THE ^{49}K BETA DECAY

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ABSTRACT

The decay of ^{49}K has been studied using a mass-separated ion beam by neutron and gamma-ray singles and multiparameter spectroscopic measurements. The ^{49}K activity was produced by 600 MeV proton fragmentation reactions in a uranium target. The observed beta-strength function displays two resonances centered at about 6.5 MeV and 9.5 MeV in ^{49}Ca . This structure is discussed in simple shell-model terms.

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In recent years there has been an intense interest in the study of the spin degrees of freedom using charge exchange reactions. The results of (p,n) [1,2] and (He^3 ,n) [3] reactions on ^{48}Ca ($T = T_{\gamma}$) have shown that the Gamow-Teller (GT) operator acting on a target with $N > Z$ can populate a broad distribution of T_{γ} states and also the T_{γ} component of the giant GT resonance. All these states have positive parity and can be related to configurations with particles and holes mainly distributed in two shells (f and p).

Another class of particle-hole states can be studied in the Gamow-Teller β decay of K nuclei with large neutron excess. As the ground state of heavy K isotopes ($A > 48$) can be related to configurations with the proton hole in the $d_{3/2}$ or $s_{1/2}$ shell and the valence neutrons in $f_{7/2}$, $2p_{3/2}$ and/or $f_{5/2}$ shells, the GT beta decay of these isotopes will provide information on negative parity p-h states in the daughter nuclei with particles and holes distributed in several shells. A description of these states cannot at present be carried out in the complete sd-fp shell model basis. However, simple estimates can be made to locate the centroids of p-h states.

A previous study of the ^{49}K decay has been reported by Détraz et al. [4]. It has provided a value of the half-life and gamma transitions up to 4.2 MeV. Since then, the experimental possibilities to study very neutron rich potassium isotopes have considerably increased due to new target-ion source techniques [5] which allow production out to mass 53 for K isotopes. The present paper describes new results on ^{49}K obtained in a study where different techniques were combined to attempt a complete description of the β strength.

The isotope ^{49}K was produced at the ISOLDE on-line mass separator by bombarding a 12 g/cm^2 uranium carbide target heated to 2000°C , with the $1.6 \mu\text{A}$, 600 MeV proton beam from the CERN synchrocyclotron. After a fast diffusion from the target to a surface ionization source, the extracted beam was mass-separated and deflected into different experimental areas in order to perform a set of spectroscopic measurements. As ^{49}K was found to be a very strong delayed neutron precursor, high resolution neutron and γ -ray spectroscopy as well as n- γ coincidence techniques have been used to obtain the excitation spectrum of ^{49}Ca .

The half-life of ^{49}K was measured both by beta and neutron counting; the average value, $T_{1/2} = 1.26 \pm 0.05 \text{ s}$, is in agreement with the previous result ($T_{1/2} = 1.1 \pm 0.3 \text{ s}$, ref. [4]). The neutron branching ratio was determined from simultaneous beta and neutron measurements. The beta activity was detected in a 1 mm thick plastic scintillator located inside a neutron long-counter equipped with eight ^3He proportional counters. The relative beta to neutron efficiency was

obtained from a comparison with ^9Li the P_n value of which has been recently remeasured at ISOLDE and found to be $P_n = 50 \pm 4\%$ [6]. The P_n values measured using this method for $A = 48-51$ K nuclei, are reported in Table 1 :

Table 1

Measured neutron-branching ratios in the decay of heavy potassium isotopes

	P_n (%)	$Q_\beta - B_n$ (MeV)
^{48}K	1.14 ± 0.15	2.0
^{49}K	86 ± 9	5.2
^{50}K	29 ± 3	7.6
^{51}K	47 ± 5	9.6

It appears that the total intensity of the delayed neutron branches shows a strong maximum for $A = 49$ while the available energy window ($Q_\beta - B_n$) for beta delayed neutron emission increases regularly from $A = 48$ to $A = 51$. The high P_n value deduced for ^{49}K ($P_n = 86 \pm 9\%$) may be taken as first indication that the main configurations favoured by GT beta decay are located above the neutron binding energy ($B_n = 5.147$ MeV) [7].

The delayed neutrons were investigated first with high-resolution ^3He ionization chambers. Thirteen well separated lines were observed and could be related to the upper part ($E_x > B_n$) of the ^{49}Ca level scheme.

Gamma-ray measurements were made with a 109 cm^3 Ge(Li) detector, in a multianalysis mode of 2×1.5 s after each ion collection. The observed gamma rays are assigned to the decay of the levels at 2027, 3585, 4272 keV in ^{49}Ca and of a new one at 4072 ± 2 keV, the excitation energy of which is almost identical to that of a level in ^{49}Sc , populated by the subsequent $\text{Ca} \rightarrow \text{Sc}$ decay. The contributions from both levels were evaluated from decay rate considerations. The gamma spectrum revealed also the deexcitations of two levels in ^{48}Ca originating from β^- delayed neutron decay : the first 2^+ state at 3832 keV ($3832 \rightarrow 0$) and the second 0^+ at 4284 keV ($E_Y = 452$ keV, $4284 \rightarrow 3832$). A bidimensional measurement, recording neutron time-of-flight versus gamma energy, confirmed this result. With a window set on the 3832 keV gamma ray the coincident neutron spectrum indicates at least three neutron groups (0.12 ± 0.03 , 0.30 ± 0.05 and 0.60 ± 0.06 MeV) corresponding to the decay of highly excited levels in ^{49}Ca feeding the 2^+ state of ^{48}Ca . It has not been

possible to evaluate the energy of the neutron branch populating the 0^+ level at 4284 KeV as a consequence of the high background for low energy gamma rays and of the weak intensity of the 452 keV line ($I(452 \text{ keV})/I(3832 \text{ keV}) = 0.08 \pm 0.01$).

