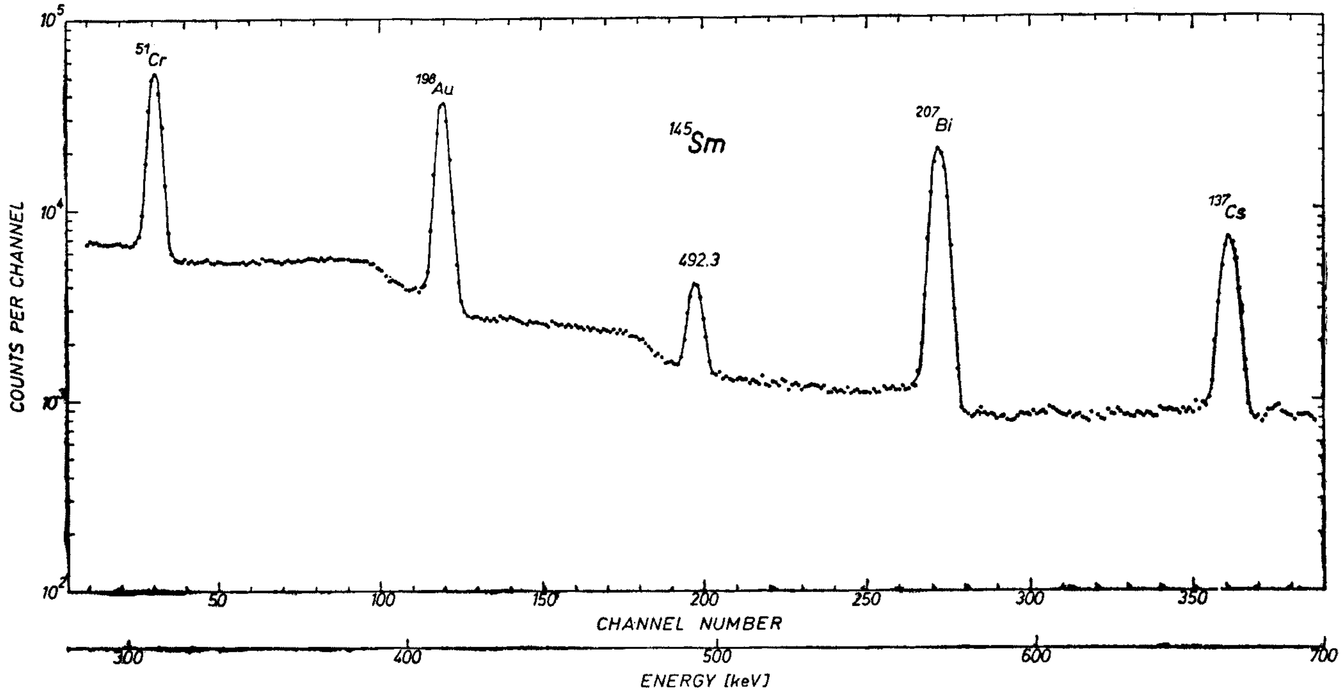
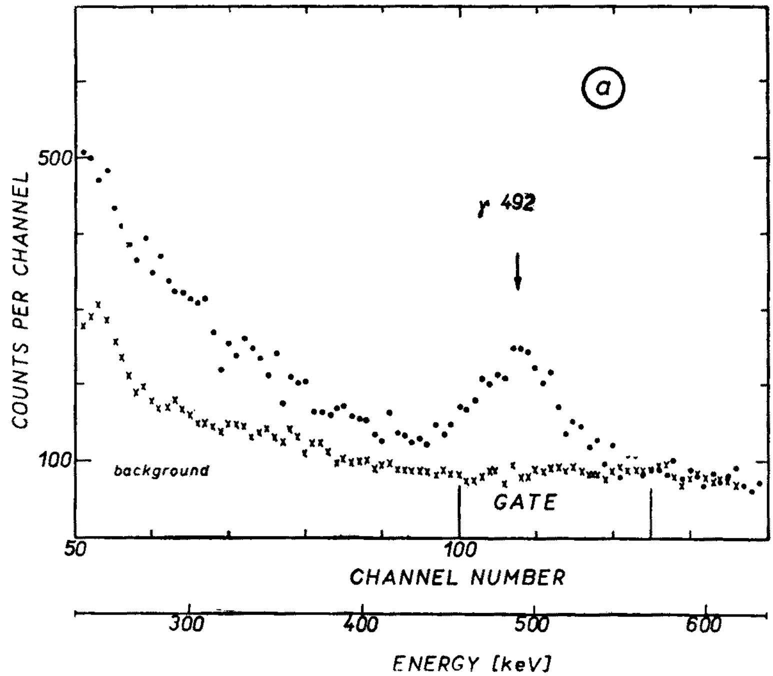


