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ISOSPIN-FORBIDDEN β-DELAYED PROTON EMISSION FROM ^{22}Al[*]

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A new isospin-nonconserving Hamiltonian for *sd*-shell nuclei is applied to the calculation of branching ratios of the isospin-forbidden proton emission following the beta decay of ^{22}Al.

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1. Introduction

In the last decade, the isospin-symmetry breaking phenomena get more and more attention from both theoretical and experimental sides. These studies are promoted by advances in experimental techniques and detection power, allowing to tremendously increase the accuracy of measurements (like nuclear masses, lifetimes and branching ratios). At the same time, development of microscopic approaches and computational performance enlarges theoretical abilities to calculate isospin-symmetry breaking.

Recently, we have developed a new set of isospin-nonconserving (INC) Hamiltonians for *sd* shell-model calculations [1, 2], based on the realistic isospin-conserving USD [3], USDA or USDB [4] interactions, supplemented by the two-body Coulomb interaction and a phenomenological term modelling the isospin-symmetry breaking part of the effective nucleon–nucleon interaction. The unknown strength parameters were found by a least-squares fit to experimental splittings of the isobaric multiplets throughout the *sd* shell (see Ref. [2] for details).

In this contribution, we present the application of the INC Hamiltonian to the calculation of branching ratios of the isospin-forbidden proton emission.

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2. Beta-delayed proton emission from ^{22}Al

One of the decay modes of proton-rich nuclei is the beta-delayed nucleon (multinucleon) emission [5]. Here we consider the disintegration of ^{22}Al. The ground state (most probably, 4^+ state) of this proton-rich nucleus decays by a β^+ emission to the excited states of ^{22}Mg. The strongest branch is the Fermi decay to the isobar-analogue state (IAS) at about 14 MeV excitation energy. It is this state in which we are interested in the present study, because it decays further by proton, di-proton or alpha particle emission to the low-lying states of ^{21}Na, ^{20}Ne or ^{18}Ne, respectively. Due to the peculiar Q-value systematics, all mentioned processes would be forbidden if the isospin symmetry were exact. Thus, to describe the branching ratios for the decay of the IAS, one needs an INC Hamiltonian.

Figure 1 presents a partial decay scheme of ^{22}Al. We focus on the proton emission from the IAS in ^{22}Mg. The experimental information on these transitions is rather scarce. At most, two branches to two of the four lowest states of ^{21}Na have been observed in a given experiment [6–8].

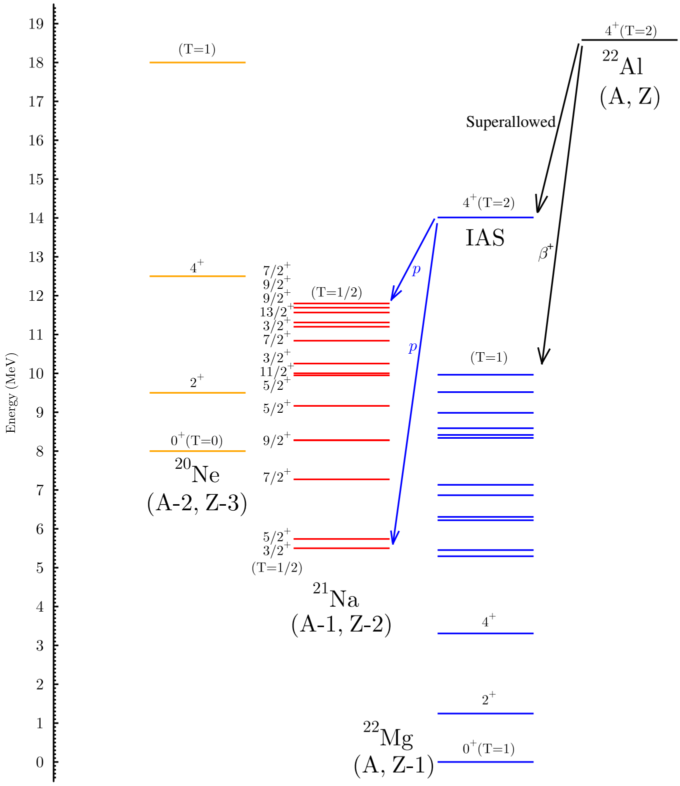

Fig. 1. Partial decay scheme for a beta-delayed proton emission from the ^{22}Al.

