Study of Ca isotopes via neutron capture reactions

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Abstract
Preliminary results are presented from a γ-spectroscopy study of low-spin states of several Ca isotopes, produced by neutron capture on a Ca target, at very high coincedence rates. The experiment was performed at the PF1B cold-neutron facility at ILL (Grenoble, France), using the array of HpGe detectors, named EXILL.

1. Introduction

Nuclei around doubly closed shells play a crucial role in determinating both the nucleonic single-particle energy levels and the two-body matrix elements of the effective nuclear interactions. In addiction, they offer an excellent tool to study the coupling between a particle/hole and collective excitation of the core. This is a key ingredient to explain important phenomena, such as the observed reduction of spectroscopic factors, the anharmonicity of vibrational spectra, the damping of Giant Resonances, etc. Experimentally, several indications have been found of discrete states of particle-phonon nature, mostly in medium-heavy nuclei, while only few examples are known in lighter mass regions.
The nuclei under examination in this work, ^{41,49}Ca isotopes, have 1 neutron outside the doubly magic ^{40}Ca and ^{48}Ca cores and they represent good systems in which particle-vibration coupled states can be investigated. This is because phonos such as the 3^-, have sizable collectivity.

In order to study the nature of the excited state in ^{41,49}Ca isotopes, their energy, spin, parity and lifetime have to be measured experimentally with a good precision. Of particular importance is the comparison of experimental data with calculations either based on a shell-model approach or taking into account couplings between core excitations (such as vibrations) and single particle.

In this work we present a detailed low spin γ-spectroscopy study of Ca isotopes, produced by a neutron capture reaction on a ^{48}Ca target. 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 HpGe detectors.

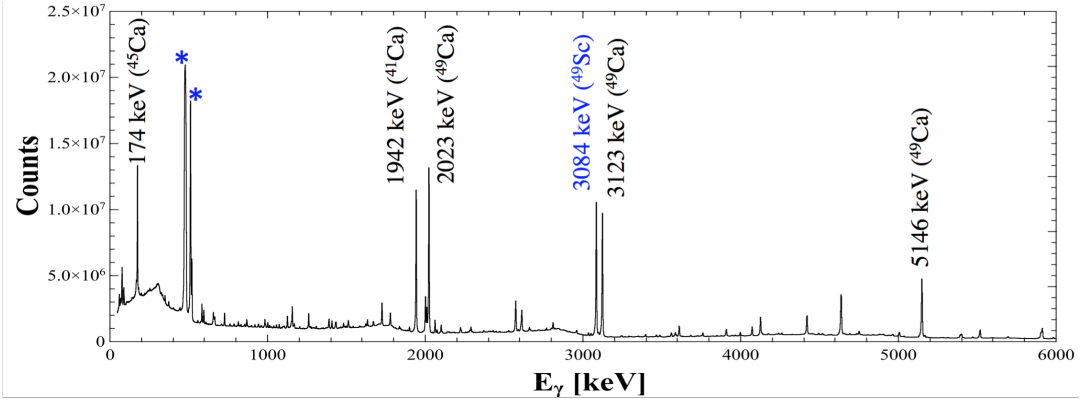

Fig. 1: Total γ spectrum measured in the n-capture reaction with the Ca target. The strongest transitions from ^{41,45,49}Ca and ^{49}Sc are given. Background lines are marked by stars.

2. The experiment

The experiment was performed at the PF1B cold-neutron facility at Istitut Laue Langevine (Grenoble, France), where the world's brightest continuous neutron flux is delivered with a thermal-equivalent of 2×10^{10} ns^{-1}cm^{-2}. The HpGe array EXILL was used, 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.

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. Figure 1 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.

3. The analysis

The experimental analysis is devoted to investigate the possible levels that are good candidate to be member of the multiplet generated by coupling single particle states and the 3^- octupole vibration of the core nucleus. As a starting point, the neutron separation energies were calculated by using several cascades and values of 8363.10(42), 7414.34(35) and 5146.46(50) keV were found for ^{41}Ca, ^{45}Ca and ^{49}Ca, respectively. Such values agree, within the errors, with the ones reported in literature.

As a consequence of the low energy of the $1/2^+$ capture level in ^{49}Ca, only two-steps cascades were observed in ^{49}Ca, 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. Figure 2 shows the preliminary level scheme of the ^{49}Ca nucleus. The characterization of the levels and of the γ-transitions is the key aspect of this work. This can be done by measuring the angular correlation between two γ-rays of the same cascade. 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 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

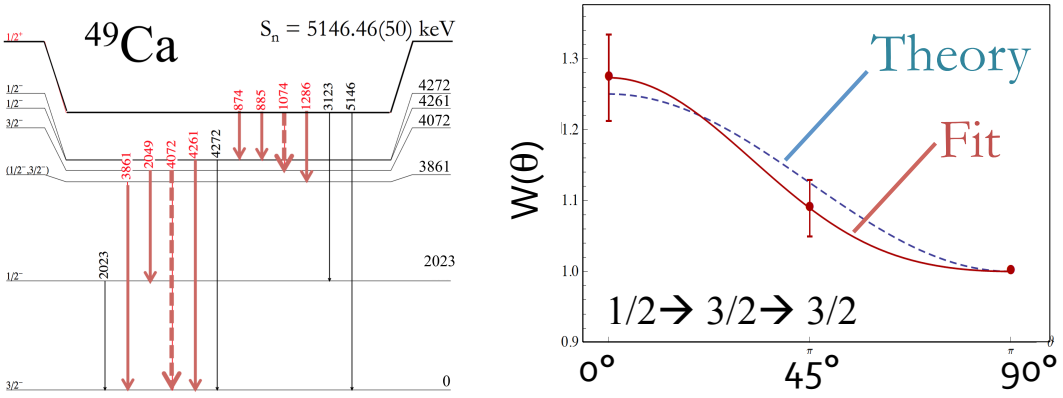

Fig. 2: Left panel): Preliminary level scheme of ^{49}Ca with newly found transitions given in red. Right panel: Angular correlation of the 1074 and 4072 keV transitions (dotted arrows in right panel. Solid and dashed lines are the experimental fit and the theoretical interpolation (obtained by fitting the δ mixing parameter), giving the spin assignment 1/2, 3/2 and 3/2, for the initial, middle and final states, respectively.

the final level with spin J_3) is well described by a linear combination of Legendre polynomials P_k

$$W(\vartheta) = \sum_{\text{even k}}^{\text{k}_{\text{max}}} A_{\text{kk}} P_{\text{k}}(\cos\vartheta) Q_k(1) Q_k(2) \tag{1}$$

where ϑ is the angle between the directions of γ_1 and γ_2 and Q_k are the attenuation coefficients. By fitting the parameters A_{kk} it is possible to evaluate the spin of the initial, intermediate and final states, the multipolarity of the transitions and the possible mixing ratio. Right panel of Fig. 3 shows the results obtained considering the angular correlation between 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.

4. 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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