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PROPOSAL

STUDY OF GAMOW-TELLER TRANSITIONS RELATED TO THE TWO-NEUTRON EMISSION MODE AT ISOLDE

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Summary

The purpose of the experiment is to locate the states involved in the two-neutron emission mode in neutron rich light nuclei. The experimental device consists of a double time of flight system with efficient neutron counters and gamma detection. Information about the mechanism responsible for the two particle emission will be also collected.

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Introduction

The possibility to observe the β-delayed emission of two protons (or neutrons) was pointed out already in 1960 (1). The first observation of β-delayed two neutrons radioactivity was reported in 1979 (2,3) and very recently, two cases of β-delayed two protons emission have been found (4,5).

The investigation of two-particles emission provides a potential new field for studying pairing and potential barrier effects. It allows also to investigate the upper part of the Gamow-Teller strength distribution from the β-decay of exotic nuclei.

The techniques for production of very neutron rich (or deficient) nuclei have reached a level where the yields allow, in selected cases, to set up the first detailed study of the two delayed particles emission.

We propose to measure the energy distribution of the two delayed neutrons in the case of ^{30}Na and to determine the beta strength function correlated with this emission.

I - Two neutrons precursors

From mass tables, a great number of possible precursors of two particles emission can be found far from stability. The (β,2n) emission is possible for nuclei with $Q_{2n} = Q_{\beta} - S_{2n} > 0$, where Q_{2n} is the window for two neutrons decay, S_{2n} the removal energy of two neutrons and Q_{β} the mass difference between isobar nuclei. Values of P_n (total number of emitted neutrons for 100 beta decays, $P_n = \sum_i iP_{in}$) have been measured recently for different Na and K nuclei identified as 1n or 2n precursors and are reported in Table I. The number of neutron pairs available for study ($P_{2n} \times N$, N : production yield at ISOLDE in atoms/s for 1 μA proton beam) is maximum for ^{30}Na ($N \simeq 10^3$ atoms/s) and decreases rapidly with neutron excess (N < 10 atoms/s for ^{32}Na). We note that ^{11}Li can be produced with higher yields but is more difficult to investigate as the 3n emission competes strongly with the 1n and 2n modes.

Using a microscopic approach based on the theory of isobaric states (9) or the gross theory of beta decay, a theoretical estimate of P_n and P_{2n} values can be compared to the measured ones and a general agreement is found within a factor two (10).

II - Neutron spectra and beta strength function

Neutron spectra have been measured for the Na isotopes up to A = 31 (11) and for the Li isotopes up to A = 52 (12). In the case of the Li isotopes, neutron spectrometry with different techniques as well as β-n-γ coincidences have allowed (in the case of 1 neutron emission) to identify initial and final states corresponding to neutron emission. The main results are the following :

- β^- strength functions derived from these measurements reveal the excitation of discrete states, described as particle-hole states in the daughter calciums. An extended shell model calculation made by Dobado and Poves (13) with the use of a realistic interaction gives energy levels, mean lives and log ft values in good agreement with the experimental results.

- For the K nuclei with A $\leq$ 52, no evidence was found for a delayed one-neutron emission originating from excited states, in the Ca daughter nuclei, located higher than S_{2n}. In other words, the neutron channels appear to be decoupled with $\Gamma_{2n} \gg \Gamma_{1n}$ for $E_x > S_{2n}$.

For the Na isotopes, where evidence for 2n emission has been found (3), the lack of n-γ coincidence data and of high energy neutron detection prevent to determine the beta strength function for $E_x > S_n$.

III - Neutron emission mechanism

Different modes of neutron pair emission can be considered in the decay of the initial A(N,Z) nucleus :

a) A sequential (cascade) emission through states of the nuclei A-1 (N-1, Z+1) and A-2 (N-2, Z+1).

b) The emission of a correlated neutron pair with zero angular momentum (^1S_o, T = 1 state). An estimate of the relative probability of these two processes, (P_{n^2}/P_{n+n}), has been made by Lyutostanskii (9) using Hauser Feschbach approximations. P_{n^2}/P_{n+n} has been found $\leq$ 12 % in all cases. Up to now, no data can be compared to these calculations.

On the other hand, previous studies of (n,2n) processes, which distinguish precompound and compound nucleus emission mechanisms (14) do not provide information in the case of light nuclei, where structure effects are important.

