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GAMOW-TELLER BETA DECAY OF A = 48-51 POTASSIUM ISOTOPES AND SHELL MODEL DESCRIPTION

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Work in collaboration with : P. Baumann, M. Bounajma, Ph. Dessagne, A. Huck, G. Klotz, A. Knipper, Ch. Miehé, J. Rachidi, M. Ramdane (CRN, Strasbourg) G. Marguier (IPN, Lyon) C. Richard-Serre (IN2P3/ CERN-ISOLDE) A. Dobado and A. Poves (Univ. Autonoma, Madrid)

Contribution to the Workshop
"Nuclear Structure of Light Nuclei Far From Stability : Experiment and Theory"
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The determination of the GT beta decay of n-rich K isotopes ($N \geq 28$) is of interest for the study of particle-hole states in the sd and fp shells. In this mass region, two particular features are noteworthy when undertaking an experimental investigation :

- High production yields may be obtained for mass-separated beams resulting from target fragmentation, allowing accurate measurements of the β branches.

- Information from reaction studies on ^{48}Ca targets are available [(p,p') for ^{48}Ca, (d,p), (n,n) and (n,γ) for ^{49}Ca and (t,p) for ^{50}Ca]. These data corroborate the decay studies and allow a detailed comparison with theoretical predictions.

The present study[1)] was made with a Uranium carbide target bombarded either by a 600 MeV proton or a 900 MeV 3He beam from the CERN synchrocyclotron. K isotopes were ionized with a high degree of selectivity by means of a tungsten surface ionization source. Gamma radiation and delayed neutrons following the decay of $^{48-51}$K isotopes have been studied in singles and coincidence mode. For these measurements, a 33% Ge(Li) counter was associated with large area (2880cm^2) plastic scintillators designed for neutron detection. The start of the time of flight is given by a thin cylindrical β detector which surrounds the collection point, the stop signal

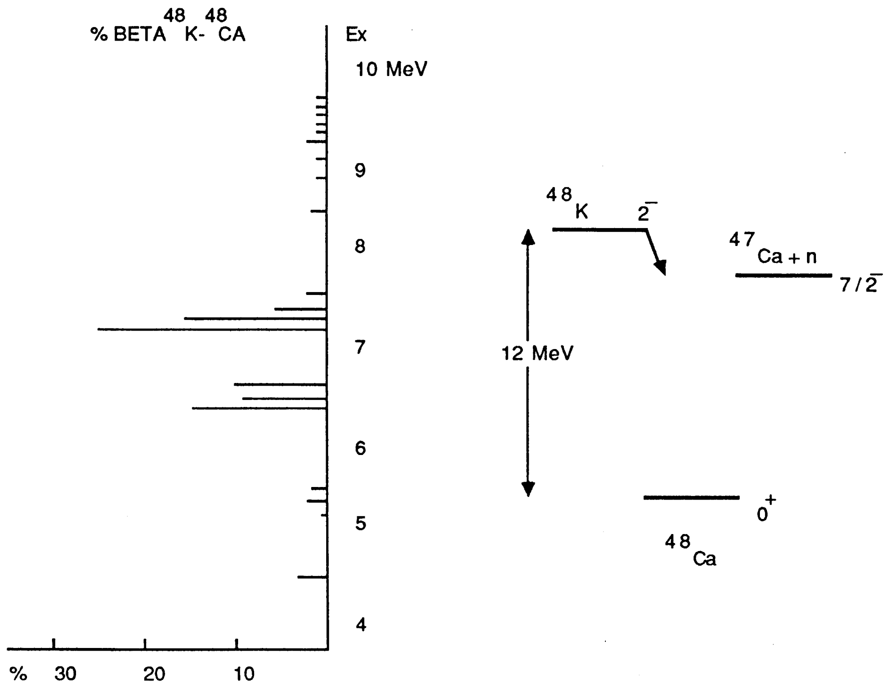


Fig. 1 Experimental values for beta branching strength in the beta decay of ^{48}K

