Microscopic description of magnetic dipole bands in the mass $A \sim 130$

K Higashiyama$^1$ and N Yoshinaga$^2$

$^1$Department of Physics, University of Tokyo, Hongo, Tokyo 113-0033, Japan
$^2$Department of Physics, Saitama University, Saitama City 338-8570, Japan

E-mail: higash@nt.phys.s.u-tokyo.ac.jp

Abstract. The negative-parity states in $^{132}$Ba are studied in terms of the pair-truncated shell model. The model reproduces experimental energy levels of the $\Delta I = 1$ band with the $\nu(h_{11/2}) \otimes \pi(h_{11/2}g_{7/2})$ configuration. From analysis of its structure, it is found that two angular momentum vectors representing valence neutrons and protons gradually close as total spin increases.

In recent years, $\Delta I = 1$ bands with strong $M1$ transitions, namely magnetic dipole bands, have been observed in many $A \sim 130$ nuclei [1, 2]. The properties of these bands have been well explained within the framework of the tilted axis cranking model [3]. However, there are very few studies which preserve both rotational symmetry and particle number conservation of interactions.

Theoretical studies of positive-parity states in mass $A \sim 130$ region have been carried out in terms of the $SD+H$ version of the pair-truncated shell model (PTSM) [4, 5]. In this model, the basis states of even-even nuclei are constructed from angular momenta zero ($S$) and two ($D$) collective pairs, and non-collective $H$ pairs, which are made by two nucleons in the $0h_{11/2}$ orbital. For a description of negative parity states, the $SD+H$ pair truncation scheme is extended to include negative-parity pairs: the $(0h_{11/2}2s_{1/2})$ and $(0h_{11/2}1d_{3/2})$ pairs for neutrons, and the $(0h_{11/2}0g_{7/2})$ pairs for protons. In the present calculation, we use the pairing plus quadrupole type interactions. The interaction strengths are the same as those in the previous study [4].

In Fig. 1, the energy spectrum obtained by the P TsM is compared with experiment for $^{132}$Ba. The calculation reproduces well positive-parity energy levels of the even-spin yrast band, especially the sudden decrease of level spacing between the $8^+_{1}$ and $10^+_{1}$ states. For the negative-parity states up to spin 9, our result gives a successful description of the experimental energy levels. In experiment, a $\Delta I = 1$ band is assigned to be built on the $\nu(h_{11/2}^2) \otimes \pi(h_{11/2}g_{7/2})$ configuration, the bandhead state of which starts at spin $11^-$ [6]. This band is expected to be a magnetic dipole band. The theoretical $\Delta I = 1$ band with bandhead state of $13^-$ having large $M1$ transitions appears somewhat higher in energy than experiment. From analysis of the wave functions (results not shown), it is found that this $\Delta I = 1$ band is built on the pure $\nu(h_{11/2}^2) \otimes \pi(h_{11/2}g_{7/2})$ configuration. In Fig. 2(a), the calculated $B(M1; I \rightarrow I - 1)$ values of the magnetic dipole band are shown as functions of spin $I$.

In Fig. 2(b), the effective angles between two angular momentum vectors of valence neutrons and protons $\theta$ for the magnetic dipole band are shown as functions of spin $I$. For the $14^-$ state, two angular momenta are approximately perpendicular to one another. It is seen that
Figure 1. Comparison of energy spectrum in experiment (expt.) with that of the PTSM (PTSM) for $^{132}$Ba. For each spectrum the level sequence on the left represents the yrast band. The magnetic dipole band is shown on the right-hand side. The experimental data are taken from Refs. [6, 7].

Figure 2. (a) $B(M1)$ values calculated in the PTSM. No experimental data are available. (b) The effective angles calculated in the PTSM. (c) The squares of the angular momenta for valence nucleons calculated in the PTSM.

two angular momentum vectors gradually close as spin $I$ increases up to spin 19. This situation is very similar to that of the shears mechanism [3].

In Fig. 2(c), the squares of angular momenta for valence neutrons and protons $\langle I^2 \rangle$ are plotted as functions of spin $I$. The theoretical result exhibits sudden changes of the values of $\langle I^2 \rangle$ between the $15^-$ and the $16^-$ states for both neutrons and protons. It shows that the magnetic dipole band is more complicated in structure than that described by the shears mechanism. Further experimental investigations of the magnetic dipole bands are needed in order to understand their structure.

References
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