BRIEF REPORTS

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Prolate-oblate band mixing and new bands in ^{182}Hg

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In-beam γ-ray spectroscopic studies of ^{182}Hg have revealed five new bands. The 2^+ state of the prolate band has been identified at an energy of 548.6 keV and is higher than in ^{184}Hg. A two parameter band mixing calculation results in an interaction energy of 83 keV between the prolate 2^+ and the oblate 2^+ states. Several additional new bands are seen including some which are interpreted as quadrupole vibrational bands built on the excited prolate minimum.

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In even-even Hg isotopes with A = 180–188 an oblate ($\beta_2 \sim -0.15$) ground state band is found to coexist with an excited prolate ($\beta_2 \sim$0.25) band at low spins and low excitation energies [1]. This coexistence can be explained in terms of shape competition at low excitation energies between a large proton gap at Z = 80 favoring slight oblate deformation and a neutron shell gap present for N = 102–108 favoring large prolate deformation in the single-particle levels.

Recent studies of ^{186}Hg [2] and ^{184}Hg [3] have revealed several new bands in these isotopes. In ^{186}Hg, Ma *et al.* [2] reported a negative parity, odd spin band, with deformation ($\beta_2 \sim$ 0.35) intermediate between normal prolate deformation and super deformation. In ^{184}Hg, an odd spin band with a large moment of inertia similar to the band in ^{186}Hg was also observed. However, the deformation of this band was not measured.

In the case of ^{182}Hg, only the 2^+ level of the oblate band and the prolate band from the 4^+ to 12^+ states were known earlier [4]. The 0^+ and 2^+ members of the prolate band were not known. The earlier studies of ^{182}Hg revealed that the energies of the high spin members ($4^+ \longrightarrow 12^+$) of the prolate band are lower in energy relative to ^{184}Hg and ^{186}Hg. These studies have led to the suggestion that the oblate-prolate energy difference in ^{182}Hg is still smaller than that in ^{184}Hg and ^{186}Hg. Dracoulis *et al.* [5] reported that the prolate-oblate energy difference in ^{180}Hg is higher relative to ^{182}Hg, establishing a clear minimum in the prolate-oblate energy difference at $N = 102$. Even in ^{180}Hg, the 2^+ and 0^+ members of the prolate band are not observed. Because of the interactions between $2^+$and 0^+members of the oblate and prolate bands, the energies of the 2^+ and 0^+ states of the prolate band may be altered significantly from the values calculated by using the rotational formula and high-spin members of the band. Any conclusion about the prolate-oblate energy difference based on the high-spin members may be questioned.

We carried out new studies of ^{182}Hg, in an effort to identify the 2^+ and 0^+ members of the prolate band and higher spin states and to search for the existence of the new band structures recently observed in ^{184,186}Hg [2, 3].

Three experiments were carried out in our studies of ^{182}Hg. In the first two experiments, ^{182}Hg nuclei were populated by using the reaction ^{154}Gd(^{32}S, $4n$) at beam energies of 160–165 MeV. The target was 1.16 mg/cm^2 thick and enriched to 92.3%. The first experiment was performed at the Holifield Heavy Ion Research Facility

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(HHIRF) with 18 Compton-suppressed Ge detectors in the spin spectrometer and 54 NaI detectors as a multiplicity filter. A multiplicity of > 12 was selected to enhance the $4n$ reaction channel. A total of 17 × 10^6 double γ-γ coincidences were recorded.

The second experiment was done in the Compact Ball, at the HHIRF, in which four of the 16 Compton-suppressed Ge detectors were replaced by four BaF_2 detectors to enhance the multiplicity selection. In the above reaction a considerable fraction of the fusion cross section is associated with charged particle emission [(^{32}S, $p4n$), (^{32}S, $2p2n$), and (^{32}S, $2p3n$)] and fission, while only $\sim$ 15% of the total cross section is in the (^{32}S, $4n$) channel of interest. In order to tag and remove the charged-particle channels from the $E_\gamma \times E_\gamma$ matrix, a simple 4π charged particle sensitive system, named "The Tube" [6] was used. It consisted of a plastic scintillator tube, which surrounded the target and was segmented into four optically isolated cylindrical arcs. Three $E_\gamma \times E_\gamma$ matrices were constructed by requiring a total γ-ray multiplicity $M_\gamma > 4$ and that none, one, or two charged particles were detected, respectively. The multiplicity contained at least two Compton-suppressed Ge detectors, augmented by γ rays in the BaF_2 detectors, the Ge detectors whose anti-Compton shield also fired, or the plastic tube that fired in its γ-ray portion. Based on observed discrete gamma lines, the 0-particle matrix was found to contain 30% of the 1-particle tagged matrix and a small portion of the 2-particle tagged matrix. These observations are consistent with an average particle selection efficiency of 70%. A pure (^{32}S, xn) matrix containing 5.4×10^7 events between 0 and 2 MeV was produced by subtracting the appropriate fractions of the 1-particle and 2-particle matrices from the 0-particle matrix.

