STUDY OF LOW-SPIN STATES IN Ca ISOTOPES VIA NEUTRON CAPTURE REACTIONS*

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Preliminary results are presented from a γ-spectroscopy study of low-spin states of ^{41,49}Ca isotopes, produced by neutron capture on a Ca target, at very high coincidence rates. The experiment was performed at the PF1B cold-neutron facility at ILL (Grenoble, France), using the EXILL array, consisting of EXOGAM, GASP and ILL-Clover detectors.

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1. Introduction

One of the main issues in nuclear physics concerns the interplay between single particle and collective degrees of freedom, which is a manifestation of the many body nature of the atomic nucleus. Nuclei around doubly closed shells offer an excellent testing ground to investigate such a phenomenon, particularly in terms of couplings between core excitations (*i.e.* phonons) and single particles outside the closed shell core [1]. This type of couplings are at the origin of the anharmonicities of vibrational spectra, damping phenomena, quenching of spectroscopic factors, ...

The coupling between a core vibration (phonon of multipolarity λ) and a single particle with spin j generates a multiplet of states that are characterized by a well defined parity and by angular momenta between $|\lambda - j|$ and

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$\lambda + j$. At the leading order, the coupling is linear with the vibration, therefore its strength can be evaluated by measuring the transition probability to the ground state.

From the experimental point of view, indications of particle–phonon coupled states have been found mostly in medium-heavy nuclei [1], while scarce information exists for medium-light systems [2–5] and moving away from the stability valley. In the latter case, particle–phonon coupled states would also provide complementary information on the robustness or softness of the nuclear collectivity far from stability.

In this context, the doubly magic ^{48}Ca is particularly interesting. In the work by Montanari *et al.* [2, 3] (an in-beam γ-spectroscopy study of n-rich nuclei around ^{48}Ca populated the ^{48}Ca+^{64}Ni binary reaction, at $\approx$ 6 MeV/u), it was demonstrated that the $9/2^+$ level of ^{49}Ca (at 4.017 MeV) is a member of the multiplet of states ($3/2^+$, $5/2^+$, $7/2^+$ and $9/2^+$) arising by coupling the 3^- octupole phonon of ^{48}Ca with the unpaired $p_{3/2}$ neutron. To obtain a complete picture of particle–phonon coupled states in the ^{49}Ca nucleus, one should also study the other members of the $p_{3/2} \otimes 3^-$ multiplet, employing a reaction mechanism which allows to populate them with sizable cross section. In this contribution, we report preliminary results from a neutron capture experiment on a ^{48}Ca target, aiming at a high-resolution γ-spectroscopy of low-spin states in ^{49}Ca, from the capture level to the ground state.

2. Experimental setup and data analysis

The experiment was performed at the PF1B cold-neutron facility at the Istitute Laue Langevine (Grenoble, France), using the EXILL array, consisting of 8 EXOGAM clovers, 6 large coaxial detectors from GASP and 2 ILL-Clovers, placed at 90°, 45° and 0° with respect to the beam direction (the latter at 180° with respect to the GASP detectors), respectively. The total photopeak efficiency was about 6%. A digital data acquisition allowed event rates up to 0.84 MHz to be handled [6].

The (n, γ) reaction was performed using a 620 mg $CaCO_3$ target with 69.2 %, 27.9% and 2.5% istopic abundances of ^{48}Ca, ^{40}Ca and ^{44}Ca, respectively. As a consequence, a large fraction of double and triple γ coincidences were coming from ^{41}Ca, ^{45}Ca and from ^{49}Sc, populated by β-decay of ^{49}Ca. In general, the populated nuclei of ^{41,45,49}Ca were found to decay from the capture level by primary (E1) transitions of several MeV and to populate in a statistical way, excited states within few units of spin. By using several cascades, the neutron separation energies were calculated to be 8363.10(42), 7414.34(35) and 5146.46(50) keV for ^{41}Ca, ^{45}Ca and ^{49}Ca, respectively. Such values agree, within the errors, with the ones reported in literature [7].

Figure 1 (a) shows the total spectrum measured in the n-capture reaction, with strong lines coming from the de-excitation of ^{41,45,49}Ca and ^{49}Sc. A preliminary level scheme of ^{49}Ca is given in panel (b), with newly found transitions marked in grey (red). As a consequence of the low energy of the $1/2^+$ capture level in ^{49}Ca, only two-steps cascades are observed, with intermediate states of negative parity. On the contrary, in ^{41}Ca and ^{45}Ca multisteps cascades were observed, populating intermediate states of both positive and negative parities. In particular, several positive parity states are found in 3–4 MeV region where one expects to find states of particle–phonon nature, based on the coupling between the $p_{3/2}$ neutron and the 3^- octupole phonon of ^{40}Ca and ^{44}Ca, at 3.7 and 3.3 MeV, respectively.