The ground state feeding of ^{49}Ca was inferred from two independent evaluations : the comparison of the $\text{Ca} \rightarrow \text{Sc}$ activity to that of $\text{K} \rightarrow \text{Ca}$ and a direct measurement of the beta and gamma activities using two counters with known absolute efficiencies. This determination ($I_{\beta_0} = 10\%$) makes possible the calculation of absolute values for all the beta branches.

Using for Q_{β} an estimate obtained from mass formula [9] ($Q = 11 \text{ MeV}$), the corresponding log ft values have been deduced and are listed in the decay scheme (figure 1) which summarizes the information from this study. It is worth mentioning that most of the excited states in ^{49}Ca observed in this work are not seen in the $^{48}\text{Ca}(d,p)^{49}\text{Ca}$ reaction which can be explained by the particle-hole nature of the states populated in the allowed beta decay.

From the combined neutron and gamma ray data, the beta strength function of ^{49}K was derived. It is shown in figure 2, quoted in terms of reduced Gamow-Teller transition probabilities per 100 keV versus excitation energy. The influence of an experimental analysing limit for beta feeding of $I_{\beta} = 6 \times 10^{-3}$ of the top part of the measured strength distribution, is also indicated. The general increase of the beta strength distribution with the energy, observed in the experiment, is reproduced by the gross theory of beta decay [10]. However, there are also evident deviations due to nuclear structure effects with the appearance of two pronounced maxima around 6.5 MeV and 9.5 MeV excitation energy. In a shell model approach, the ground state of ^{49}K ($J = 1/2, 3/2; T = 11/2$) can be described as a ^{40}Ca core with the dominant configurations for valence particles :

$$(p_{3/2}, p_{1/2}, f_{5/2})_{0,1}^2, (f_{7/2})_{0,4}^8$$

and for holes :

$$(s_{1/2}, d_{3/2})_{(1/2, 3/2)}^{-1}, 1/2$$

where subscripts stand for J and T values. The Gamow-Teller nuclear matrix element will allow to connect final states in ^{49}Ca with the same components coupled to $T' = T-1$ and to $J' = J, J+1$. The description of such states in ^{49}Ca is listed in Table 2 where the different intermediate couplings have been taken into account. In this table any of the subshells $p_{3/2}$, $p_{1/2}$ and $f_{5/2}$ is denoted as r.

Table 2

T = 9/2 particle-hole states in ^{49}Ca

Configurations	E_x (MeV) (for $r = p_{3/2}$)
a $\left\{ [(sd)^{-1}f^8 (T=4)]_{9/2} r^2 (T=1) \right\}_{9/2}$	9.4
b $\left\{ [(sd)^{-1}f^8 (T=4)]_{9/2} r^2 (T=0) \right\}_{9/2}$	9.7
c $\left\{ [(sd)^{-1}f^8 (T=4)]_{7/2} r^2 (T=1) \right\}_{9/2}$	5.0
d $\left\{ [(sd)^{-1}f^8 (T=3)]_{7/2} r^2 (T=1) \right\}_{9/2}$	12.0
e $\left\{ [(sd)^{-1}f^9 (T=7/2)]_4 r^1 (T=1/2) \right\}_{9/2}$	6.2

The evaluation of the excitation energies for these configurations implies a knowledge of the interaction parameters for two particles in the different shells with $T = 0$ and $T = 1$. The adequate information is not yet complete and remains precisely the goal of our investigations on light nuclei far from stability. However, an estimate based on the Bansal-French formula with parameters extracted from effective interactions has been done. The fp-averages were taken from a modified Kuo-Brown interaction, successful in describing the fp-shell spectroscopy [11]. The excitation energies expected for the centroids of states corresponding to the different configurations with $r = p_{3/2}$ are reported in Table 2.

From this table it appears that the expected excitation energies fall into two groups, one at 5-6 MeV (states c and e) and the other above 9 MeV (states a, b and d). The observed structure in the ^{49}K strength function has certainly its origin in these two groups. The occupation of $p_{1/2}$ and $f_{5/2}$ shells produces an increase of the excitation energy compared to the $r = p_{3/2}$ occupation. For example in the case of state (e) where one particle is in the upper shell, the expected excitation energy would move from 6.2 MeV ($r = p_{3/2}$) to 8.2 MeV ($r = p_{1/2}$) and 9.7 MeV ($r = f_{5/2}$). At present, this situation renders difficult the evaluation of the relative contribution from the different configurations to the observed maxima in the GT beta strengths.

It is important to note that the same approach with the same parameters gives reasonable results for the p-h states of ^{48}Ca and ^{50}Ca . As for the ^{49}K decay, the present work shows that a simple shell model reproduces the main features of the beta-strength function. However, for a more quantitative understanding of the

of the particle-hole structure of neutron-rich calcium isotopes, the investigation of neighbouring nuclei is also necessary. Both experimental and theoretical work on the decay properties of the isotope sequence $^{47-52}\text{K}$ are under way.

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Fig. 1 : Decay scheme of ^{49}K

Fig. 2 : Beta strength function of ^{49}K decay
in terms of reduced GT transition probabilities.