Evidence for the existence of the [2 0 2]3/2 Deformed Band in mirror nuclei ^{25}Mg and ^{25}Al

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In axially-symmetric deformed nuclei the Nilsson orbits [1] are labeled by using asymptotic quantum numbers $[Nn_z\Lambda]\Omega$, where N is the total oscillator quantum number and n_z the number of quanta along the z axis. The projections of the orbital and total angular momenta of the single particle along the z axis are denoted by Λ and Ω, respectively. In the presence of axial symmetry about the z axis, the z component K of the total spin J is a good quantum number, and $K = \Omega$ holds for the rotational band based on the Nilsson orbit.

In the middle of the *sd* shell, odd-mass nuclei with mass number $19 \leq A \leq 25$ have a strong prolate deformation [2], and their low-lying states form rotational bands based on intrinsic configurations of single neutron or proton Nilsson orbits. Of the six Nilsson orbits originating from *sd* shells, five orbits have been known for a long time [2]. The lowest [2 2 0]1/2 orbit and the next [2 1 1]3/2 orbit form the ground-state bands in the $A = 19$ mirror nuclei (^{19}F and ^{19}Ne) and both $A = 21$ (^{21}Ne and ^{21}Na) and $A = 23$ nuclei (^{23}Na and ^{23}Mg), respectively. The [2 0 2]5/2 orbit, the only $K^\pi = 5/2^+$ Nilsson orbit in the *sd*-shell region, forms the ground-state band in the $A = 25$ mirror nuclei ^{25}Mg and ^{25}Al studied here, and the [2 1 1]1/2 and [2 0 0]1/2 bands form the excited bands [2].

The highest-lying [2 0 2]3/2 orbit, on the other hand, has never been properly identified although it was predicted already in the middle of the 1950s [1, 3]. This orbit would lie at the Fermi level for nuclei with neutron or proton numbers N or $Z \approx 19$. Therefore, the expectation was that this orbit would not be observed, because nuclei with these N or Z are not deformed near the stability line due to the shell closure at Z and/or $N = 20$.

Low-lying states of $A = 25$ mirror nuclei ^{25}Mg and ^{25}Al are well described by the particle-rotor model [2, 4, 5]. The study of intra- and inter-band Gamow-Teller (GT) and $M1$ transitions shows that the K-selection rules work very well [6], suggesting a good axially-symmetric shape of these nuclei. Since higher mass *sd*-shell nuclei are less deformed or spherical [2], the last opportunity to find the [2 0 2]3/2 rotational band without waiting for the study of exotic nuclei is to survey the higher excitation region of the $A = 25$ nuclei.

After fifty years of its prediction, this highest-lying [2 0 2]3/2 orbit among the six Nilsson single-particle orbits originating from the *sd* shells in prolately deformed nuclei and the rotational band on this orbit were identified. The band members were observed in ^{25}Al at excitation energies of $6 - 7.5$ MeV in a high-resolution ^{25}Mg(^{3}He, t) charge-exchange reaction at 0° (see Fig. 1) having a strong selectivity for Gamow-Teller transitions. In the comparison with the analogous $M1$ transitions in ^{25}Mg, the $J^\pi = 3/2^+$ band-head state and the excited $5/2^+$ and $7/2^+$ members were clearly assigned, as shown in Fig. 2.

Details are discussed in Ref. [7].

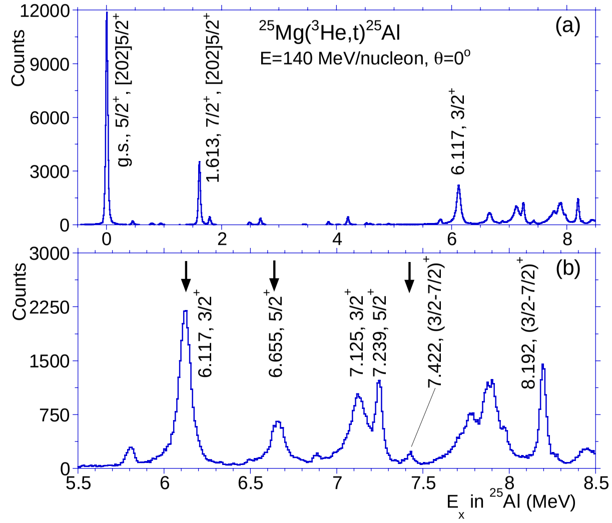

Figure 1: The ^{25}Mg(^{3}He, t)^{25}Al reaction spectra of (a) the range up to the excitation energy of 8.5 MeV and (b) expanded 5.5 − 8.5 MeV region. The members of the new rotational band are indicated by arrows.

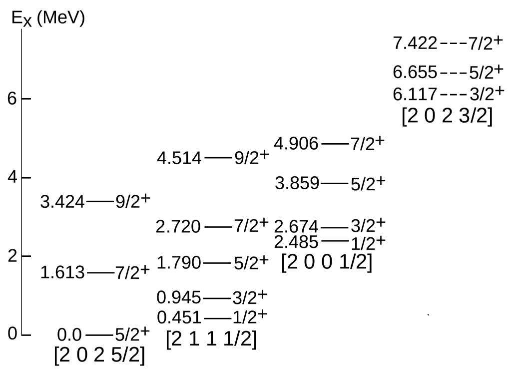

Figure 2: The band structures of the low-lying positive-parity states in ^{25}Al shown by full lines [2], and the states of the newly identified [2 0 2]3/2 band (dotted lines). Each state is denoted by its excitation energy (in MeV) and J^{π} value.

References

[1] S.G. Nilsson, Mat. Fys. Medd. Dan. Vid. Selsk. **29**, No. 16 (1955).

[2] A. Bohr and B. Mottelson, *Nuclear Structure* (Benjamin, New York, 1975), Vol. 2, and references therein.

[3] B.R. Mottelson, and S.G. Nilsson, Mat. Fys. Skr. Dan. Vid. Selsk. **1**, No. 8 (1959).

[4] A.E. Litherland et al., Can. J. Phys. **36** (1958) 378.

[5] F. Heidinger et al., Z. Phys. A **338** (1991) 23.

[6] Y. Shimbara *et al.*, Eur. Phys. J. A **19** (2004) 25.

[7] Y. Fujita *et al.*, Phys. Rev. Lett. **92** (2004) 062502.