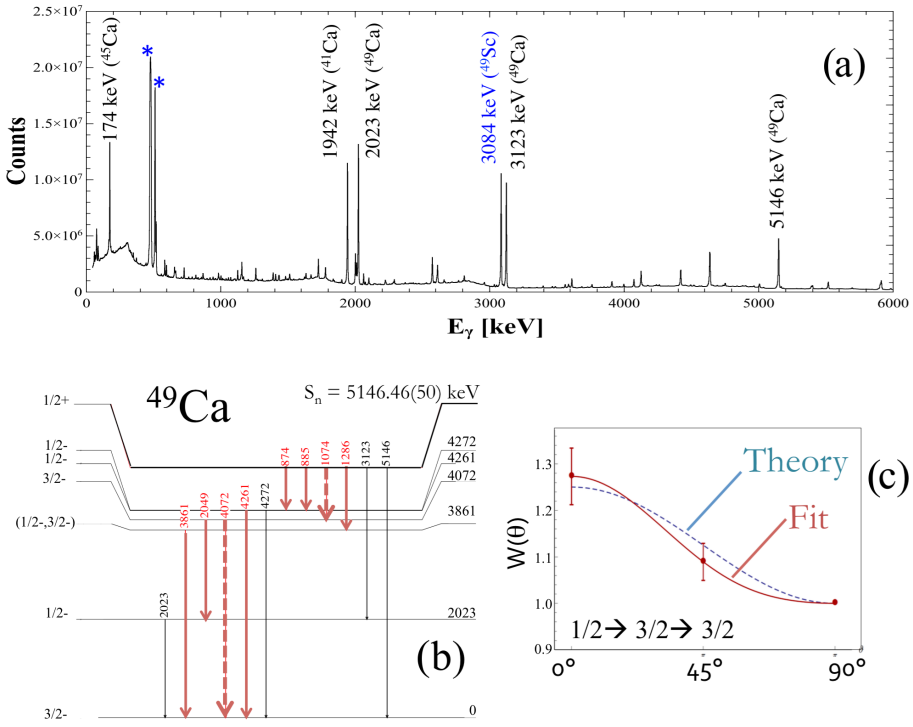

Fig. 1. (a) Total γ spectrum measured in the n-capture reaction with the Ca target. The strongest transitions from ^{41,45,49}Ca and ^{49}Sc are given. Background lines are marked by stars. (b) Preliminary level scheme of ^{49}Ca with newly found transitions given in grey (red). (c) Angular correlation of the 1074 and 4072 keV transitions (dotted arrows in (b)). Solid and dashed lines are the experimental fit and the theoretical interpolation (obtained by fitting the δ mixing parameter), giving the spin assignment $1/2, 3/2$ and $3/2$, for the initial, middle and final states, respectively.

A key aspect of this work is the measurements of γ–γ angular correlations, performed with the EXOGAM clovers, to firmly establish the spin of several excited states. The symmetry of the EXOGAM detectors allowed angular correlation measurements at three relative angles between the detectors, *i.e.* 0°, 45° and 90° degrees. The analysis was performed following the formalism of Krane *et al.* [8], adopting their convention on the sign for the mixing coefficient δ. The expression for the angular correlation function between two consecutive γ transitions, γ_1 and γ_2 (in a cascade emitted from an unoriented state with spin J_1, through an intermediate level with spin J_2 to the final level with spin J_3) can be expanded into a series of Legendre polynomials P_k of rank k

$$W(\theta) = 1 + a_{22}q_2P_2(\cos(\theta)) + a_{44}q_4P_4(\cos(\theta))\,, \tag{1}$$

where θ is the angle between the directions of γ_1 and γ_2, while q_2 and q_4 are the attenuation coefficients taking into account the finite geometry of the apparatus. Figure 1 (c) shows the angular correlation obtained for the 1074 and 4072 keV transitions of ^{49}Ca. The spin of the initial, intermediate and final states are confirmed to be 1/2, 3/2 and 3/2, respectively, taking the 4073 keV line as a pure dipole and a mixing δ on the 1074 keV transition equal to $-1.87^{+0.19}_{-0.22}$, which indicates a strong dipole character.

3. Conclusions

Preliminary results were presented from a neutron capture experiment performed at ILL (Grenoble) on a Ca target. The setup consisted of the high-efficiency Ge array EXILL, which allowed to perform high-resolution γ-spectroscopy and angular correlation studies of ^{41,45,49}Ca nuclei. The work aims, in particular, at identifying states arising by coupling single particles to core excitations, such as the 3^- octupole phonon in the corresponding ^{40,44,48}Ca cores.

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