

THE ^{49}K BETA DECAY

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Abstract

The decay of ^{49}K has been studied through neutron and gamma spectroscopy techniques. The ^{49}K activity was formed by 600 MeV proton fragmentation reactions in a uranium carbide target. The observed β -strength, in addition to the general behaviour expected from the gross theory of β -decay, 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.

1. Introduction

Recent experiments^{1,2)} using charge exchange (p,n) and (He³,t) reactions on $^{48}\text{Ca}(T = T_>)$ have shown that the Gamow-Teller (GT) operator acting on a target with $N > Z$ can populate a broad distribution of $T_<$ states and also the $T_>$ 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. Very recently the excitation of "stretched" states, based on a proton-particle, neutron-hole configuration with both the particle and the hole in the same shell has been also reported with the (p,n) reaction on ^{48}Ca 3).

The observation of the Gamow-Teller strength in the β decay of K nuclei with large neutron excess clearly complements the previous informations, giving access to another class of particle-hole states. As the ground state of heavy ($A > 48$) K isotopes can be related to configurations with the proton hole in the $d_{3/2}$ or $2s_{1/2}$ shell and the valence neutrons in $f_{7/2}$, $2p_{3/2}$ and/or $f_{5/2}$ shells, the G.T. β decay of these isotopes will provide informations on negative parity particle-hole states in the daughter nuclei with particles and holes distributed in many shells. It is clear that 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.

The present paper describes a series of new results obtained in the investigation of the β -decay of ^{49}K . The goal of this study was, by combining different techniques, to obtain a complete description of the β -strength and to attempt an interpretation of the observed structures in terms of shell model states.

A previous study of the ^{49}K decay has been reported by Detraz et al.⁴⁾. It has provided the first value of the half-life ($T_{1/2} = 1.1 \pm 0.35$ s)

and the strongest gamma lines up to 4.2 MeV. The experimental possibilities to study the ^{49}K beta decay have considerably increased due to new target-ion-source techniques⁵⁾ which allow production of heavy K isotopes out to mass 53.

2. Experimental Procedures and Results.

In the present experiments, ^{49}K was produced at the on-line mass separator ISOLDE by bombarding a 12 g/cm² uranium carbide target heated to 2000°C, with 1.6 μA , 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. The production yield of ^{49}K was 10⁵ atoms/s. As ^{49}K was found to be a very strong delayed neutron emitter, high resolution neutron and γ ray spectroscopy and n- γ coincidence techniques have been used in order to define the excitation spectrum of ^{49}Ca .

The half-life of ^{49}K was measured both by beta and neutron counting. The results obtained were $T_{1/2}(\beta) = 1.27 \pm 0.08$ and $T_{1/2}(n) = 1.25 \pm 0.05$ s. We adopt the value 1.26 ± 0.05 s in agreement with the previous result 4).

The neutron branching ratio was determined from simultaneous beta and neutron counting. The beta activity was detected in a 1 mm thick plastic scintillator located inside a neutron long-counter equipped with eight ^3He proportional detectors. The relative beta to neutron efficiency was obtained from a comparison with the ^9Li neutron branch which has been recently remeasured at ISOLDE and found to be $P_n = 50 \pm 4$ % 6). The P_n values, measured with this method for $A = 48 - 51$ K nuclei, are reported in Table 1 :

	$P_n(\%)$	$Q_{\beta-B_n}(\text{MeV})$
^{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