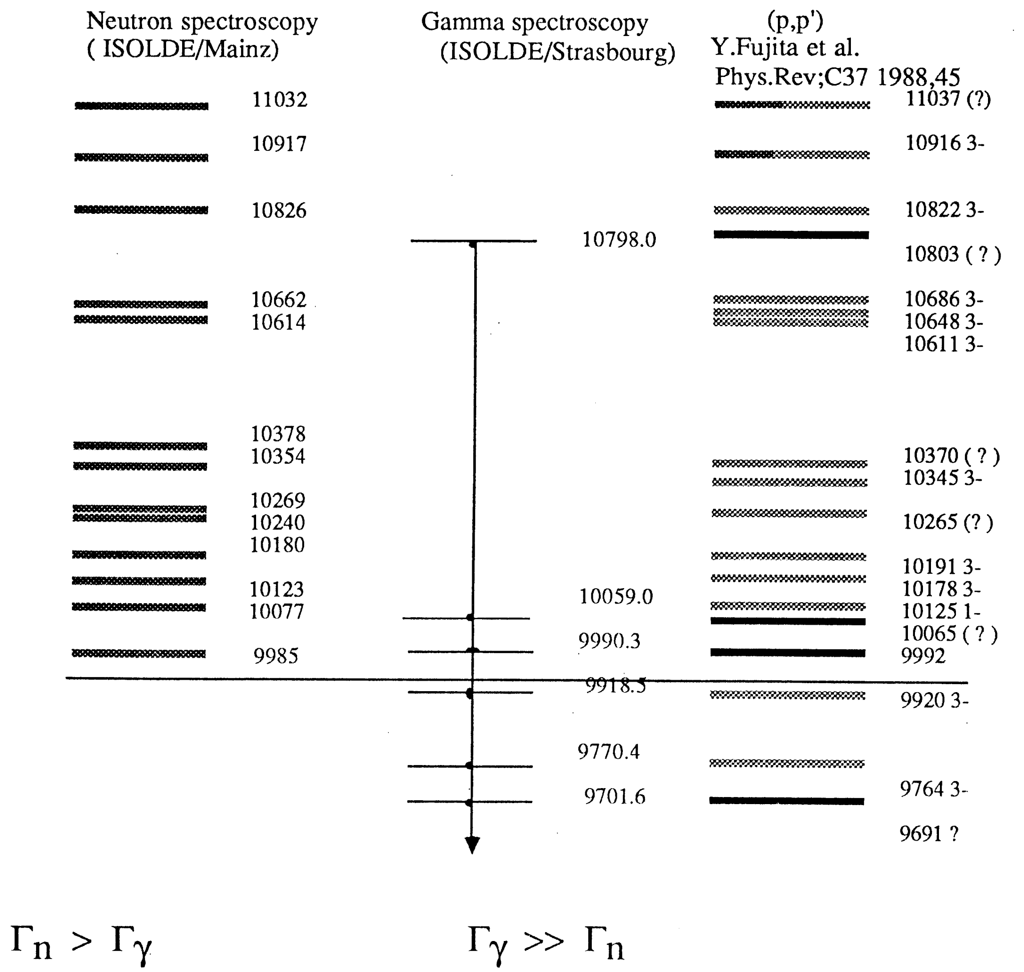


Fig. 2 Unbound levels in ^{48}Ca (excitation energy in keV) observed in delayed neutron spectroscopy (ref.2), gamma spectroscopy (ref.1) and (p,p') reaction (ref.3)

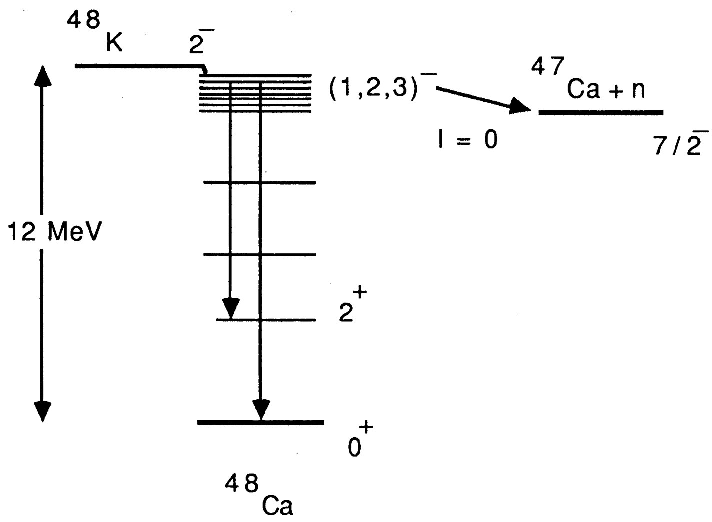
corresponding to the detection of events in the large scintillators. These scintillators, curved for isochronous flight paths (l=100 cm) and centered at the collection point, allow neutron detection with a large solid angle (280 msr) and a good time resolution (1.1ns FWHM). In the discussion of experimental results with theoretical estimates of Poves and Dobado, we will also include the neutron spectroscopy data, obtained by the Mainz group with He^3 counters[2)].

In the present contribution, we will give an overall comparison between the experimental distribution of β strength, established by these experiments, and the shell model estimates. Before, we discuss briefly some of the salient features of the N=29-32 K decays.

