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NUCLEAR STRUCTURE OF ^{228}Th *

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The level structure of ^{228}Th was studied using different experimental methods. The complete octupole quadruplet, three excited $K^\pi = 0^+$ bands and two excited $K^\pi = 2^+$ bands were identified.

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1. Introduction

The nucleus ^{228}Th is located in a transitional region from octupole to quadrupole deformation: the even-even isotopes ^{226}Th, ^{228}Th and ^{230}Th are considered to be octupole-deformed, octupole-soft and vibrational-like, respectively. A detailed study of the structure of ^{228}Th might thus enable insights into the mechanisms governing these shape transitions. We have investigated ^{228}Th with a number of experimental techniques. In the present contribution we briefly summarize the different experiments and discuss the results. Detailed accounts have been published in [1–6].

2. The electron capture decay of ^{228}Pa

The EC decay of ^{228}Pa to ^{228}Th has been studied using mass-separated sources. In an early investigation we measured γ-ray and conversion-electron spectra, and $e^- - \gamma$ coincidences with a setup consisting of an orange spectrometer and four Compton-suppressed Ge-detectors. These investigations lead to a level scheme with several collective bands below ~ 1.4 MeV, and

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two-quasiparticle excitations up to ~ 2 MeV [1]. However, some questions remained, in particular in connection with the $K^\pi = 1^-$ member of the octupole quadruplet. We therefore restudied this decay with $\gamma - \gamma$ coincidences using five Compton-suppressed Ge-detectors. The most significant result of the $\gamma - \gamma$ coincidence measurement was the realization that a level at 968 keV, interpreted earlier as 3^- level, is a doublet of levels with 0.1 keV spacing, assigned as 2^- and 4^+ members of the first-excited $K^\pi = 1^-$ and 0^+ bands, respectively [2]. This finding enabled a reinterpretation of several members of the vibrational bands as shown below.

3. The ^{230}Th(p,t)^{228}Th reaction

Triton spectra were measured using the Q3D spectrometer of the accelerator laboratory in Munich [3]. The most significant finding was the assignment of $I^\pi = 0^+$ to a level at 939 keV — which was earlier interpreted as 2^- member of the $K^\pi = 1^-$ band — based on the angular distribution of the tritons establishing $L = 0$ transfer. Several unknown levels were observed between 1 and 1.4 MeV, which could not be interpreted in [3]. With the new assignments from the radioactive-decay work these levels can now be understood.

4. In-beam spectroscopy in the ^{226}Ra(α,2n)^{228}Th reaction

Studies of rotational bands populated in the ^{226}Ra(α,2n)^{228}Th reaction were performed at the Bonn cyclotron. In an earlier investigation aimed at an identification of the ground and first excited $K^\pi = 0^-$ bands to high spins, γ-rays were measured in coincidence with L_{II} conversion electrons of the $4^+ \rightarrow 2^+$ ground-band transition. The two bands were observed up to the 18^+ and 17^- members, respectively [5]. These measurements indicated that a study of excited bands should be possible, and in a subsequent measurement of $\gamma - \gamma$ coincidences the first-excited $K^\pi = 0^+$ and 2^+ bands were observed up to the 12^+ and 10^+ levels, respectively [6].

5. The level scheme of ^{228}Th

The collective rotational bands observed in ^{228}Th are shown in Fig. 1. The ground and first excited $K^\pi = 0^-$ band merge at higher spins into a single band with alternating parity, as expected for nuclei with stable octupole deformation. The intrinsic electric dipole moment induced by the octupole deformation was determined from B(E1)/B(E2) ratios and found to be independent of spin up to $I^\pi = 15^-$ with an average of $D_0 = 0.12(1)$ fm. This result is a factor of ~ 5 smaller than that for the octupole deformed ^{224}Th and a factor of ~ 10 larger than that for ^{232}Th, supporting the transitional character of ^{228}Th [5]. The full quadruplet of octupole shape oscillations is observed (right part of Fig. 1).

