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Short Note

High-spin states in ^{44}Ca

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Abstract. High-spin states of the ^{44}Ca nucleus populated in the 68 MeV ^{18}O + ^{30}Si reaction have been studied in a γ-γ-recoil coincidence experiment. The level scheme of ^{44}Ca has been extended up to 12.2 MeV. In particular, the negative-parity band has been identified with the highest $I = 13^-$ level at 10.6 MeV. This state is interpreted as the band-terminating state for the $(d_{3/2}^{-1} f_{7/2}^5)$ configuration.

PACS. 21.60.Cs Shell model – 23.20.Lv Gamma transitions and level energies – 27.40.+z $39 \leq A \leq 58$

The excitations observed in the $f_{7/2}$-shell nuclei provide a unique opportunity to study various aspects of nuclear properties due to not only the intrinsic motion of individual nucleons and the shell effects, but also originating from a coherent motion of many nucleons. Such phenomena lead to the evolution of nuclear deformation, shape coexistence, creation of band-terminating states and other collective properties.

In the lightest and heaviest nuclei of the region, the yrast levels are built by the coupling of few valence quasiparticles and thus exhibit properties characteristic of spherical nuclei. Approaching the middle of the shell, the coherent motion of many valence nucleons results in the formation of yrast rotational bands. In this region, the ^{48}Cr nucleus having the maximum number of valence particles is considered as the best rotor with the deformation parameter $\beta = 0.28$ at low spin [1,2]. Moreover, in many $f_{7/2}$ nuclei, deformed structures coexist with the yrast excitations and their nature has recently been extensively studied. Very regular rotational bands of unnatural-parity states have been identified in the light odd-A ^{43}Ca, ^{45}Sc and ^{45}Ti nuclei [3]. Theoretical description of their character requires collective $d_{3/2}$-$f_{7/2}$ cross-shell excitations. In ^{45}Sc the positive-parity band extends up to the band-terminating state at spin $I^\pi = 31/2^+$ [4], which is the maximum available spin for the $(\pi d_{3/2}^{-1} f_{7/2}^2 \nu f_{7/2}^4)$ configuration [5]. Similar properties are exhibited by the rotational band of negative-parity states recently observed in the odd-odd ^{46}V nucleus [6] where the band-terminating state has also been identified. It is intriguing, however, that until now very little has been known about unnatural-parity levels in the even-even $f_{7/2}$-shell nuclei. Usually in these nuclei, negative-parity states lie higher in excitation energy and their rotational behaviour is less pronounced. Only in two cases, namely in the ^{44}Ti [7] and ^{48}Cr nuclei [2], such negative-parity bands have been observed up to the high spin $I^\pi = 13^-$ state, still below the maximum spin value for the band termination.

In this work, we present results of our study of high-spin states in the ^{44}Ca nucleus. The experiment was performed using the VIVITRON accelerator at IReS Strasbourg, utilising the high-efficiency EUROBALL IV germanium γ-array in coincidence with the Recoil Filter Detector (RFD) [8]. The ^{44}Ca nuclei were populated in the (^{18}O,2p2n) reaction with a pulsed beam of 68 MeV ^{18}O ions bombarding a metallic, 800 μg/cm^2 thick ^{30}Si target [9]. The use of the RFD allowed for a significant reduction of a large Doppler broadening of γ-lines caused by high velocity ($v/c = 2.8\%$) of ^{44}Ca recoils [4]. A thorough inspection of γ-γ- and γ-γ-γ-recoil coincidences, together with DCO ratios and γ-polarisation information, provided the high-spin level scheme of the ^{44}Ca nucleus (fig. 1).