$^{48}K \rightarrow {}^{48}Ca$ β decay

The ^{48}K decay is a unique example of β^- decay with high Q value (Q_β = 12.09 MeV), populating more than 30 levels in the daughter nucleus with, for most of them, a spin and parity value established by different experiments. This spectroscopic information is valuable to understand the β decay. A schematic representation of the distribution of the β strength is given in Fig.1 which reveals the selective population of ^{48}Ca levels around 7 MeV excitation energy and locates thereby the center of gravity of p-h states. When compared to previous investigations[12,13)], we note in the present work higher values for β branches populating high excited states (especially for the 7301 keV level). This result is related to the increase in sensitivity for detection of high energy γ rays resulting from the use of high efficiency Ge detectors. If now we consider the upper part of the excitation range in ^{48}Ca around the neutron separation energy (S_n = 9.94 MeV), which corresponds to an important fraction of the G.T. strength, we can compare the level scheme corresponding to levels established by neutron[2)] and by γ spectroscopy[1)] with the one established from (p,p') analysis[3)] (Fig.2). In this last case, the comprehensive study by Fujita et al[3)] has led to J^π assignments for almost all levels.

On the basis of the excitation energy and decay properties, a one to one relation can be established in most cases between the levels populated in the ^{48}K β decay,corresponding to p-h configurations, and those observed in pp'. For the states revealed by delayed neutron spectroscopy, we find $J^\pi = 3^-$ counterparts in the pp' work while the levels resulting from the γ measurements correspond most likely to $J^\pi = 1^-$ in pp' and give rise to E1 γ-decays. Then the situation appears to be the following : from ^{48}K ($J^\pi = 2^-$), GT β transitions populate $J^\pi = 1^-, 2^-, 3^-$ levels in ^{48}Ca. Subsequent neutron decay to ^{47}Ca g.s.($J^\pi = 7/2^-$) with odd l values are forbidden and even ones are mostly l = 0. Therefore the neutron decay selects $J^\pi = 3^-$ states in the daughter nucleus and unbound 1^-(or 2^-) levels are revealed by their radiative decay. In Fig.3, we have represented the B(GT) strength distribution corresponding to 3^- states in ^{48}Ca. The enveloppe of this distribution shows a resonance like structure, centered around 10.5 MeV. This resonance (Low Energy Octupole Resonance-LEOR) was previously observed by Fujita et al[3)] by pp' reaction. The $^{48}K \rightarrow {}^{48}Ca$ GT transitions give the first example of the observation of such a resonance in a β decay study.



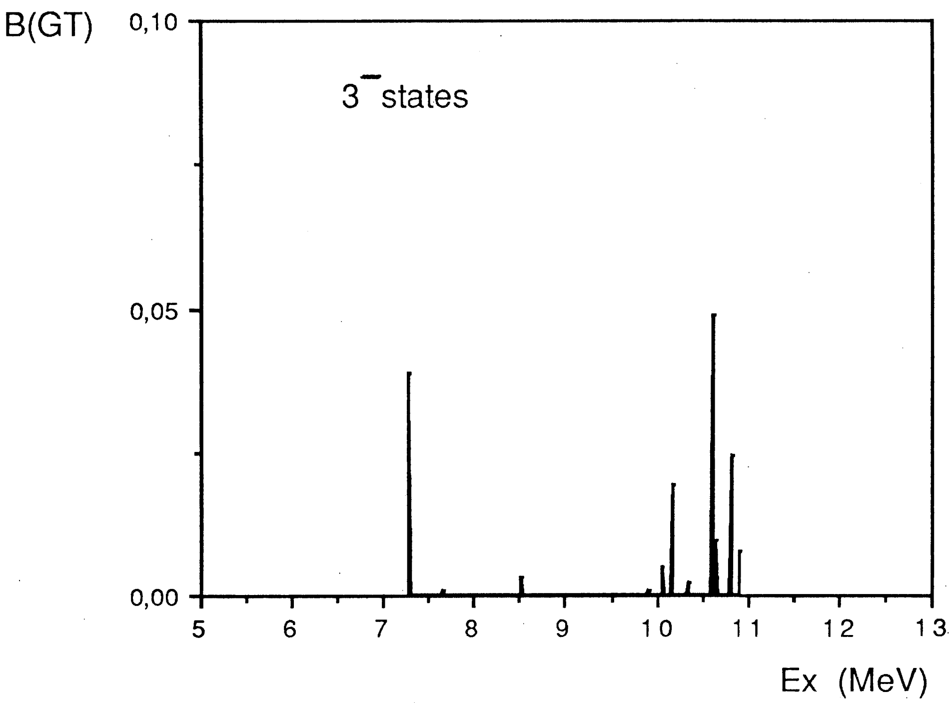


Fig. 3 B(GT) strength distribution for the beta decay of ^{48}K. Only the strength corresponding to final states with $J^{\pi} = 3^-$ (assignments from ref.3) is reported on the plot.