A third experiment was a by-product of our experiment [7] on ^{183}Hg. The ^{182}Hg nuclei were produced in the ^{155}Gd(^{32}S, $5n$) reaction at a beam energy of 160 MeV. In this experiment γ transitions belonging to ^{182}Hg were identified with a mass gate on A = 182 fragments at the focal plane of the Fragment Mass Analyzer (FMA) at Argonne National Laboratory. Prompt γ rays emitted at the target position were detected with an array of 10 Compton-suppressed Ge detectors in coincidence with A = 182 reaction products at the FMA focal plane.

Several types of coincidence matrices were built for the analysis of γ-γ coincidence data. A large γ-γ coincidence matrix was used to establish the coincidences between the various γ rays. A multiplicity of > 4 was selected to enhance the $4n$ channel. In order to assign spins to the levels, a matrix was built employing the γ detectors close to 0° and 180° on the x axis and the other detectors close to 90° on the y axis. Ratios of directional correlations from oriented nuclei (DCO) were extracted from the latter matrix and were used to establish the multipolarities of γ transitions.

The γ spectrum obtained by gating on A = 182 residues is shown in Fig. 1. The inset in Fig. 1 shows the ordinate expanded for 200–700 keV. The transitions in band 3 (see Fig. 3) are labeled. A γ spectrum in coincidence with transitions in band 3 is shown in Fig. 2. This γ-ray spectrum was created by summing the coincidence spectra obtained by gating on the transitions in band 3. The 548.6-keV transition is in coincidence with transitions in the yrast band and 471.9- and 749.1-keV γ rays. These coincidence relationships can only be explained by placing it as a transition from the 2^+ member of the prolate band to the ground state. The 549-keV transition placed in band 6 and the 548-keV transition tentatively placed in band 1 are very weak. The much larger intensity of the 548.6-keV transition compared to the 749.1-keV transition which populates the level suggests that an unobserved highly converted 64.6-keV transition from the 4^+ level populates the new 2^+ level as well. The level scheme based on γ-ray coincidence relationships and transition intensities is shown in Fig. 3.

Band 1 in Fig. 3 is the slightly deformed oblate band. Two transitions have been tentatively placed into this band because one sees weakly the 577.8- and 548-keV

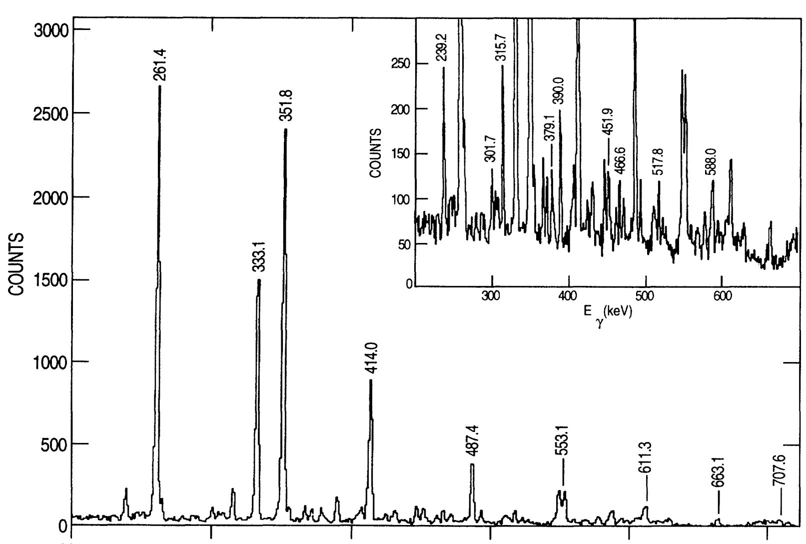

FIG. 1. The γ-ray spectrum obtained by gating on A = 182 residues. The inset shows the ordinate expanded for 200–700 keV. Many of the transitions in band 3 are labeled.