Fig. 2. Singles gamma-ray spectrum of ^{145}Sm with four calibration sources. 5 cm^3 Ge(Li) detector, 15h run



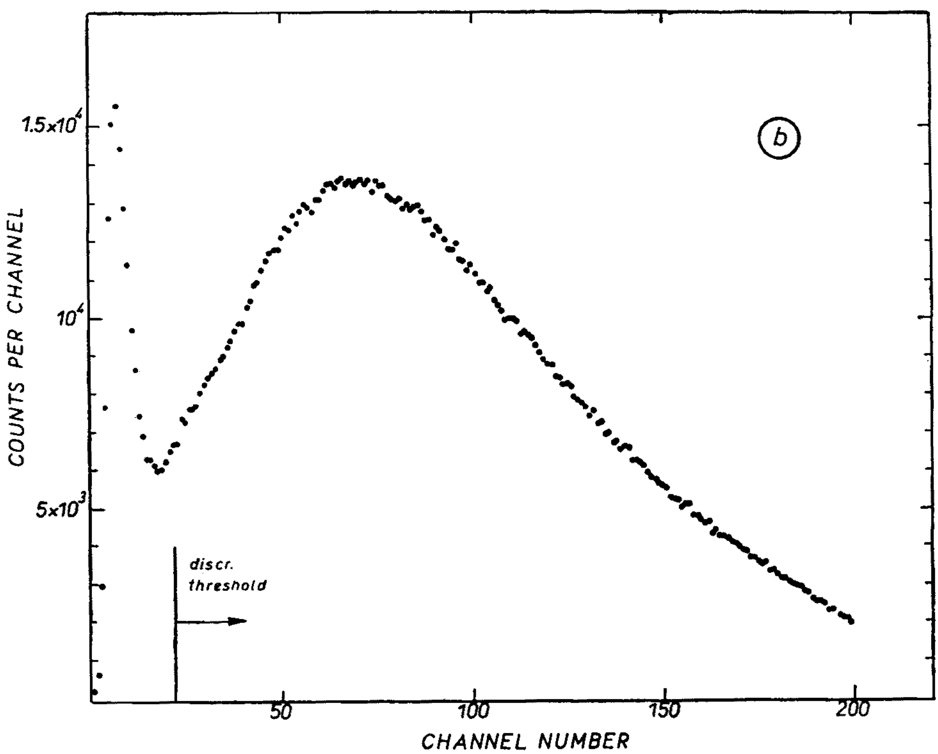


Fig. 3. Singles scintillation spectra and gates: a) γ-ray spectrum; 7.5 cm × 7.5 cm NaI(Tl) crystal, 56 AVP photomultiplier; b) X-ray spectrum; 5.12 cm × 1.5 cm plastic scintillator, Pilot B (loaded with 10% Pb); 56 AVP photomultiplier

where ω_K is the K fluorescence yield for Pm, $(\varepsilon\Omega)_X$ is the efficiency times the solid angle of the X-ray detector, and ε_C is the coincidence efficiency. The value obtained may be compared with theory provided the electron capture decay energy is known. The latter has been obtained for ^{145}Sm from the analysis of the internal bremsstrahlung singles and coincidence spectra in a separate experiment [2]: $Q_{EC} = (115 \pm 10)$ keV.