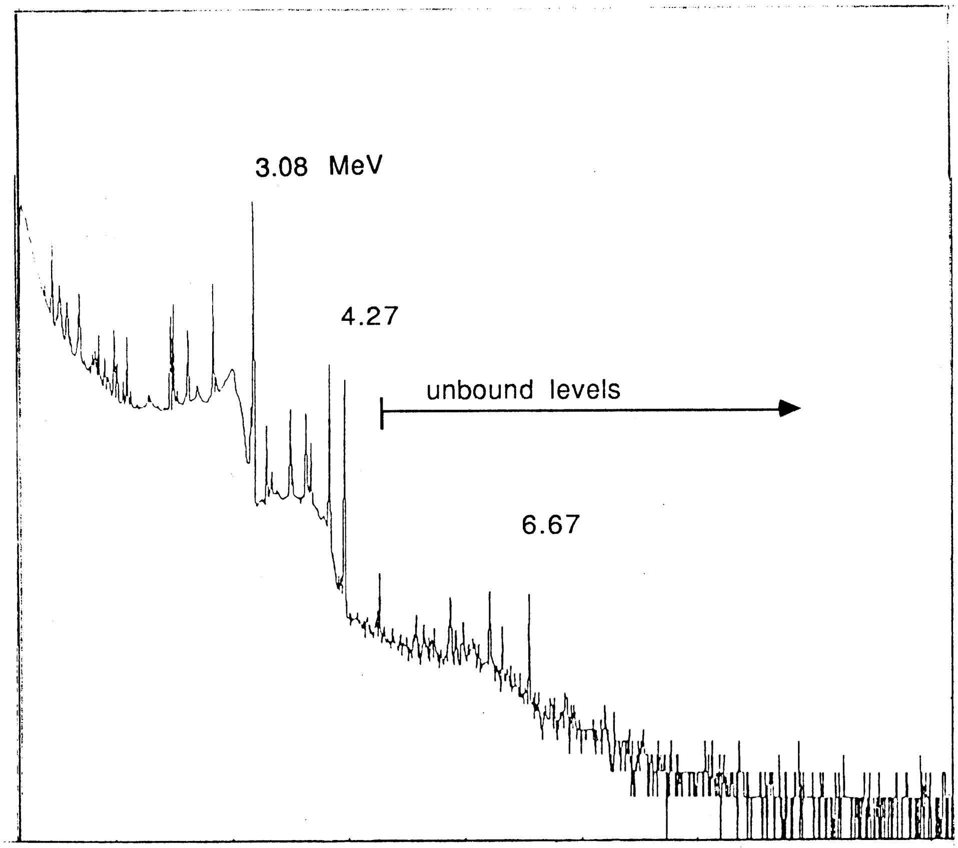


Fig. 4 Gamma spectrum in the decay $^{49}K \rightarrow {}^{49}Ca$

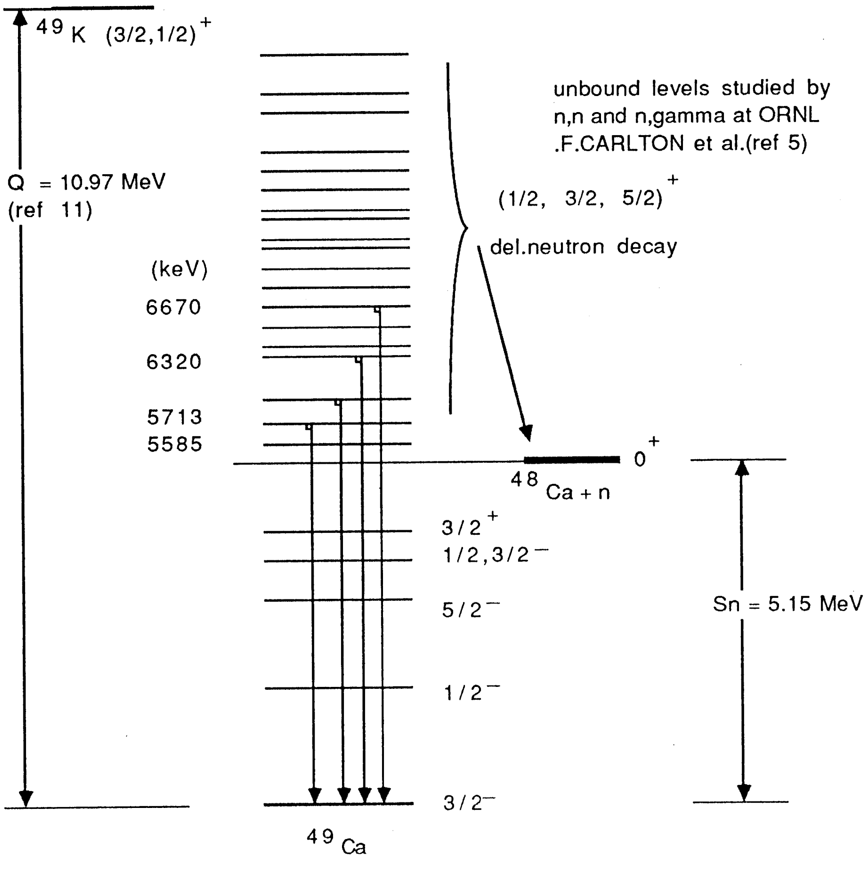


Fig. 5 Gamma decay of unbound states in ^{49}Ca

$^{49}K \rightarrow {}^{49}Ca$ β decay

Previous investigations of $^{49}K(\beta^-)^{49}Ca$ were made at ISOLDE[4] and have established the main β transitions. Our motivation in the present study was to search for weaker decays at high excitation energy with an improved γ sensitivity and to compare the results with data available on the ^{49}Ca level structure.In this connection the situation is completely different from the preceeding case. From previous works, ^{49}K ground state is known to have $J^\pi = 1/2^+$ or $3/2^+$. In these conditions, all the states [$J^\pi = (1/2^+ - 5/2^+)$] populated at high excitation energy by GT transitions can decay directly to ^{49}Ca g.s.($J^\pi = 3/2^-$) by E1 transitions. As a result, the γ emission from unbound states is favoured and several unbound levels, located above the neutron separation energy (S_n = 5.15 MeV), are established through their radiative decay. In the γ spectrum (Fig.4) prominent lines allow to locate 4 levels at 5585, 5713, 6320 and 6670 keV populated by allowed GT transitions. Their position is reported in Fig.5 with other unbound levels established from the $^{49}K \rightarrow {}^{49}Ca$ study and observed only through neutron emission. In the β decay experiment, energy calibration at high energy was achieved using the 6129 keV line in ^{16}O [$^{13}C(\alpha,n)^{16}O^*$ source] after recoil corrections.

