USING β-DECAY TO MAP THE $E2$ STRENGTH IN THE Cd ISOTOPES AND THE DOWNFALL OF VIBRATIONAL MOTION*

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The β decay of ^{112}Ag has been used to populate spin 0^+ and 2^+ states in ^{112}Cd to 3 MeV excitation energy. The statistical quality obtained allows the extraction of very weak γ-ray branching ratios that, combined with known level lifetimes, enables the determination of the $B(E2)$ values or upper limits for transitions populating the proposed two-phonon states. While candidates for 3^+, 4^+, and 6^+ three-phonon levels have been identified, there are no candidates for the 0^+ and 2^+ three phonon levels, and the upper limits of the $B(E2)$ values indicate that phonon $E2$ strength is not fragmented, but absent below $5\hbar\omega_2$.

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1. Introduction

A fundamental question in nuclear structure physics is the extent to which multi-phonon quadrupole vibrational states survive, especially to high-

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excitation energies where the level density becomes large. On the one hand, based on microscopic considerations and the effects of the Pauli principle, it might be expected that multi-phonon states are a rarity. On the other hand, the apparent success of models that naturally incorporate multi-phonon excitations, such as the Bohr model [1] or the Interacting Boson Model (IBM) [2], might be taken as evidence that vibrational phonon states are rather robust. Multi-phonon states, if they do exist, are typically expected in excitation energy regions where the level density is rapidly increasing. Possible mixing with nearby levels can cause the fragmentation of the $B(E2)$ strength posing a substantial observational challenge to experiment.

To address this issue, we have initiated a programme of high-statistics β-decay experiments to investigate the nuclear structures of the Cd isotopes, which are amongst the best examples of vibrational nuclei [3], beginning with the decay of ^{112}Ag. Combined with available level lifetimes (see, *e.g.*, Ref. [4]), the branching ratio data permit $B(E2)$ values to be determined for very weak γ-ray branches from highly non-yeast levels.

2. Experimental details

The experiment to study the β-decay of ^{112}Ag was performed at the TRIUMF-ISAC radioactive beam facility. Up to 40 μA of 500 MeV protons bombarded a thick tantalum production target, resulting in a mass-selected beam of $\sim 7.5 \times 10^6$ ions/s of $^{112}\mathrm{In}^m$, $\sim 2.3 \times 10^6$ ions/s of ^{112}In, and $\sim 4.8 \times 10^5$ ions/s of ^{112}Ag. The decay was observed with the 20 HPGe detectors of the 8π γ-ray spectrometer [5], and approximately 1×10^8 events were sorted into a random-background-subtracted matrix. Figure 1 displays the spectrum obtained with a gate taken on the 617-keV $2_1^+ \to 0_1^+$ transition.

Branching ratios were determined by either gating from above or below the level of interest. Gating from above used the standard method of dividing the intensity of the γ ray of interest by the total intensity out of that level. Gating from below involved the method described in Ref. [6] using

$$N_{12} = N I_{\gamma 1} \epsilon_{\gamma 1} B_{\gamma 2} \epsilon_{\gamma 2} \epsilon_{12} \eta(\theta_{12}) \,. \tag{1}$$

N_{12} is the number of counts in the coincidence peak between two cascading γ rays, $I_{\gamma 1}$ is the intensity of the “feeding” γ ray of the pair, and B_{γ_2} is the branching ratio of the “draining” γ ray of the pair. The singles photopeak efficiencies are given by ϵ_{γ_1} and ϵ_{γ_2} and N characterizes the coincidence data for a given decaying isotope and is considered a normalization constant, ϵ_{12} is the coincidence efficiency, and $\eta(\theta_{12})$ is the angular correlation attenuation factor. The intensity of the γ ray of interest, $\gamma 1$, is determined by

$$I_{\gamma 1} = \frac{N_{12}}{\epsilon_{\gamma 1} B_{\gamma 2} \epsilon_{\gamma 2}} = \frac{I'_{\gamma 1}}{B_{\gamma 2} \epsilon_{\gamma 2}} \,, \tag{2}$$