2. *Experiment*

2.1. Source preparation

The 340d ^{145}Sm activity of about 20 μC was obtained as a daughter product of ^{145}Eu. The latter was produced by bombarding a tantalum target in the inner beam of the 680 MeV proton synchrocyclotron of the JINR in Dubna and separated by standard chemical procedures. The Sm fraction was then purified several times by ion exchange methods. The purity of the source was checked using a Ge(Li) counter and found to be better than 10^{-7}, except for the 17y daughter product, ^{145}Pm.

2.2. Singles gamma-ray spectrum

The accurate energy value of the γ-ray transition de-exciting the $3/2^+$ level in Pm was needed in order to determine the energy for the EC transition to this level. The singles Ge(Li) spectrum was measured using the mixed source technique with four calibration sources (*cf.* Fig. 2). The value, obtained using a simple fitting procedure and the GIER computer, is

$$E_\gamma = 492.31 \pm 0.15 \text{ keV}.$$

This is to be compared with the previous values obtained from the scintillation spectra: 485 ± 5 [3] and 495 ± 5 [2].

2.3. Coincidence measurement

The coincidence experiment was done using a time-to-amplitude converter (TAC) as a fast coincidence unit. The singles spectra from the two scintillation detectors used and the selected energy windows are shown in Fig. 3. The pulse spectrum from TAC gated by these singles spectra was used to measure the quantity N^C_{X-492}. It is seen (*cf.* Fig. 4) that the converter peak is well defined with flat portions of the spectrum on each side due to the random coincidences. The pile-up rejection system is not used and some excess of the counting rate to the right of the converter peak may be expected due to the pile-up effect. It is assumed that the area under the peak plus that of the pile-up spectrum correspond to the total number of the true coincidences, with $\varepsilon_C = 1$ (*cf.* formula (1)).

The random coincidence spectrum was measured using the two sources method. The γ detector was removed from the lead shield and exposed to the 511 keV radiation from a ^{22}Na source, while the ^{145}Sm source remained attached to the X-ray detector. The normalization of the random spectrum was done in two ways: by comparing the singles counting rates in the γ-detector and by comparing the flat portions of the converter spectra to the