Many properties (E_x,J^π,Γ_n and Γ_γ) of ^{49}Ca energy levels are known from (n,n) resonance and (n,γ) capture studies performed at the ORELA facility (Oak Ridge)[5]. It is of particular interest to use this information and check if $5/2^+$ states in ^{49}Ca are populated by allowed transitions in the β decay and therefore if the $J^\pi = 1/2^+$ assignment for ^{49}K g.s. can be rejected. To adress this question, we compare in Table 1 information on ^{49}Ca levels obtained from resonance (or capture) and from ^{49}K β decay though we do not expect a strong overlapping between the configurations involved in the different processes.

We note that the high resolution resonance and capture work allows a determination of the partial widths, Γ_n and Γ_γ, whereas from γ and delayed neutron measurements, only the ratio of the two partial widths, Γ_n/Γ_γ, can be deduced.The absolute value of the excitation energy measured in the two different experiments can differ by an amount which is difficult to evaluate. At E_x = 6670 keV a level is observed in both experiments, yet from the ratio Γ_n/Γ_γ obtained in our work and the Γ_n value from ORELA an unrealistic value for Γ_γ is deduced (exceeding by a factor 500 the upper estimates for an E1 transition). We come then to the conclusion that the "level" at 6670 keV is, at least, a doublet. For the level at 5583 (or 5585) keV, the two experiments can be in agreement, within the error barrs. More interesting is the level we observe at 5713 ± 2 keV, very close to the weak neutron resonance at 5707 keV, measured at Oak Ridge. In this case, we calculate a radiative width, Γ_γ, equal to 75 meV, corresponding to 4.4 10^{-4} W.u., value in the range of the observed E1 transitions. If we assume that the two observations correspond to the same level, we can assign $J^\pi = 3/2^+$ to ^{49}K ground state. The systematics of $1/2^+$ - $3/2^+$ energy difference in K isotopes is given in Table 2. Present results would indicate that $J^\pi = 3/2^+$ corresponds to ground state for all K isotopes, except ^{47}K.