IV - Experimental device

We propose to study the two neutrons emission of ^{30}Na using β-n_1-n_2 coincidences in a double time of flight experiment. A γ detector [Ge(Li) 30 % efficiency or INA (Tℓ) 3" x 3"] will be used in coincidence in order to identify find bound states in ^{29}Mg and ^{28}Mg. The neutron detectors will be the experimental equipment currently employed by us for the potassium studies (see figure 1). It consists of :

- A NE 110 scintillator sheet (160 x 18 x 1.25 cm) with an efficiency of 9 % for 2 MeV neutrons and a solid angle of 27 msr.

- A NE 110 scintillator sheet (160 x 18 x 5 cm) with an efficiency of 36 % for 2 MeV neutrons and the same solid angle.

The two counters are bent with a radius of curvature equal to the flight path (100 cm) and associated each to two phototubes (XP 2020) and a meantimer yielding a time resolution of about 1 ns. The start signal of the time of flight is obtained from a thin scintillator surrounding the collection point and detecting the beta emission.

If the two particle emission takes place through a small number of discrete states of the daughter nucleus, A(N-1, Z+1), the events of the double time of flight should be located (see figure 2) in well defined regions of the (t_1, t_2) plane (t_1 and t_2 : time of flight corresponding to n_1 and n_2). A sequential 2n decay should give an isotropic emission which will be checked.

The large detectors are not suited to detect a correlated neutron pair which should be emitted in a very small solid angle. A separate experiment will be necessary to identify this decay mode, different devices are presently under study.

We request 30 shifts of ISOLDE running time on the following measurements :
- test and calibration of the experimental set-up using ^{29}Na,
- measurement of the neutron spectra and of the correlation between neutron

pairs for ^{30}Na,
- search for 2n emission in ^{52}K or in heavy neon isotopes.

V - Future experiments

A similar discussion can be repeated for the study of the two delayed protons emission from neutron deficient light nuclei with, in that case, a possible He^2 contribution and a Coulomb repulsion between the emerging particles. The need for special detection techniques is evident. As a first exploratory work, we suggest a careful measurement of P_p and $T_{1/2}$ values using a large solid angle scintillator, ICS(Tℓ), operated in the pulse shape discrimination mode. Possible candidates at ISOLDE would be : ^{16}Ne, $^{30}C\ell$, ^{34}K, ^{35}Ca and ^{38}Sc.