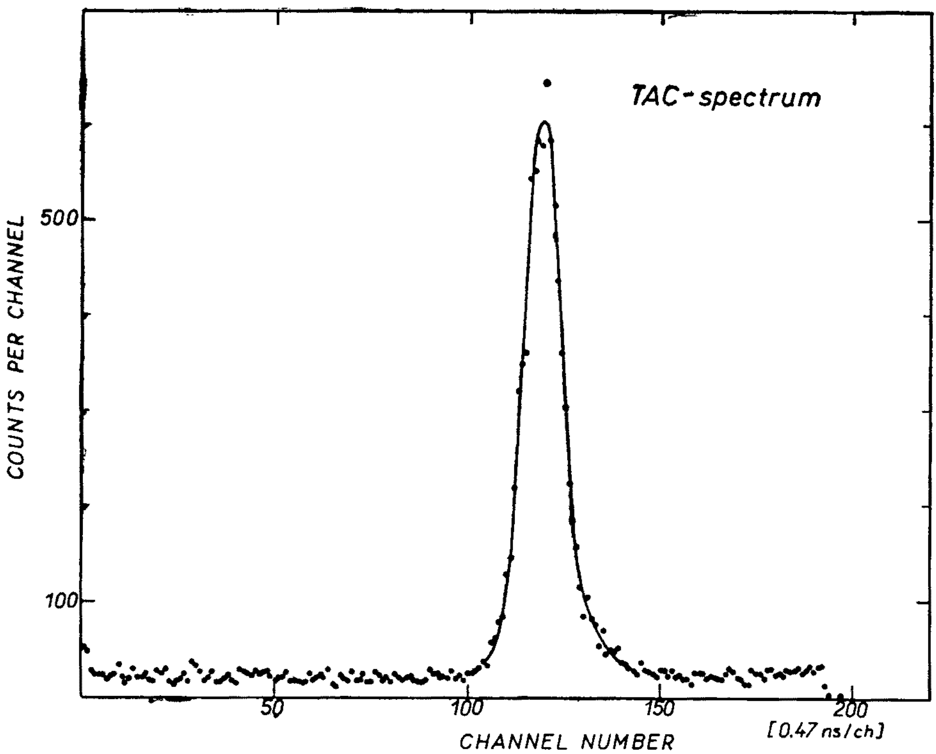


Fig. 4. Coincidence spectrum from time-to-amplitude converter. Measuring time 21 h. One of the two runs

left of the converter peak. The normalization factors obtained agreed very well among themselves.

The singles counting rate in the γ window was measured continuously during the coincidence runs.

2.4. Corrections; efficiency determinations

Apart from the true coincidence background, which was maesured in a separate run with the ^{145}Sm source removed, there are a few other corrections to be applied:

a) There is the tail of the internal bremsstrahlung (IB) spectrum extending under the 492 keV peak. The 1 S component of this spectrum is in true coincidence with the KX rays. The coincidence as well as the singles IB spectra from ^{145}Sm have been studied in detail in a separate experiment [2]. Using these data, the correction for the IB—KX-rays coincidence counting rate is found to be $(2.6 \pm 0.3)\%$ of the total value.

b) The number of counts in the γ window must be corrected for the background as well as for the contribution of the singles IB spectrum. The former was measured directly, while the latter was obtained, by extrapolating the IB spectrum of Ref. [2] under the 492 keV peak, to be $1.5 \pm 0.8\%$.