TABLE 1. Unbound levels in ^{49}Ca

(n,n) and (n,γ) [ORELA/Oak Ridge] Ref.5		delayed neutron and β,γ [CERN/ISOLDE] this work	
E_x (keV)		E_x (keV)	
6670	$J^\pi = 5/2^+$ $\Gamma_n = 160$ keV	6670 ± 2	$\Gamma_n/\Gamma_\gamma = 148 \pm 34$
5583	$J^\pi = 1/2^+$ $\Gamma_n = 4.3$ keV $\Gamma_\gamma = 2.5$ eV	5585 ± 2	$\Gamma_n/\Gamma_\gamma = 4000 \pm 2000$
		6320 ± 2	$\Gamma_n/\Gamma_\gamma = 296 \pm 100$
5707	$J^\pi = 5/2^+$ $\Gamma_n = 80$ eV	5713 ± 2	$\Gamma_n/\Gamma_\gamma = 1060 \pm 300$

TABLE 2. $1/2^+$ - $3/2^+$ energy difference in K isotopes

A	41	43	45	47	49
$E_x\ (1/2^+)_1$ MeV	0.98	0.56	0.47	0.0	?
$E_x\ (3/2^+)_1$ MeV	0.0	0.0	0.0	0.36	(0.0)

It would be highly desirable to explore the low energy structure of ^{49}K in order to confirm the 1/2-3/2 level crossing at A=49.

$^{50}K \rightarrow {}^{50}Ca$ β decay

The decay scheme of ^{50}K (Fig.6) has been established on the ground of n-γ and γ–γ coincidences. If we take into account the P_n value of Carraz et al.[4] (P_n = 29 ± 3 %), a large fraction of the decay remains unobserved after analysis of the n and γ spectra. The sum of intensities feeding bound excited levels in ^{50}Ca comes only to 11.6 % of the total β decay leaving 60 ± 10 % for the β transition to ^{50}Ca g.s. It should be noted that a large direct production yield of ^{50}Ca, from the ion source, precluded a measurement of this ground state branch by comparing parent and daughter activity.

The low energy level structure of ^{50}K is expected to be described by the $J^{\pi} = (0\text{-}3)^-$ multiplet, resulting from the $1d_{3/2} \times 2p_{3/2}$ coupling.The large β branching ratio to ^{50}Ca, 0^+,ground state (corresponding to log ft = 5.8) is then quite anomalous for a forbidden transition. This anomaly can be understood by using the shell model predictions [6] for ^{50}K. In this calculation, Poves indicates the level ordering of the $(0\text{-}3)^-$ multiplet and $J^{\pi} = 0^-$ is given for ^{50}K g.s. Accordingly, only 1^- states are connected in ^{50}Ca by GT transitions and the low density of ^{50}Ca states populated in the experiment can be explained.

As regard to the $^{50}K(0^-)$g.s. $\rightarrow$ $^{50}Ca(0^+)$g.s. decay, the high transition rate is related to pseudoscalar matrix elements. In this particular case, ($\Delta J=0$, $\Delta\pi$ yes), only rank zero matrix elements of the two components of the axial current contribute to the transition rate and strong meson-exchange enhancement is expected[7]. For light nuclei ($A \leq 40$), a number of ($\Delta J=0,\Delta\pi$ yes) cases have been studied previously and the comparison of the experimental β rate with shell model estimates has revealed a considerable enhancement of the experimental beta decay rate, attributed to meson exchange currents[7]. It should be noted that, all the transitions studied so far as : $^{16}C(0^+) \rightarrow {}^{16}N(0^-)$, logft = 6.7 ref[8]; $^{16}N(0^-) \rightarrow {}^{16}O(0^+)$, log ft = 5.5 ref[9] are predominantly $2s_{1/2} \rightarrow 1p_{1/2}$. The ^{50}K decay is the first case where essentially $2p_{3/2} \rightarrow 1d_{3/2}$ matrix elements are involved.

A more precise determination of the ($0^- \rightarrow 0^+$) transition rate is then contemplated.

Comparison of experimental values of B(GT) with shell model estimates

The neutron-gamma coincidence experiments allow to establish the level scheme in the daughter nucleus up to 10 MeV and the corresponding β strength function is put in terms of reduced GT transition probability. Experimental $^{48\text{-}51}K$ B(GT) distributions are not discussed here in detail. A summary of the results is given in Fig.7a where experimental strength within each 200 keV energy interval is summed up and plotted as histogram in the 4 cases.