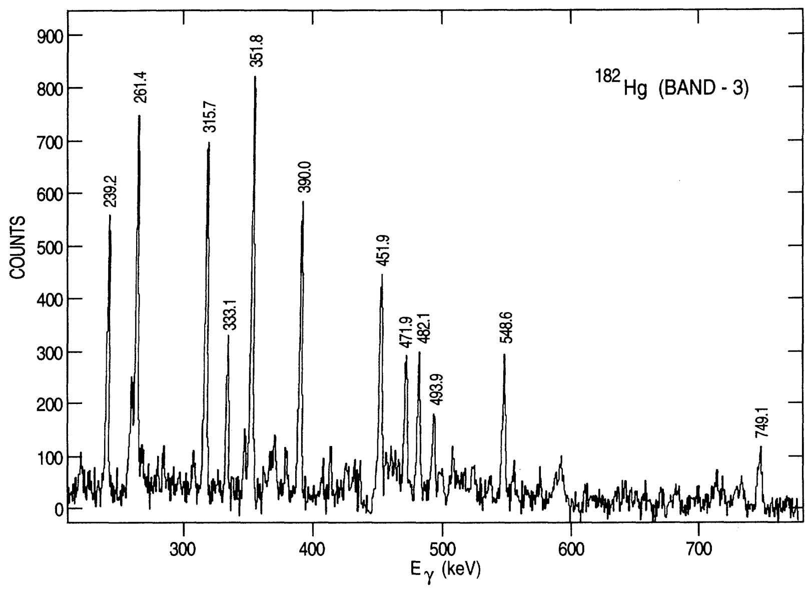

FIG. 2. γ-ray spectrum in coincidence with transitions in band 3.

