STUDY OF ^{41}Ca VIA COLD NEUTRON CAPTURE*

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The low-spin structure of the ^{41}Ca isotope, populated by neutron capture, has been investigated by high resolution γ-spectroscopy techniques. The experiment was performed at the PF1B cold neutron facility at the Institut Laue–Langevin (Grenoble, France) employing the EXILL array, consisting of 46 HPGe crystals. Several new γ rays have been observed and two excited states were newly established.

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1. Introduction

Nuclei around doubly-closed shells play a crucial role in determining both the nucleonic single-particle energy levels and the two-body matrix elements of the effective nuclear interactions. Of particular importance is the comparison of experimental data with calculations either based on a shell-model approach or taking into account couplings between excitations of the core (such as vibrations) and single particles [1–5].

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In this paper, we present a high resolution γ-spectroscopy study of ^{41}Ca, a one-neutron-valence system with respect to the ^{40}Ca core. ^{41}Ca was populated by neutron capture, therefore extended information on the low-spin excited states, below the neutron binding energy, is expected. This will also allow us to search for low-spin excitations arising from the coupling of the $f_{7/2}$ neutron particle with the 3^- octupole vibration of the ^{40}Ca core, at 3.7 MeV, which has a very strong collectivity (B(E3)$\sim$ 31 W.u.). This $3^- \otimes 7/2^-$ coupling generates, in fact, a multiplet of positive-parity states ($1/2^+$, $3/2^+$, $5/2^+$, $7/2^+$, $9/2^+$, $11/2^+$, and $13/2^+$), which are expected to be located in the 3–4 MeV region, close to the 3^- excitation energy.

2. Experiment and data analysis

The ^{41}Ca nucleus was produced by cold neutron capture on a target with the following isotopic composition: ^{40}Ca (60.5%), ^{46}Ca (31.7%), ^{44}Ca (5.35%). The experiment was performed at the PF1B cold-neutron facility at ILL (Grenoble, France), with a capture flux on target of 10^8 neutrons/(s$\times$cm^2). The experimental set-up consisted of 46 HPGe crystals: 8 EXOGAM clovers, 6 GASP detectors, as well as two clovers from the ILL LOHENGRIN Instrument, ensuring a total photopeak efficiency of 6% [6].

From the capture level at 8362 keV, ^{41}Ca decays by primary (mainly E1) transitions of several MeV, populating in a statistical way excitations below the neutron binding energy. As the measured spectrum was very complex, owing to a large number of decay paths and the multi-isotopic composition of the target, the γ-coincidences technique was applied, sorting the data into $\gamma\gamma$- and $\gamma\gamma\gamma$-coincidence histograms. A representative spectrum, gated on the 520 and 1943 keV transitions, is shown in Fig. 1 (a).

The ^{41}Ca decay scheme established presently is given in Fig. 1 (b): γ energies observed thus far are marked in black, newly found transitions, *i.e.*, 11 primary and 26 secondary γ rays, are shown in red (vertical gray). The decay from the capture state ($J^\pi = 1/2^+$) to the ground state ($J^\pi = 7/2^-$) allowed to populate low-spin ($J = 1/2$, $3/2$, or $5/2$) excited states, of both negative or positive parity. Two levels, at 3564 and 6373 keV, were newly identified. The former is both fed and deexcited by one transition only, making it impossible to define the order in the cascade (the energy of the tentatively established 3564 keV level is marked by a dashed line in Fig. 1 (b)). The order of the 1989–4431 keV cascade (and the energy of the 6373 keV excitation) was established owing to the observation of a weak 3911 keV transition feeding the 2462 keV state in coincidence with the 1989 keV primary γ ray. Possible candidates for $3^- \otimes 7/2^-$ excitations are marked in blue (horizontal gray) in Fig. 1 (b).

