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STUDY OF COLLECTIVITY IN ^{88}Zr USING THE HORUS SPECTROMETER*

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We report on a $\gamma\gamma$ coincidence measurement on ^{88}Zr. One point of interest was a potential 2^+ *mixed-symmetric* state. We measured the multipole mixing ratio for the decays of the second and third 2^+ states and precisely determined the energies of the 2^+_3 and 0^+_2 states. In addition, two new levels and seven new γ transitions were observed. The experiment was performed at the FN-Tandem accelerator at the University of Cologne, using the reaction $^{89}\mathrm{Y}(p,2n)^{88}\mathrm{Zr}$ at 17 MeV beam energy. The γ-rays were detected with the Horus HPGe array.

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1. Introduction

Mixed-symmetry states are nuclear states which are not completely symmetric with respect to the proton–neutron degree of freedom [1]. In the collective model, these states can be viewed as out-of-phase vibrations of valence protons and neutrons. The 2^+_{ms} state is the fundamental one-phonon excitation in vibrator-like nuclei. It is predicted that these states should have a strong M1 transition to the symmetric 2^+_1 state and a weak E2 transition to the ground state.

Looking at the region around the $N = 50$ neutron shell closure, it was found that data on low-lying collective excitations and their symmetric/mixed-symmetric character was available for several even–even nuclei on the $N = 52$ side [2], while rather little was known about the $N = 48$ nuclei ^{88}Zr and ^{90}Mo. We, therefore, decided to re-examine these with modern $\gamma\gamma$ coincidence methods. In this work, we will focus on the results for ^{88}Zr; results on ^{90}Mo are available from [3].

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2. Experimental set-up

The Horus spectrometer [4] features 14 detector positions that can be variably equipped. The distance of the detectors to the target can be kept rather small (8–15 cm). When fully equipped, the spectrometer can reach a photopeak efficiency of up to 1.8% at 1332 keV. Due to geometrical constraints, only some of the detectors can be BGO-shielded. For the experiment described here, we used one Euroball cluster detector and 9 individual HPGe detectors, of which 6, including the Euroball cluster, were BGO-shielded. In approximately one week of beam time, we acquired about 100 one-hour "runs" of data and observed 2.4×10^9 $\gamma\gamma$ coincidence events.

The ^{88}Zr nuclei were produced in the reaction $^{89}\mathrm{Y}(p,2n)^{88}\mathrm{Zr}$, using 17 MeV protons provided by the Cologne FN-Tandem accelerator. Due to technical problems, higher beam energies were not available at the time. We used a 10 mg cm^{-2} ^{89}Y target. As ^{89}Y is the only stable yttrium isotope, a target made from naturally occurring yttrium will contain only that isotope, with no isotopic purification steps needed. Besides the $(p,2n)$ reaction, a strong contribution of the (p,n) channel leading to ^{89}Zr was observed. The impact of γ-rays from that reaction on the data analysis will be discussed in the next section.

In order to determine spins and multipole mixing ratios, the technique of angular correlation analysis as described in [5] was used. This technique examines the relative intensities of coincident γ-rays as seen by detector pairs in different positions with respect to the target. These intensities can

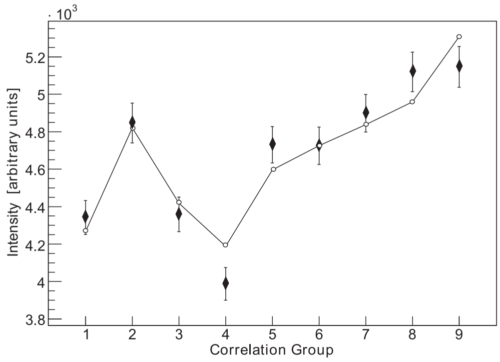

Fig. 1. Determination of the multipole mixing ratio of the $2^+_2 \rightarrow 2^+_1$ decay from the $2^+_2 \rightarrow 2^+_1 \rightarrow 0^+_{\mathrm{gs}}$ cascade. Shown are experimental values (diamonds with error bars) — the number of events where one detector in the correlation group saw the energy of the upper transition in the cascade, and the other detector saw the lower transition in the cascade, corrected for relative efficiency — and the results of the fit (open circles). The line is drawn to guide the eye.