In the present study, we calculate branching ratios for a proton emission from the IAS of the ^{22}Al ground state in ^{22}Mg to the energetically allowed states of ^{21}Na (see Table I). From the USD-based INC Hamiltonian, the Fermi transition to the IAS in ^{22}Mg carries about 98% of the total strength. The spectroscopic factors θ_l^2 for the emission of $l = 0$ and $l = 2$ protons are present with uncertainties, related to the spread in the results obtained from slightly different approaches to the short-range correlations [2].

TABLE I

^{21}Na	$E^{\mathrm{th}}_{\mathrm{exc}}$	$10^4\theta^2$		$\mathit{\Gamma}_p(l)$ [keV]		BR
	[MeV]	$l = 0$	$l = 2$	$l = 0$	$l = 2$	(%)
$3/2^+_{\mathrm{gs}}$	0.0		0.090(2)		0.041(1)	1.5(1)
$5/2^+_1$	0.236		0.267(4)		0.111(2)	4.1(1)
$7/2^+_1$	1.779	0.009(4)	4.73(21)	0.011(5)	1.186(54)	43.5(21)
$9/2^+_1$	2.780	0.006(0)	2.54(23)	0.006(0)	0.407(36)	15.0(13)
$5/2^+_2$	3.694		0.28(7)		0.026(6)	1.0(2)
$11/2^+_1$	4.428		1.91(30)		0.104(16)	3.8(6)
$5/2^+_2$	4.556		0.37(5)		0.018(3)	0.7(1)
$3/2^+_2$	4.785		0.25(2)		0.010(1)	0.4(0)
$7/2^+_2$	5.328	0.184(4)	0.72(17)	0.077(2)	0.016(4)	3.4(2)
$3/2^+_3$	5.784		0.10(0)		0.001(0)	0.0(0)
$9/2^+_2$	6.078	0.90(5)	0.17(2)	0.209(11)	0.001(0)	7.6(4)
$13/2^+_1$	6.141		0.54(3)		0.004(0)	0.1(0)
$9/2^+_3$	6.192	1.05(3)	6.9(2)	0.218(6)	0.041(1)	9.4(3)
$7/2^+_3$	6.274	1.02(7)	14.2(4)	0.192(14)	0.072(2)	9.6(6)

The proton widths have been calculated as $\mathit{\Gamma}_p(l) = 2\gamma^2\theta_l^2 P_l(Q_p)$, where γ^2 is the Wigner single-particle width $\gamma^2 = 3\hbar^2c^2/(2\mu R_0^2)$, $P_l(Q)$ is the penetrability, Q_p is the Q-value for the proton emission [9, 10]. Contribution from higher lying states from the proton Q-window is negligible (about 0.5%).

The present results can be compared with the earlier study by Brown [10] based on the INC Hamiltonian developed in Ref. [11]. It is seen that the gross features of the process are very similar. The level schemes in both calculations are very close. The differences in excitation energies of ^{21}Na are within ~ 50 keV. Regarding the proton emission rate, in both calculations two main branches correspond to the transitions to the $7/2^+_1$ and $9/2^+_1$ states. Besides, the two close lying $9/2^+$ states at ~ 6.07 MeV and ~ 6.19 MeV excitation energy take about 15–16% of the strength. It is concentrated in one state following [10], and it is almost equally distributed between two states in our calculation.

However, there are some differences. First, we notice that the present calculations predict a larger amount of the total spectroscopic strength inside the proton Q-window in comparison with that of Ref. [10]. The total proton width is about 2.7 keV, compared to about 1 keV [10].

In addition, small branching ratios are often different. For example, our calculation predicts more strength to the $5/2_1^+$ than to $3/2_{\mathrm{gs}}^+$ state in agreement with the spectrum given in Ref. [6], while the results of Ref. [10] support about equal distribution of the strength among these two states. It would be very helpful to have a number of proton branching ratios measured simultaneously in one experiment in order to test theoretical predictions.

The USDB-based INC Hamiltonian produces a larger amount of the isospin mixing in the IAS and thus larger values of spectroscopic factors, leading to the total proton width of ~ 8 keV. In addition, the distribution of the proton strength is different (for example, the $5/2_2^+$ state is predicted to carry about 21% of the total width). Calculations with the USDA-based Hamiltonian produce two closely lying 4^+ states around 14 MeV (about 20 keV difference) which share almost equally the Fermi strength.

3. Summary and outlook

In this contribution, we have presented the application of the INC Hamiltonian to calculation of the branching ratios for a beta-delayed proton emission from ^{22}Al. In general, the results are similar to the previous study by Brown [10], although the total width is predicted to be about twice larger. There are visible differences for small branches. The values of spectroscopic factors are very sensitive to the details of the Hamiltonian. The work on other precursors is in progress. We hope that those results would shed more light on the INC Hamiltonian properties.

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