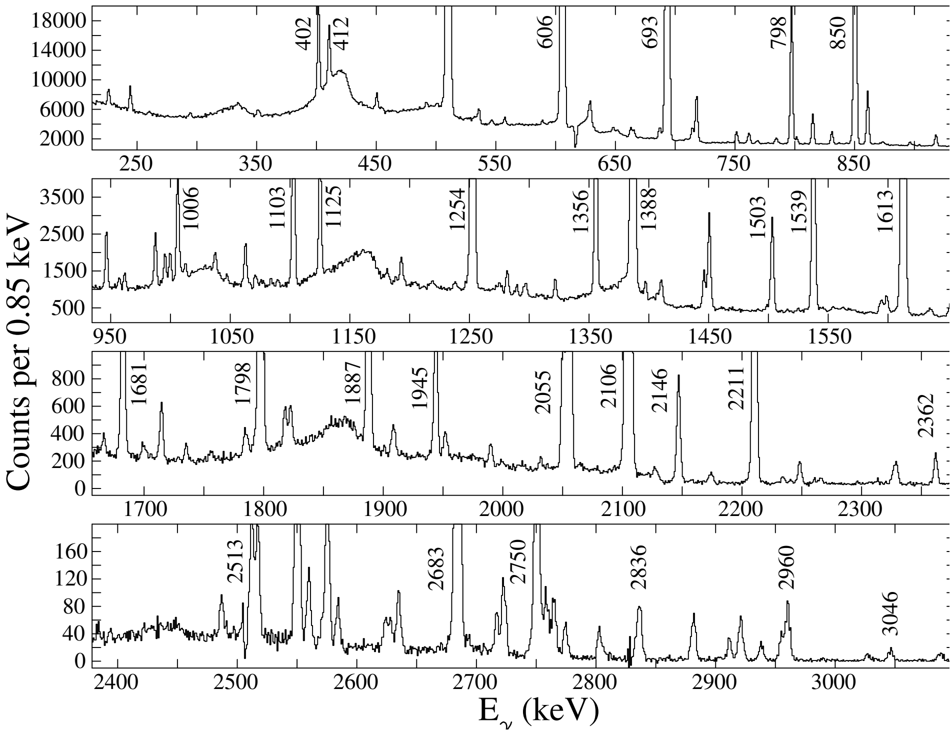

Fig. 1. Portion of the γ-ray coincidence spectrum with the 617-keV $2^+ \rightarrow 0^+$ transition obtained following the β-decay of ^{112}In/^{112}Ag.

where $I'_{\gamma 1} = N_{12}/\epsilon_{\gamma 1}$. The branching ratio is then defined as

$$\mathrm{BR}_{\gamma 1} = \frac{I'_{\gamma 1}}{B_{\gamma 2}\epsilon_{\gamma 2}} \Big/ \sum_j \frac{I'_{\gamma_j 1}}{B_{\gamma_j 2}\epsilon_{\gamma_j 2}}\,, \tag{3}$$

where the summation over j extends over all transitions decaying from the level of interest. In the sorting and analysis of the data the gates are set sufficiently wide so that all of the intensity is taken so that to a high degree of accuracy ϵ_{12} can be ignored. Because of the symmetry of the 8π array, the correlation factor $\eta(\theta_{12})$ has a negligible effect as well. When there was no indication of a peak present in the coincidence spectra, the 2σ limit was calculated using the procedure outlined in Ref. [7]. Branching ratios or upper limits were established for all possible transitions from excited 0^+ and 2^+ levels below 3 MeV feeding the 0_3^+, 2_2^+, and 4_1^+ two-phonon states and the 0_2^+ and 2_3^+ $2p4h$ proton intruder states.

3. Results and conclusions

Using the lifetimes for excited states in ^{112}Cd determined in Ref. [4], the decay $B(E2)$ values or upper limits are established for all possible decays of the 0^+ and 2^+ levels below 3 MeV excitation energy to the proposed two-phonon 0^+_3, 2^+_2, and 4^+_1 states. The sum of the upper limits for decay of the 0^+ states to the 2^+ two-phonon level is 17 W.u., much less than the 90 W.u. expected from the harmonic oscillator, and 52 W.u. from IBM-2 calculations [8]. For the 2^+ levels, the sum of the upper limits for decay to the 0^+, 2^+, and 4^+ two-phonon triplet are 55 W.u., 14 W.u., and 7 W.u., respectively. The upper limit of the $B(E2)$ values for decay to the 4^+ state, in particular, is much less than the 31 W.u. expected from the harmonic oscillator. Detailed IBM-2 calculations [8] are able to reproduce this decay pattern, but only as a consequence of extensive mixing with the intruder configuration that results in an extremely large $B(E2)$ value predicted to the intruder 2^+ state, the 2^+_3 level; the calculated sum of 180 W.u. greatly exceeding the observed limit of 60 W.u. [8].

The results of this work confirm the conclusions of Refs. [4,9] that there are no suitable candidates for the 0^+ and 2^+ members of the three-phonon triplet. Further, it is also demonstrated that the prerequisite $B(E2)$ strength does not appear to be fragmented, but absent below $\approx 5\hbar\omega_2$. We are thus forced into a position that we must either invoke extreme anharmonicities, or abandon the spherical vibrator interpretation. We favor the latter solution, and the emerging pattern of $B(E2)$ values suggest a rotational interpretation, as outlined in Ref. [10].

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