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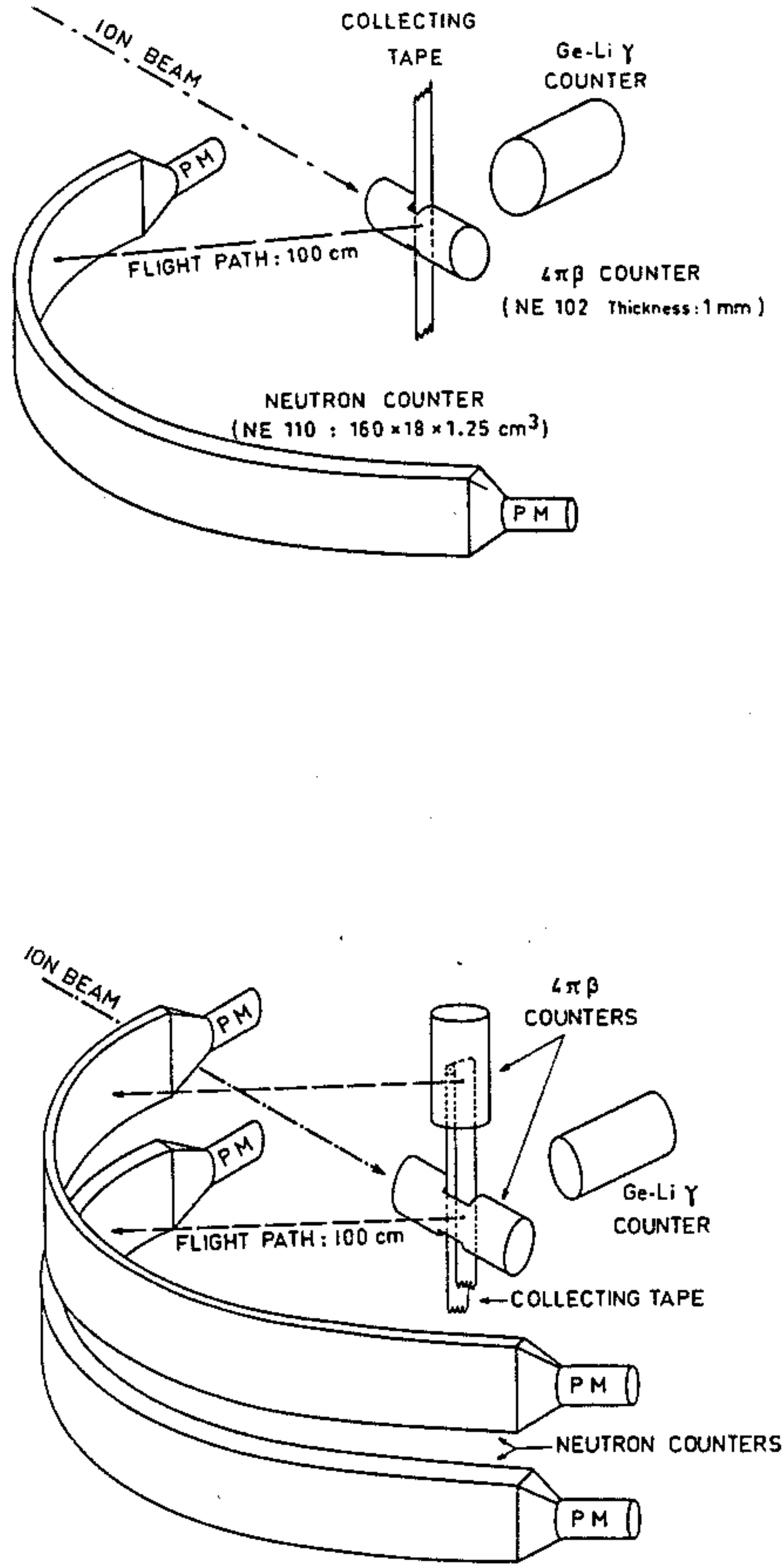

Figure 1 : Experimental set up used previously for 1n detection

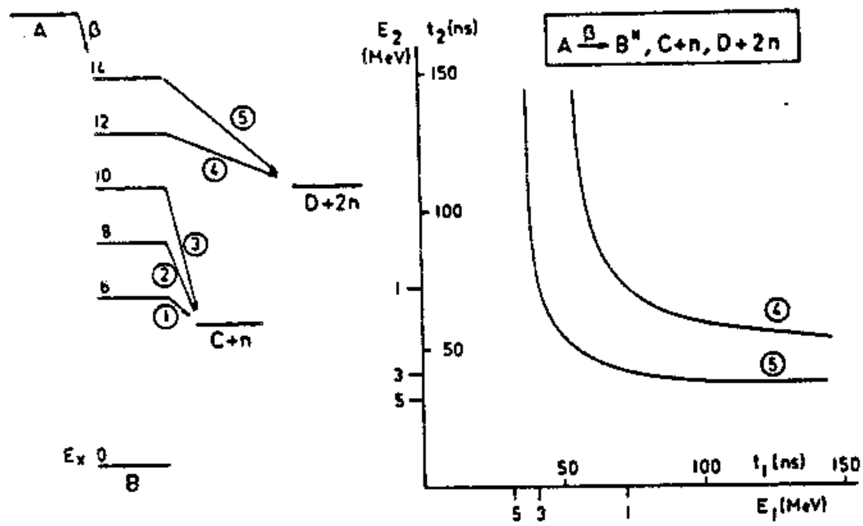

Figure 2 : Illustration of the double time of flight method

TABLE I (References 6-8)

	$T_{1/2}$ (s)	Q_β (MeV)	$Q_\beta - S_{2n}$ (MeV)	P_n	P_{2n}
^{50}K	0.47	13.9	2.4	29	
^{51}K	0.32	12.6	2.6	47	
^{52}K	0.10	16.0	6.5	107	
^{53}K	0.03	15.1	7.1	100	
^{29}Na	0.044	13.3	1.0	21	
^{30}Na	0.048	16.3	6.1	30	1.4
^{31}Na	0.017	15.3	6.1	38	1
^{32}Na	0.013	18.3	8.8	24	8.3