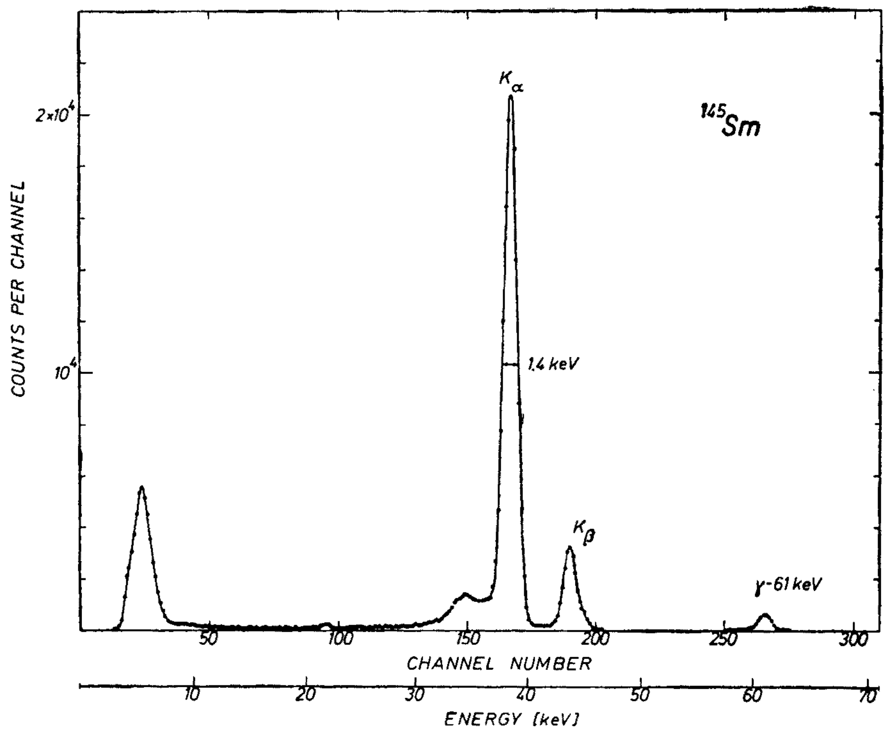


Fig. 5. Singles X- and γ-ray spectrum; Si(Li) detector

c) In order to determine the detection efficiences for the K_α, K_β and 61 keV γ lines, unresolved in the X-ray detector, the following procedure was applied. The absolute intensities of these lines were obtained from the singles X- and γ-ray spectrum measured with an efficiency calibrated Si(Li) detector in a standard geometry (Fig. 5). The same spectrum was then measured with the Pilot B scintillator acting as an absorber inserted between the source and the Si(Li) detector. Comparison of the two spectra, after correcting for the angular dependence of absorption in the Pilot B, gave the efficiency ratio for the X-rays and the

61 keV γ-rays:

$$\frac{(\varepsilon\Omega)_{61}}{(\varepsilon\Omega)_X} = 0.68 \pm 0.02.$$

The value $(\varepsilon\Omega)_X$ of formula (1) is thus:

$$(\varepsilon\Omega)_X = \frac{N_{X+61}}{A_X + A_{61}\dfrac{(\varepsilon\Omega)_{61}}{(\varepsilon\Omega)_X}} = 0.31 \pm 0.04 \tag{2}$$

where N_{X+61} is the singles counting rate from the X-ray detector in the coincidence experiment; A_X and A_{61} are the absolute intensities of the X- and 61 γ-rays measured with the Si(Li) detector.

3. *Result and discussion*

The experimental data obtained from one of the runs are quoted in Table I.

TABLE I

Experimental data

Singles counting rate in the γ-window $\times 10^3$	True coincidence counting rate $\times 10^3$
$N^S_{total} = 181.9 \pm 0.4$	$N^C_{total} = 7.79 \pm 0.12$
$N^S_{IB} = 1.4 \pm 0.7$	$N^C_{x-IB} = 0.16 \pm 0.02$
$N^S_{background} = 99.8 \pm 2.0$	$N^C_{background} = 1.45 \pm 0.20$
$N^{singl}_{492} = 80.7 \pm 2.2 \times 10^3$	$N^C_{X-492} = 6.2 \pm 0.2 \times 10^3$

The final results for the decay of ^{145}Sm to the 492 keV level in ^{145}Pm are presented in Table II. The ft values were deduced using the Q-value of Ref. [2] and the $T_{1/2} = 340 \pm 3$ days of Ref. [3].

TABLE II

Final results

$$P_K = 0.27 \pm 0.03$$

$$\log f_0 t = \log f_{0K} t_K = 11.00 \pm 0.15$$

$$\log f_1 t = \log f_{1K} t_K = 8.13^{+0.25}_{-0.30}$$

It should be noted that the value $P_K = 0.6 \pm 0.1$ has previously been reported [3]. This value is probably in error as it had been obtained by normalizing the γ spectra to the ratio of the singles and coincidence internal bremsstrahlung spectra. This procedure requires the assumption that the IB spectrum is due only to the K-electron capture. The contribution from the higher electron shells to the IB spectrum of ^{145}Sm, however, is large over the entire energy range (*cf.* Ref. [2]) and might easily be sufficient to explain the discrepancy.

Fig. 6 shows the theoretical dependence of P_K *versus* the EC decay energy, Q. The curves as well as the $\log ft$ values of Table I were calculated using the tables of Zyrianova [4]. The M and higher shells contribution was taken into account according to Robinson [5]. As is seen from Fig. 6 the exchange and overlap correction (proposed by Bahcall [6] and calculated recently by Vatai [7]) is nearly negligible for this rather high Z. The errors of the Q- and P_K-values, shown in Fig. 6, are one standard deviations. The $P_K = 0.27 \pm 0.03$ value obtained determines beyond doubt the character of the electron capture transition in question as unique first-forbidden. On the other hand, the experimental uncertainties, mainly in the Q-value, do not permit one to consider the slight deviation of the P_K value from the theoretical curve as significant for the detailed comparison with theory.