One observation is evident from Fig.7a. If we consider the center of gravity of the first maximum in the B(GT) distribution (which should correspond mainly to $f_{5/2} \rightarrow f_{7/2}$ transitions), it appears that comparing A=48, 50 and 49, 51 we observe a shift of these structures, roughly

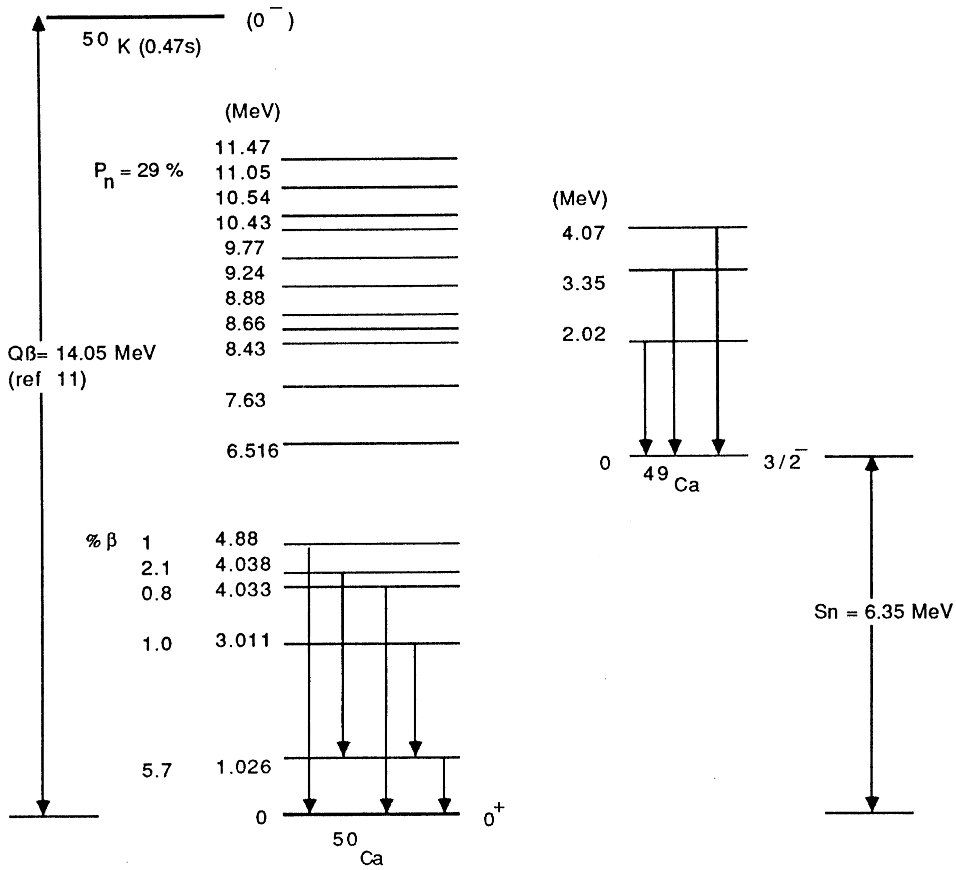
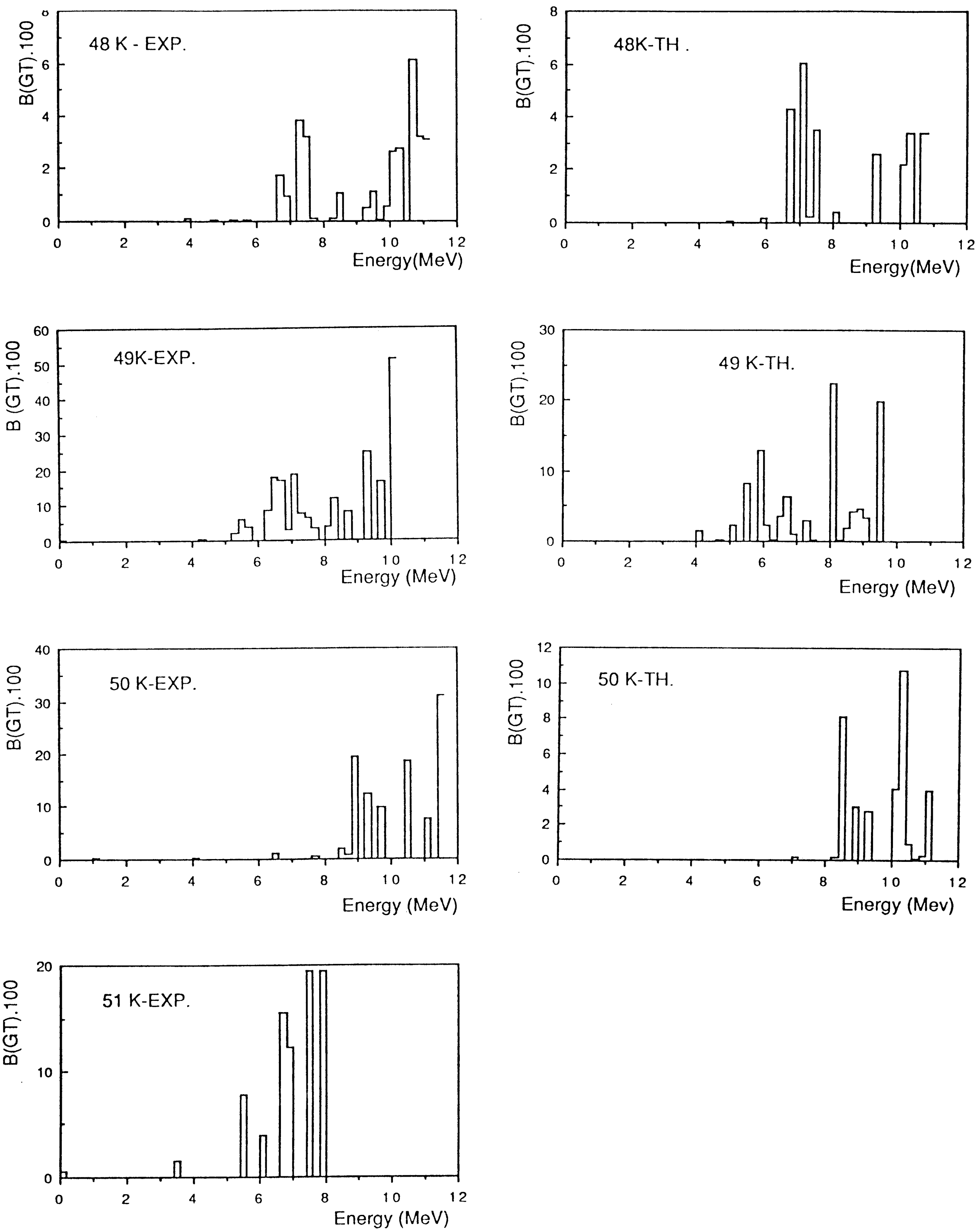