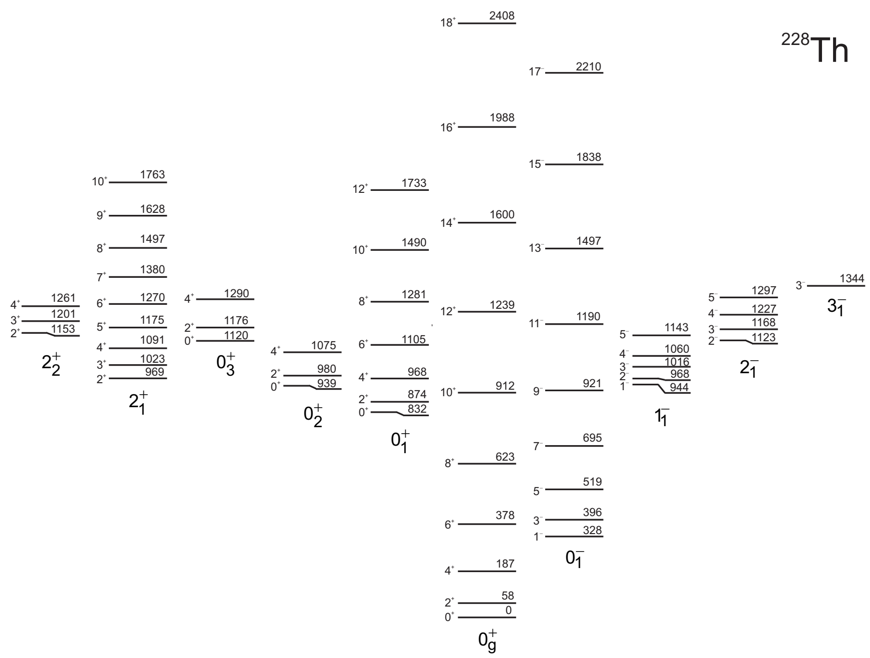

Fig. 1. Level scheme of ^{228}Th

The moments of inertia as function of spin are displayed in Fig. 2. The characteristic zigzag of the values for the $K^\pi = 1^-$ band results from its Coriolis coupling with the neighbouring 0^- and 2^- bands, where the 0^- band has no even-spin members. The observed energies of the octupole levels can be reproduced satisfactorily with a common moment of inertia $\sim 25\%$ larger than that of the ground band and Coriolis coupling matrix elements $\sim 30\%$ smaller than the spherical limit [2].

Three intrinsic excitations with $K^\pi = 0^+$ and two with 2^+ are observed with energies well below the threshold for two-quasiparticle excitations. Only the structure of the lowest 2^+ band is theoretically understood: it has properties corresponding to those expected for one-phonon γ-vibrations. The first two excited 0^+ bands have properties very different from those expected for β vibrations. We note in particular their increased moments of inertia (see Fig. 2), their dominant decay by E1 transitions to the first-excited 0^- band and their strong excitation in the (p,t) reaction. The third 0^+ band is only weakly observed in the ^{228}Pa decay and in the (p,t) reac-

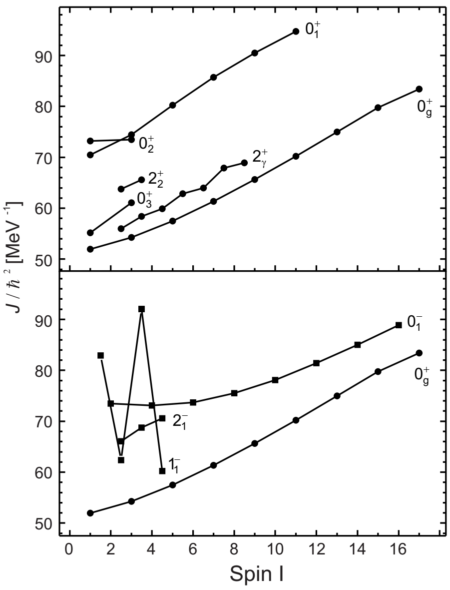

Fig. 2. Moments of inertia as function of spin

tion. It decays predominantly to the ground band and compared to that its moment of inertia is only $\sim 10\%$ larger. Finally, a second-excited 2^+ band is observed, which decays predominantly by E0 transitions to the γ band. Corresponding bands are also observed in the neighbouring nuclei, but the structure of these bands is largely unexplained. Possible interpretations of these additional $K^\pi = 0^+$ and 2^+ excitations have been discussed by Bohr and Mottelson who emphasize, that the interpretation of these excitations is crucial to the understanding of the β and γ vibrations [7].

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