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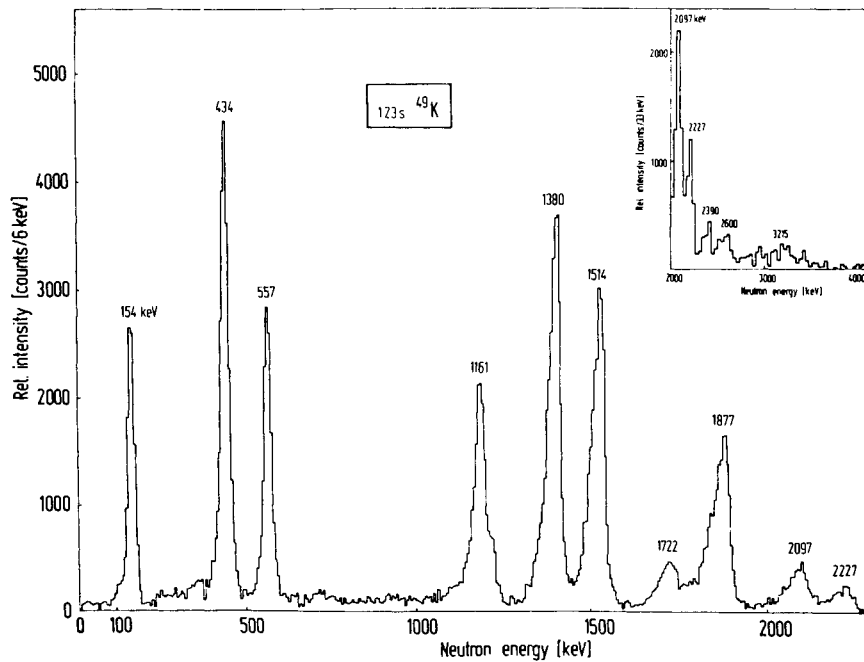


Fig.1 : Delayed neutron singles spectrum from ^{49}K decay

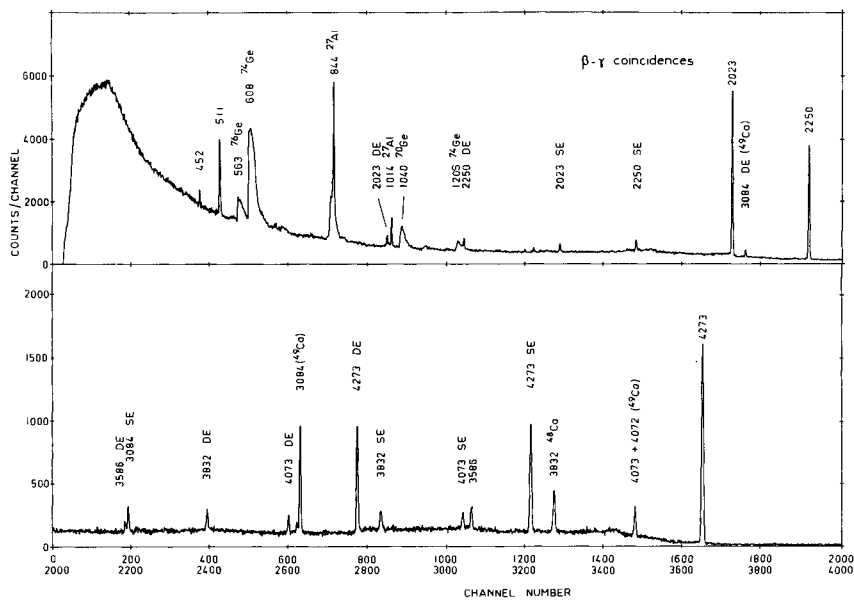


Fig.2 : γ -ray spectrum registered in coincidence with β rays from ^{49}K .

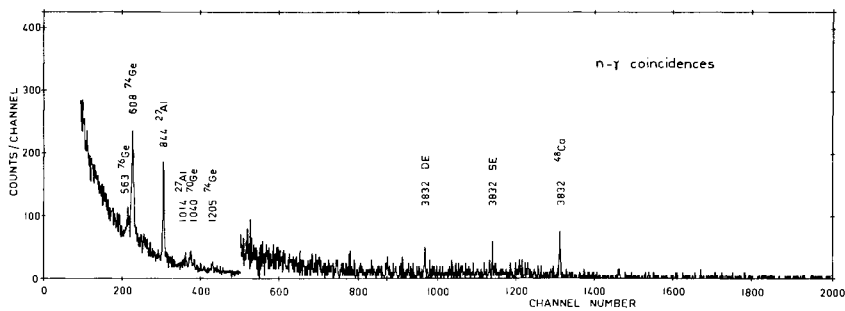


Fig.3 : γ -ray spectrum in coincidence with β delayed neutrons from ^{49}K .

