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Low-lying T = 0 states in the odd–odd N = Z nucleus ^{62}Ga

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ABSTRACT

New, low-lying levels in the odd–odd, N = Z nucleus ^{62}Ga have been identified using a sensitive technique, where in-beam γ rays from short-lived nuclei are tagged with β decays following recoil mass identification. A comparison of the results with shell-model and IBM-4 calculations demonstrates good agreement between theory and experiment, with the majority of predicted low-lying, low-spin T = 0 states now identified. There is a dramatic change in the level density at low excitation energies for the N = Z nucleus ^{62}Ga when compared with neighbouring odd–odd Ga isotopes where, in contrast, the low-lying level structure is dominated by configurations with T = 1 pairing interactions between excess neutrons. This illustrates the distinctively different aspects of nuclear structure exhibited by nuclei with N = Z.

Self-conjugate nuclei play an especially important role in nuclear structure. A recent example is the observation of a highly enhanced Gamow–Teller β-decay transition from the ground state of the heaviest known N = Z nucleus, ^{100}Sn [1]. In such nuclei, the protons and neutrons occupy the same orbitals resulting in strong spatial overlap, and leading to amplification of nuclear structure effects. Odd–odd, N = Z nuclei have a specific importance as states with isospin T = 0 and T = 1 have similarly low excitation energies. Indeed, above ^{40}Ca, ^{58}Cu is the only known odd–odd N = Z nucleus with a T = 0 ground-state configuration [2]. Many theoretical frameworks have been developed to probe the structure of heavy N = Z nuclei, including shell-model calculations either with a direct diagonalisation of the Hamiltonian [3] or using Monte Carlo techniques [4,5], BCS or HFB calculations extended to incorporate T = 0 and T = 1 pairing correlations [6,7], and Isospin Invariant Interacting Boson Model calculations (IBM-4) [8]. A higher density of low-lying, T = 0 states is predicted in all calculations of odd–odd N = Z nuclei than currently observed. This is not thought to represent intrinsic deficiencies in the models, but rather a selectivity in the levels identified by experiments performed to date [8]. In the current Letter, we report new results on the low-lying structure of the odd–odd, N = Z nucleus ^{62}Ga using a sensitive experimental technique, wherein a variation of the recoil decay tagging method (RDT) [9,10] using positrons as the tag (RBT) [11,12] has been allied with a mass-separator device for the first time, thus allowing extremely clean γ-ray spectra to be generated.

The low-lying yrast level structure of ^{62}Ga was first identified by Vincent et al. in a γ-ray spectroscopy study using a heavy-ion fusion-evaporation reaction [13]. This structure was confirmed, and a number of non-yrast T = 0 states were identified in ^{62}Ga for the first time, in a measurement by Rudolph et al. [14]. In the latter work [14], potential candidates for low-lying T = 1, 2^+ and 4^+ states were also reported. However, despite this progress, ambiguities remained and a number of states predicted by theory were not identified.

In the present experiment, a beam of 103-MeV ^{40}Ca ions from the Argonne ATLAS accelerator bombarded a $\sim$ 490 μg/cm^2-thick ^{24}Mg target to produce ^{62}Ga nuclei via the 1p1n fusion-evaporation channel. Prompt γ rays were detected by the Gammasphere array [15,16], consisting of 96 HPGe Compton suppressed detectors. Recoiling reaction products with mass A = 62 and charge state 18^+ were transmitted to the focal plane of the Fragment Mass Analyzer (FMA) [17], where slits were employed to reduce contributions from neighbouring mass groups and scattered beam

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particles. The mass-to-charge ratio of transmitted recoils was measured at the focal plane of the FMA by a parallel-grid avalanche counter (PGAC), which also provided timing information. A transmission ionisation chamber (IC) was installed downstream of the PGAC to measure energy loss which provided discrimination between recoils and scattered beam particles. Finally, the recoils were implanted into a highly-segmented double-sided Silicon strip detector (DSSD) of area 64×64 mm^2 and thickness 1 mm, consisting of 160×160 strips of 400-μm pitch. This DSSD was designed to provide high sensitivity for correlations between relatively short-lived ($T_{1/2} \sim 100$ ms) implanted ions and their subsequent β decays. Implantation rates were kept below 200 Hz in order to ensure background-free singles γ-ray spectra.

Tagging with short-lived β decays has been successfully implemented previously, but allied to a gas-filled rather than mass-separator device, where an additional selection of β decays with high-energy positrons was applied for background reduction [11,12]. Here, the use of mass separation largely eliminates the flux of strongly-produced, non-isobaric residues at the focal plane, allowing direct mass selection (and identification) of the recoils. The reduced background of both implant and decay events at the focal plane greatly improves the cleanliness of correlations between short-lived implanted ions and their subsequent decays, allowing the generation of extremely clean γ-ray spectra without relying on the detection of high-energy positrons.

The present experiment was performed with newly-installed digital acquisition systems for Gammasphere, the FMA ancillary detectors and the DSSD, based on the electronics developed for the GRETINA array [18]. Low event rates allowed the experiment to be carried out with a trigger requirement of a single signal in either Gammasphere or the DSSD, resulting in a maximum flexibility in the offline analysis. Efficiency and energy calibrations for γ rays were carried out with standard ^{152}Eu and ^{56}Co sources. Values of angular correlation ratios $R_{32:90}$, given by the ratio of the γ-ray intensity measured at $\sim 32°$ to the intensity measured at 90°, were used to establish the multipolarity of transitions with sufficient statistics. $R_{32:90}$ values of 0.72(4) and 1.15(3) for pure $\Delta I = 1$ and $\Delta I = 2$ lines in ^{62}Zn, respectively, were used for reference. The full level scheme of transitions observed in the present work for ^{62}Ga is found in Fig. 1.