Fig. 6 Decay scheme of $^{50}K \rightarrow ^{50}Ca$



(a) (b)

Fig. 7 B(GT) strength distribution for the β decay of K isotopes
Experimental (7a) and theoretical (7b) strengths within 200 keV intervals

equal to the Q_β variations (Q_β respectively equal to 12.0, 11.0, 14.05 and 12.6 for A = 48, 49, 50 and 51). In other words, the energy difference between the parent state and the more important ones connected by GT decay, is almost constant and equal to 4.5 MeV. This value is to be compared to the energy difference between ^{50}Ca g.s. and the first 1^+state in ^{50}Sc, resulting from the $f_{7/2} \times f_{5/2}$ coupling, $\Delta E = 3.1$ MeV.

A comparison of experimental values of B(GT) with shell model calculations is given in Fig.7a and 7b where the corresponding quantities have been calculated for $^{48-50}K \rightarrow ^{48-50}Ca$ by Poves and Dobado[6]. The calculation will not be described here, two features should be noted :

- the valence space for K g.s. and p-h states in Ca is limited to $(sd)^{-1}$ $(fp)^{A-40+1}$ with 1 hole in $2s_{1/2}$ or $1d_{3/2}$, 8 or 7 particles in $1f_{7/2}$ and the remaining particles in $2p_{3/2}$ or $1f_{5/2}$
- the calculation gives the energy difference between the K g.s. and the Ca p-h state which is converted in excitation energy in the final nucleus by using experimental Q_β values.

The calculation reproduces quite well the main trends of the GT distribution and illustrates the predictive power of shell model evaluations far from stability. In particular J^π values for $^{48-50}$K have been found in agreement with predictions. It should be noted that from Fig.7a and 7b, the quenching of the GT strength is not directly apparent as a renormalization of single particle matrix elements has been done in the calculation.

Conclusion.

By γ and neutron spectroscopy techniques, a detailed study of the excited states of $^{48-51}$Ca levels has been made, with special emphasis on the unbound region. For A = 48, when using all the spectroscopic information available on ^{48}Ca, a strong excitation of the octupole resonance from GT transitions can be distinguished. In the case of ^{49}Ca, the overlap between β decay and resonance neutron spectroscopy is small on account of the selectivity of the β process to populate particle-hole states. This case is found completely different from the ^{87}Br decay[10] where a dramatic overlap between the results from resonance or delayed neutrons enabled a detailed discussion of the ^{87}Kr level density. Finally, ^{50}K decay provides the best case to study the meson-exchange enhancement of the axial current for $p_{3/2} \rightarrow d_{3/2}$ transitions.

The Gamow-Teller strength distributions of $^{48-50}$K isotopes are largely explained by shell-model calculations involving five shells, distributed in two major shells. This success generates more interest in the experimental investigation of the large excitation energy range open to study, far from stability.

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