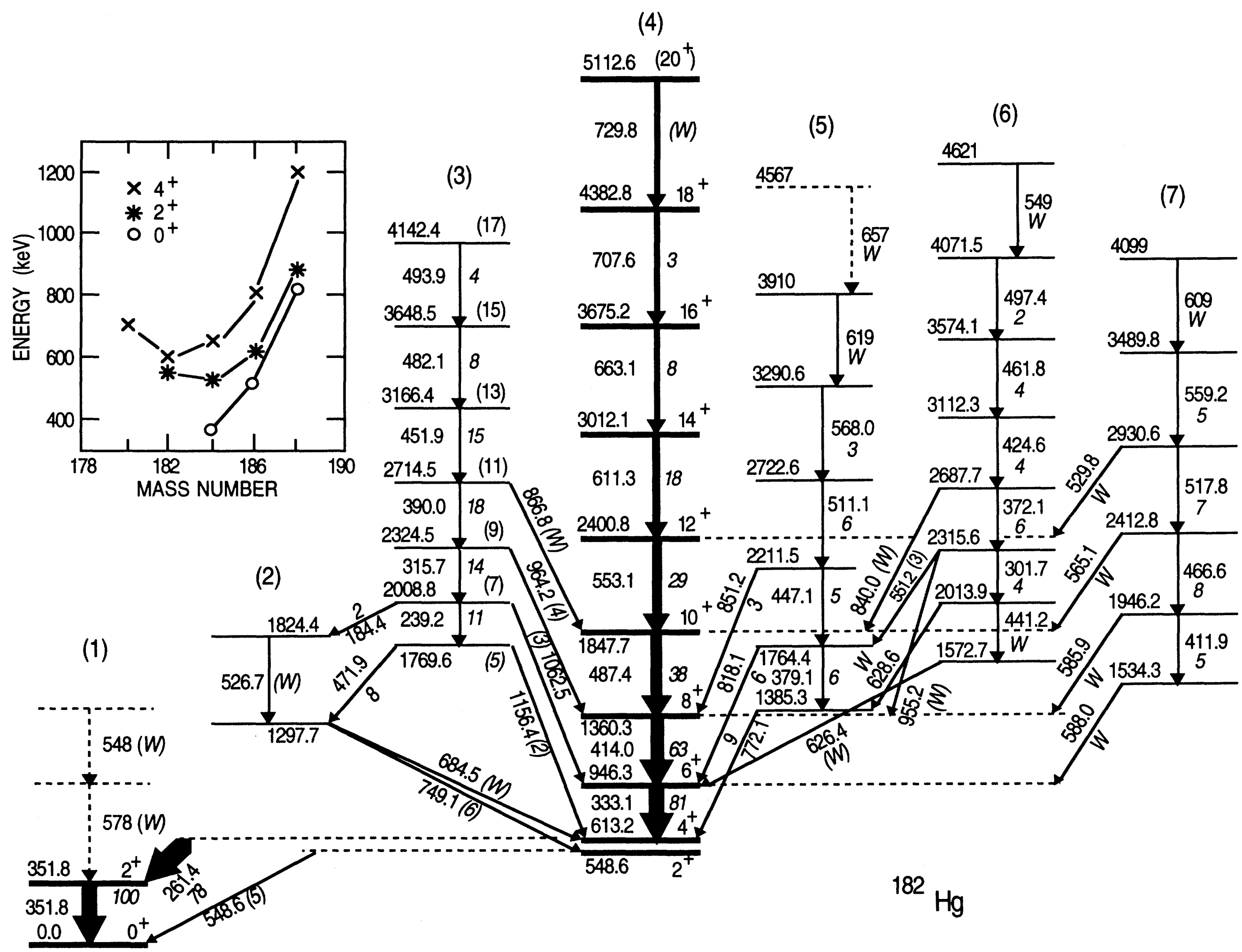

FIG. 3. Level scheme of ^{182}Hg. The inset shows the systematics of 0^+, 2^+, and 4^+ members of the observed prolate band energies. Relative γ-ray intensities are shown.

transitions in the 351.8-keV gate but not in the 261-keV gate. Their energies are consistent with the energies of the transitions in the oblate bands in ^{184,186}Hg. The prolate band 4 is now extended to spin 20. The plot of aligned angular momentum for this band shows a gentle upbend around spin 14^+, probably related to the gradual alignment of a pair of neutrons in the $i_{13/2}$ intruder orbital. The observed gentle upbend suggests that the interaction at the band crossing is strong. Similar behavior was observed in $^{184-188}$Hg.

Band 3 consists of a series of stretched-quadrupole transitions and is the second most intense populated band. The interband transitions from this band to the excited prolate band (band 4) are weak and no reasonable DCO ratios could be extracted for these transitions. The spin of the bandhead was assigned based on systematics of ^{184,186}Hg and of other N=102 isotones and on the fact that it and the rest three states feed the 4^+ to 10^+ states in band 4. The moment of inertia of this band is extremely similar to those of the negative parity bands previously observed in ^{178}Os and ^{180}Pt [8, 9]. The transition energies of band 3 differ by a maximum of 2.5 keV from the transition energies of a similar band (band 8) in ^{180}Pt below the state with suggested spin 13. So if our spin assignments are correct, these are identical bands below spin 13.

The two additional bands (bands 5 and 6) observed in ^{182}Hg are very similar in decay properties to bands observed in ^{184,186}Hg, whereas band 7 is not. Since the DCO ratios for the interband transitions from these bands to other bands have large errors, we could not assign spins or parities for the bandheads. Only the stretched $E2$ nature of the in-band transitions can be determined. These bands most likely are some type of quadrupole vibrational bands built on the excited prolate band since they feed only this band. These bands emphasize the continued importance with decreasing N of this second minimum at normal prolate deformation.

The energy of the prolate 0^+ band head drops rapidly from 825 keV in ^{188}Hg to 372 keV in ^{184}Hg (see inset in Fig. 3). The earlier studies on ^{182}Hg led to the suggestion that the prolate bandhead energy also appears to be lower in energy with respect to heavier Hg isotopes. Dracoulis *et al.* [5] established the excited prolate band in ^{180}Hg, but did not observe transitions to the prolate 0^+ or 2^+ levels. In ^{180}Hg, fitting a rotational energy formula to the higher spin states (6^+ to 14^+) of the prolate band, Dracoulis *et al.* [5] calculated the *unperturbed* 0^+ bandhead energy of 453 keV. Assuming an $\approx$ 80 keV interaction strength, they concluded that the energy of the *perturbed* 0^+ in ^{180}Hg would be at 466 keV. These results are in good agreement with IBM calculations [10] and the theoretical calculations of Bengtsson *et al.* [11] using a Woods-Saxon potential. Thus a clear minimum is established at N = 102.

The present identification of the prolate 2^+ at 548.6 keV clearly establishes that the *perturbed* prolate 2^+ energy is higher than that of the *perturbed* prolate 2^+ in ^{184}Hg. A two-parameter band mixing calculation using the *unperturbed* 2^+ state energy yields an interaction strength of 83 keV, which is similar to those for ^{186,184}Hg.

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