It is striking to note that, as the available energy window ($Q_\beta - B_n$) for beta delayed neutron emission increases regularly from $A = 48$ to $A = 51$, the total intensity of the delayed neutron branches shows a strong maximum for $A = 49$. The high P_n value observed in this case ($P_n = 86 \pm 9\%$) is an indication that configurations favoured by the ^{49}K beta decay are located above the neutron binding energy $B_n = 5.147$ MeV).

The delayed neutrons were investigated first with high-resolution ^3He ionization chambers. The neutron spectrum, corrected for detector efficiency and response ⁸⁾ is shown in Fig.1 where thirteen well separated lines are observed and can be related to the upper part of the ^{49}K strength function.

Gamma ray measurements were made with a 109 cm^3 Ge(Li) detector, in a multianalysis mode of 2×1.5 second after each ion collection and in coincidence with β rays detected with a plastic scintillator surrounding the collection point of a tape transport system. The spectrum registered during the first time bin is given in Fig.2 where all the observed lines have been identified and originate from one of the three following processes :

- the decay of levels in ^{49}Ca at 2027, 3585, 4272 and 4072 keV. The latter excitation energy corresponds to a previously unreported level almost at the same energy as the one in ^{49}Sc , populated by the subsequent $\text{Ca} \rightarrow \text{Sc}$ beta decay. The relative contribution of these two levels was evaluated from intensity and decay rate considerations
- the inelastic ^{49}K delayed neutron scattering in the germanium counter or in the surroundings. The high efficiency of this process is due to the fact that the excitation of 0^+ states in $^{70,74,76}\text{Ge}$ is followed by emission of conversion electrons totally absorbed within the Ge crystal whereas the very strong line at 691 keV (^{72}Ge) is suppressed in our case by the fact β - γ coincidence.
- the deexcitation of two levels in ^{48}Ca : the first 2^+ state at 3832 keV ($3832 \rightarrow 0$) and the second 0^+ at 4284 keV ($E_\gamma = 452$ keV, $4284 \rightarrow 3832$). This process was clearly related to the delayed neutron emission from the time dependence of the two lines in the multispectrum found in agreement with the half-life of ^{49}K .

A time of flight measurement has been performed with a 10 cm diameter plastic scintillator and combined with the Ge(Li) γ analysis in a bidimensional experiment. The coincident gamma spectrum, shown in Fig.3, is dominated by the 3832 keV line and at low energy by the radiation following nn' interaction. With a window set on the 3832 keV γ ray the coincident neutron spectrum indicates at least three neutron groups (0.12 ± 0.03 , 0.3 ± 0.05 and 0.6 ± 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 γ 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 the $\text{K} \rightarrow \text{Ca}$ one and a direct measurement of the β and γ activities using two counters with known absolute efficiencies. This determination ($I_{\beta 0} = 10\%$) makes possible the calculation of absolute values for all the β branches.

3. Discussion

Using for Q_β an estimate obtained from mass formulae ⁹⁾ ($Q_\beta = 11$ MeV), the corresponding log ft values have been deduced and are listed in the decay scheme (figure 4) which summarizes the information from this comprehensive study. From the decay scheme it can be noted that most of the excited states in ^{49}Ca observed in this work are not seen in the $^{48}\text{Ca}(d,p)^{49}\text{Ca}$ reactions which can be explained by the particle-hole nature of the states populated in the allowed beta decay.