Table III gives a summary of the all available to us experimental values of the capture ratios from various shells for the unique first-forbidden transitions. It should be noted that the ratios quoted are not directly comparable because different quantities (K-to-total or K-to-L ratios) were measured depending on the experimental conditions.

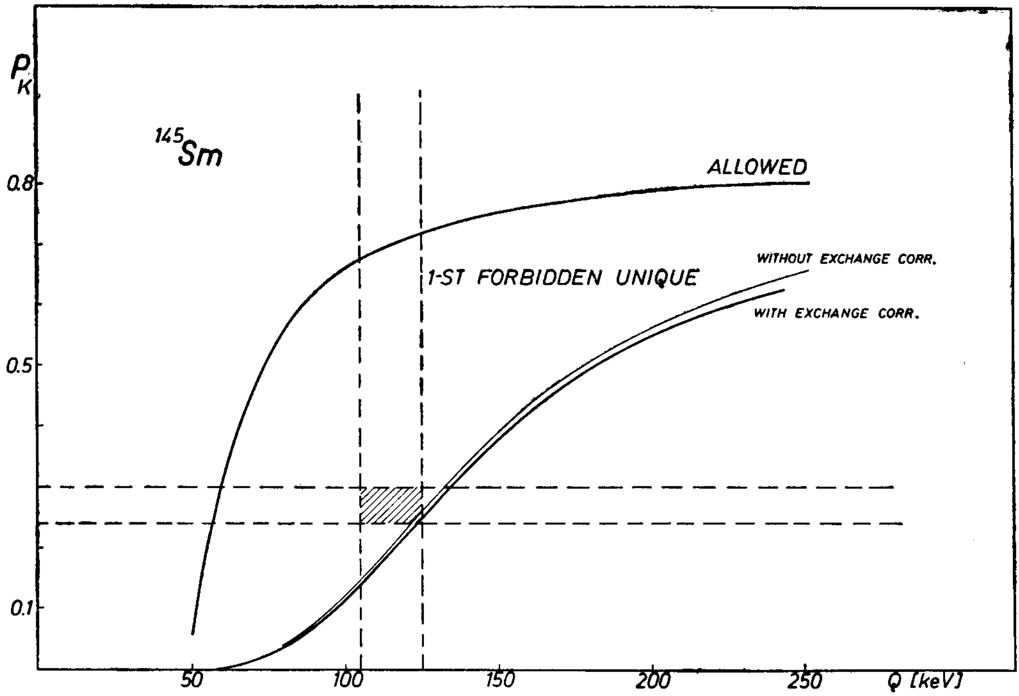


Fig. 6. Relative K capture probability, P_K, as a function of decay energy Q. Experimental values of P_K (present work) and Q (Ref. [2]) are indicated

TABLE III

Capture ratios in unique first forbidden transitions

Q [keV]	$I_i \pi_i \rightarrow I_f \pi_f$	Capture	Theory	Experimental results	References
$^{40}_{19}K$ 44±2	$4^- \rightarrow 2^+$	$L+M.../K$	0.33	0.34±0.08	a
$^{145}_{62}Sm$ 115±10	$7/2^- \rightarrow 3/2^+$	$K/K+L+M...$	*$0.19^{+0.06}_{-0.05}$	0.27±0.03	This work
$^{204}_{81}Tl$ 347±5	$2^- \rightarrow 0^+$	L/K	0.50	0.42±0.05	b
				0.41±0.03	c
				0.60±0.06	d
				0.55±0.05	e

* The errors are due to the uncertainty of Q value.

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It is seen that the experimental data are rather unsatisfactory. Neither the Z nor the energy dependence predicted by theory for the P_K value can be considered proved. For the cases of ^{40}K and ^{204}Tl the Q values are large with respect to the K-electron binding energy which renders P_K insensitive to Q. Since the role of the higher shells electrons in the unique forbidden capture processes is different than in the allowed and non-unique cases, and the correct theoretical treatment of these electrons is still in the making, it may be concluded that more precise relevant experimental information is needed.

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