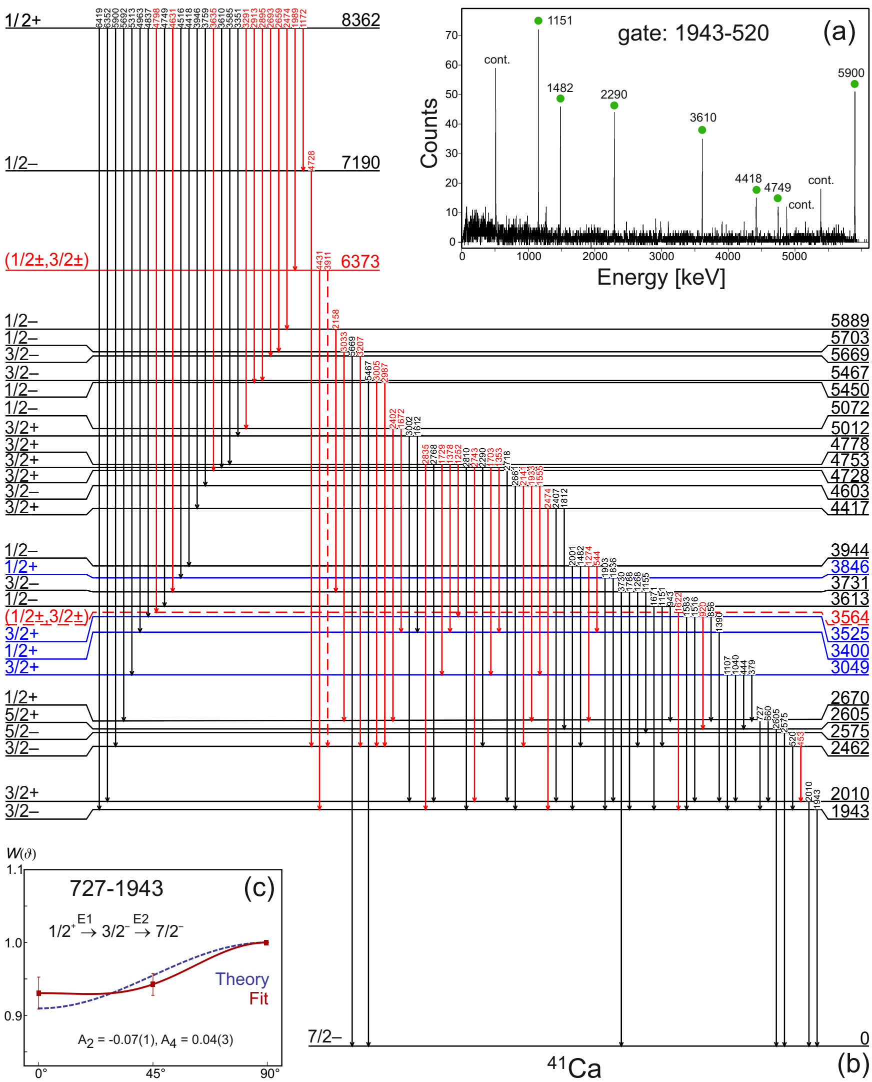

Fig. 1. (Color online) (a) Representative coincidence spectrum of ^{41}Ca from the cold neutron capture reaction ^{40}Ca$(n,\gamma)^{41}$Ca, double-gated on the 1943- and 520 keV transitions. (b) Preliminary level scheme of ^{41}Ca. The newly found levels and γ rays are marked in red (vertical gray). The dashed lines indicate tentatively identified levels and transtions (see the text). Possible candidates for excitations arising from the coupling with the 3^- phonon of ^{40}Ca are marked by the blue (horizontal gray) lines. (c) Experimental angular correlation function of the 727- and 1943 keV γ rays from ^{41}Ca (solid/red curve and the A_2 and A_4 coefficients) together with the theoretical curve calculated for the pure E1–E2 cascade (dashed/blue line).

The setup of the EXOGAM detectors (arranged into one ring around the target at every 45° in a plane perpendicular with respect to the beam), allowed us to use the $\gamma\gamma$-angular correlation analysis to extract information about γ-ray multipolarities following the procedure described in [7, 8], for a similar EXILL data set. Figure 1 (c) shows, as an example, the angular correlation function (marked by solid red line) obtained for the 727–1943 keV strong cascade leading to the ground state in ^{41}Ca. The spin of the initial, intermediate and final states, $1/2^+$, $3/2^-$ and $7/2^-$, respectively, as well as the pure E2 multipolarity of the 1943 keV γ ray were previously established. The theoretical curve, calculated for the $1/2^+ \rightarrow 3/2^- \rightarrow 7/2^-$ cascade of stretched transitions, is shown by a dashed blue line in Fig. 1 (c). The agreement of the calculated curve with the fit to the experimetal data indicates a pure E1 character for the 727 keV line.

3. Conclusions

A γ-spectroscopy study of ^{41}Ca, populated by cold-neutron capture was performed with a high-efficiency HPGe array. Several new γ rays were observed and among the identified levels, a number of positive-parity states were located in the 3–4 MeV region where one expects to find states based on the coupling between the unpaired $f_{7/2}$ neutron and the 3^- octupole phonon of ^{40}Ca. This extended experimental information on ^{41}Ca may serve as an excellent testing ground for shell-model calculations, as well as for the theoretical approaches aiming at describing the entire excitation spectrum of one-valence-particle nuclei, including complex states arising from the coupling of the valence nucleon with excitations of the doubly-magic core [5].

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