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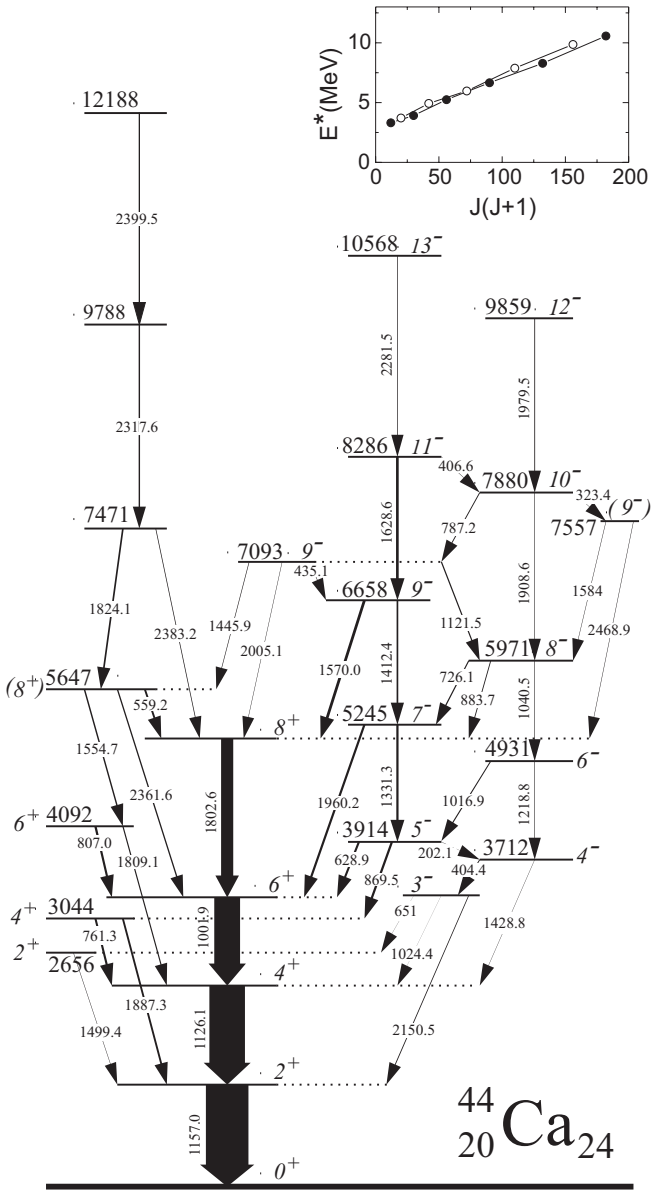

Fig. 1. Level scheme of the ^{44}Ca nucleus. The inset shows excitation energy *vs.* angular momentum for the negative-parity states with odd-spin (•) and even-spin (○) values.

In the shell model description, the ^{44}Ca nucleus has 4 valence neutrons outside the ^{40}Ca core. The coupling of these neutrons in the $f_{7/2}$ shell forms yrast positive-parity states up to the maximum spin of $I^\pi = 8^+$. In order to create states of higher spin, one of the $f_{7/2}$ neutrons has to be promoted to the next $f_{5/2}$ orbital and, therefore, the resulting excited state should lie much higher in energy. Exciting two *sd*-core particles across the energy gap can form non-yrast positive-parity states.

Up to now, only three non-yrast positive-parity levels at 2656, 3044 and 4092 keV have been identified from earlier experiments [10]. Our experiment confirms spin assignments for the two lowest states but, for the state at 4092 keV we suggest the spin $I^\pi = 6^+$. This value comes from our DCO and polarisation measurements, strongly supported by the sequence of γ-rays populating this state from high-spin levels. The definite spin for the new 5647 keV excitation could not be determined but the data suggest $I^\pi = 8^+$ as the most probable spin assignment. Three higher-lying levels at 7471, 9788 and 12188 keV are weakly populated in our experiment and therefore neither spin nor parity of these states could be established. Our data suggest, however, that stretched $E2$ character of γ-rays depopulating these states is rather unlikely.

Of special interest are the negative-parity states because they can only be formed when one or more (odd number) core particles are promoted to higher orbitals. This results in low-lying rotational bands in odd-A nuclei neighbouring to ^{44}Ca. In the ^{44}Ca nucleus only the 3 lowest negative-parity states have been observed in previous high-spin studies [11]. In our experiment, we have identified several negative-parity states and thus the level scheme is extended up to the $I^\pi = 13^-$ state at 10568 keV. The obtained level pattern shows some regularity for both even- and odd-spin sequences. The plots of excitation energy *vs.* angular momentum $J(J+1)$ result in straight lines as shown in the inset in fig. 1. The highest observed $I^\pi = 13^-$ excitation can be understood as the band-terminating state, since the maximum aligned spin available for the $(\pi d_{3/2}^{-1} f_{7/2} \nu f_{7/2}^4)$ configuration in the ^{44}Ca nucleus is 13 $\hbar$. The early shell model calculations [11] predicted energies of unnatural-parity states in the ^{44}Ca nucleus up to the $I^\pi = 10^-$ level but they do not correlate with present observations. The detailed description of the observed level structure as well as the interpretation of decay properties would require modern, advanced shell-model calculations in the full *sdpf*-configuration space.

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