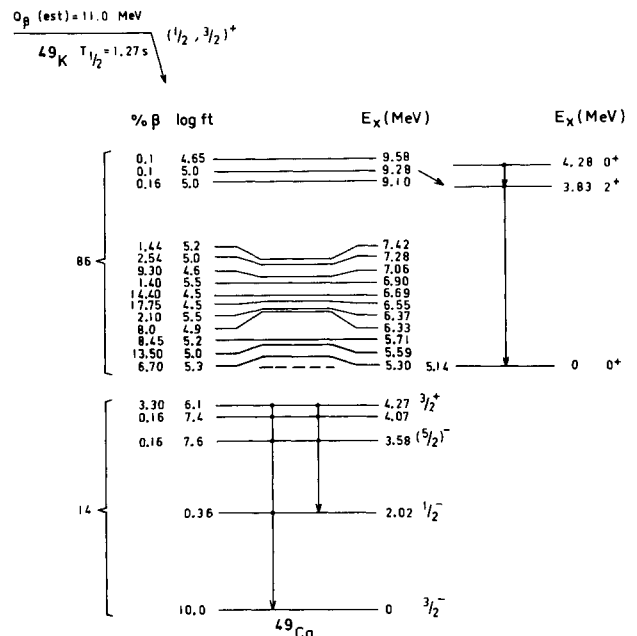


Fig.4 : Decay scheme of ^{49}K

The β^- strength function of ^{49}K was derived and is shown in fig.5 quoted in terms of reduced Gamow Teller transition probabilities per 100 keV versus excitation energy. The influence on the measured strength distribution of an experimental analysing limit for β -feeding of $I_\beta = 6 \times 10^{-3}$ is also indicated. The beta strength function reproduces the general increase with the energy which is predicted by the gross theory of beta decay ¹⁰⁾ but gives also evident deviations due to nuclear structure effects with the appearance of two pronounced maxima around 4.5 MeV and 9.5 MeV excitation energy.

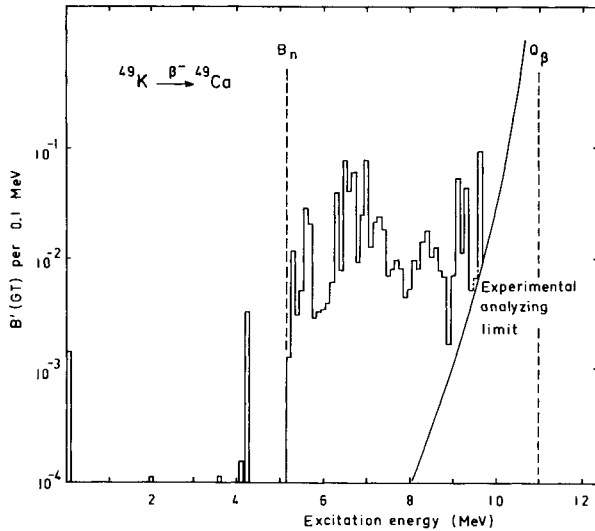


Fig.5 : β strength function of ^{49}K decay in terms of reduced GT transition probabilities

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 :

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

for valence particles, 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 Table 2 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)
a $[(sd)^{-1}f^8(T=4)]_{9/2}r^2(T=1)_{9/2}$	9.1 9.4 9.7
b $[(sd)^{-1}f^8(T=4)]_{9/2}r^2(T=0)_{9/2}$	10.3 9.7
c $[(sd)^{-1}f^8(T=4)]_{7/2}r^2(T=1)_{9/2}$	4.7 5.0
d $[(sd)^{-1}f^8(T=3)]_{7/2}r^2(T=1)_{9/2}$	11.7 12.0
e $[(sd)^{-1}f^9(T=7/2)]_{4}r^1(T=1/2)_{9/2}$	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 formulae with parameters extracted from effective interactions has been done. The use of this formalism with the same parameters has besides proved to be successful in this mass region¹¹⁾. The excitation energies expected for the centroids of states corresponding to the different configurations with $r = p_{3/2}$ are reported in table 2 where different values can result from Coulomb splitting.

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 strengths 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. For example in the case of state (e) where one particle is in the upper shells, 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 ($r = f_{5/2}$). This situation makes difficult the evaluation of the relative contribution of the different groups to the observed beta strengths.

It is important to note that the same approach with the same parameters give reasonable results for the p-h states of ^{48}Ca and ^{50}Ca . Thus we can conclude that at present, with a simple model, the main features of the β -strength function of ^{49}K decay are understood semi-quantitatively. It would be rewarding to further improve our knowledge on p-h structures in neutron rich Ca isotopes. Both, experimental and theoretical work on the decay properties of the isotope sequence $^{47-52}\text{K}$ is underway.

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