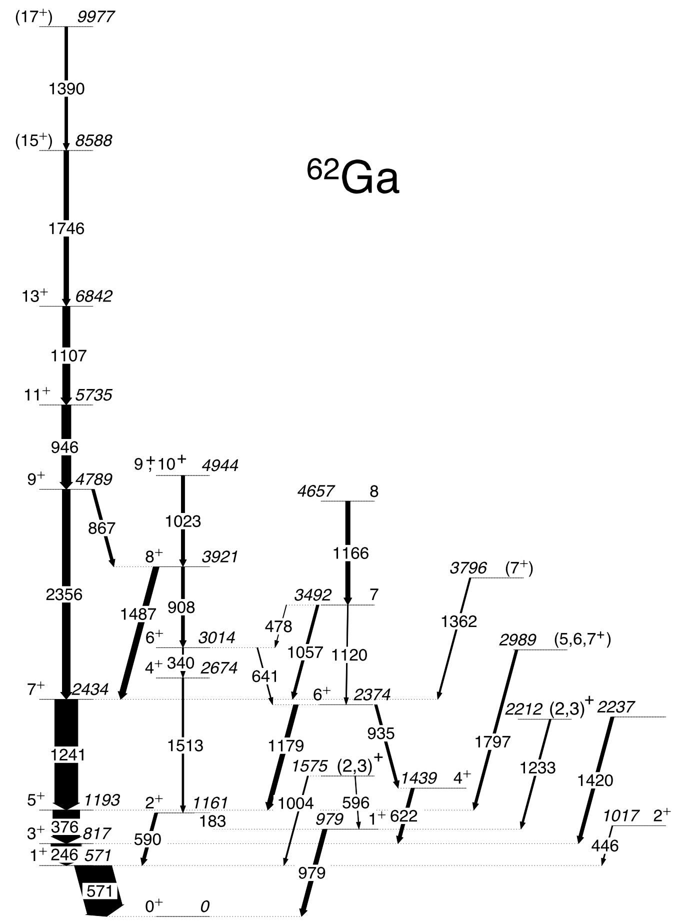

Fig. 1. Level scheme of ^{62}Ga; the width of the arrows is proportional to the relative intensities of the transitions. Further details can be found in Table 1.

Fig. 2 presents a γ-ray spectrum in coincidence with recoils that were followed within 400 ms by a β decay measured in the DSSD in a position not further than one pixel removed from the recoil implantation position. This requirement selects γ rays from short-lived ^{62}Ga nuclei ($T_{1/2} = 116.121(21)$ ms [19]). The position of the β decay is defined as the DSSD pixel where a maximum energy is deposited, since the β particles in general have a long range compared to the pixel dimensions. Choosing a smaller correlation area was found to reduce the correlation efficiency and was not needed for background reduction purposes. A spectrum of background lines from isotopes such as ^{62}Zn ($T_{1/2} \sim 9$ hours) and ^{58}Ni (stable), produced in the 2p and α2p evaporation channels, was obtained by correlating recoils with β decays occurring between 1 and 1.4 s after implantation. This spectrum was subtracted from that in Fig. 2. There is, for example, no evidence in Fig. 2 for the most intensely produced γ ray at 954 keV associated with the $2^+ \to 0^+$ transition from ^{62}Zn. Furthermore, the measured half-life of $T_{1/2} = 116.15(13)$ ms for the β decays associated with the γ-ray transitions of Fig. 2 is in good agreement with the literature value for ^{62}Ga [19]. Fig. 2, therefore, represents an essentially pure spectrum of ^{62}Ga.

Looking at the peaks annotated in Fig. 2, one can see three transitions not reported in earlier studies [13,14] at energies of 183, 590 and 979 keV. The 590-keV γ ray was observed in coincidence with the known 571-keV transition from the first excited state to the ground state, but not with other higher-lying yrast transitions, as shown in Fig. 3(a). This indicates that this 590-keV line feeds the 1^+ state at 571 keV directly from a new, low-lying level at 1161 keV. The direct feeding is confirmed by the line shape of the 571-keV γ ray in Fig. 3(a), which does not exhibit the low-energy tail observed for this transition when fed through the 3^+ yrast level at 817 keV (see Fig. 1), which is isomeric with $T_{1/2} = 3.2(11)$ ns [13]. A value of $R_{32:90} = 0.72(21)$ for the 590-keV transition rules out a stretched-E2 character at the 2σ level and is consistent with $\Delta I = 1$ dipole radiation. The ~ 200-keV energy difference between the 2^+ state at 954 keV in ^{62}Zn and the level at 1161 keV in ^{62}Ga precludes a $T = 1$ assignment for the latter state. The 1161-keV level is, therefore, assigned as $T = 0$. The expected dominant branch from the lowest-lying $T = 0$, 2^+ level is to the first excited 1^+ state [14], consistent with the dominant 590-keV γ ray from the newly-observed 1161-keV state. No direct branch to the ground state is predicted from this level [14], which is consistent with its non-observation here.

Fig. 3(b) provides a spectrum obtained by applying a coincidence gate on the 979-keV transition. The 183-keV γ ray is clearly observed in coincidence. Neither the 183- nor the 979-keV line is coincident with known yrast transitions and it is concluded that these γ rays emanate from the same, new 1161-keV level mentioned above. Relative intensities of 2(1)% and 17(2)% for the 183- and 979-keV transitions, respectively, indicate that the 183-keV line feeds a new level at 979 keV. The $R_{32:90} = 0.77(25)$ value for the 979-keV transition is indicative of $\Delta I = 1$ character, implying a 1^+ assignment for the level as states with negative parity