then be compared to theoretical predictions assuming certain initial and final spins and multipole mixing ratios, and the most likely values for these can be inferred from the theoretical distribution that fits experiment best. In some cases, a hint for the parity of an excited state can be deduced from the spins and multipolarities of a γ-ray cascade. Each pair of detectors is characterized by the angles of the two detector axes relative to the beam axis and the angle between the planes spread by the detector axes and the beam axis. Pairs of detectors for which these three angles are equivalent are grouped into *correlation groups* [6]. Fig. 1 shows an example from the data analysis, comparing measured relative intensities in the different correlation groups to the theoretical predictions with the set of parameters that gives the best fit. Obviously, theory will produce one number for each correlation group. The lines connecting the theoretical data points have no physical significance and are solely drawn to guide the eye.

3. Experimental results

For the 2_3^+ and 0_2^+ levels, we observed γ transitions and were thus able to determine their energies as 2568.3(2) keV and 2231.0(5) keV, respectively. This represents a significant improvement over earlier data [7].

For the $2_2^+ \to 2_1^+$ decay, we determined a multipole mixing ratio of $\delta = 0.26 \pm 0.04$. The corresponding fit is shown in Fig. 1. As the spin assignment for the 2_2^+ state was only tentative [7], we tried several other spin hypotheses; we could indeed exclude all but $L = 2$. The multipole mixing ratio corresponds to absolute decay strengths $B(\mathrm{E2}; 2_2^+ \to 2_1^+) = 18\,^{+14}_{-6}$ W.u. and $B(\mathrm{M1}; 2_2^+ \to 2_1^+) = 0.25\,^{+0.20}_{-0.08}\mu_N^2$. For the decay to the ground state, we obtained $B(\mathrm{E2}; 2_2^+ \to 0_{\mathrm{gs}}^+) = 2.1 \pm 1.0$ W.u.. In order to calculate these, we used half life ($T_{1/2}(2_2^+) = 0.21(9)$ps) and branching ratio from the literature [7]. These results may point to a two-phonon character of the 2_2^+ state.

For the $2_3^+ \to 2_1^+$ decay, the determination of the multipole mixing ratio proved much more difficult. The energies in the cascade of interest ($2_3^+ \to 2_1^+ \to 0_{\mathrm{gs}}^+$) are 1511.3 keV and 1057.0 keV, which is very similar to the energies in the $(7/2, 9/2^+) \to (9/2^+) \to 9/2_{\mathrm{gs}}^+$ cascade in ^{89}Zr (1060.5 keV, 1511.7 keV). We partially worked around this problem by gating on the 1511.3 keV transition and fitting only the lower part of the 1057.0 keV peak, in a similar way in all angular correlation spectra, to obtain the number of events in the full peak. With this method, we finally obtained a multipole mixing ratio of $\delta = -0.54 \pm 0.22$, which points to a significant M1 admixture to the decay. This value, however, should be regarded as preliminary until further confirmation (see below). As no lifetime is known for the 2_3^+ state, we cannot give absolute decay strengths.

We also observed γ transitions which we interpret as decays of previously unknown levels at 3074.9(3) keV and 3093.6(2) keV. However, we could not obtain their spin due to low statistics.

4. Summary and outlook

From our data, we were able to determine the multipole mixing ratio of the $2_2^+ \to 2_1^+$ decay, to obtain a definite spin assignment for the 2_2^+ state and the precise energies of the 2_3^+ and 0_2^+ states in ^{88}Zr.

Theoretical calculations using the CASCADE code [8] suggest that the cross-section for the $^{89}\mathrm{Y}(p,n)^{89}\mathrm{Zr}$ reaction will decrease as one goes up in reaction energy. This would allow a more definite determination of the $2_3^+ \to 2_1^+$ multipole mixing ratio. Consequently, a follow-up experiment was done at 19/20 MeV beam energy, using the same reaction and a similar set-up. This data is presently being analyzed.

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