Spectroscopy and reduced transition probabilities of negative parity bands up to band termination in ^{45}Ti

MA Hai-Liang(马海亮)[1;1)] YAN Yu-Liang(闫玉良)[1] ZHANG Xi-Zhen(张锡珍)[1]
ZHOU Dong-Mei(周冬梅)[1] DONG Bao-Guo(董保国)[1,2]

1 (Department of Nuclear Physics, China Institute of Atomic Energy, P.O. Box 275(18), Beijing 102413, China)
2 (Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Collisions, Lanzhou 730000, China)

Abstract The negative parity high spin states in ^{45}Ti have been investigated with the interacting shell model including the full fp shell and the configuration dependent cranked Nilsson-Strutinsky approach. Generally, the shell model has successfully reproduced the energy levels of negative parity bands, especially has a good description of the signature inversion at $17/2^-$. The reduced electric quadrupole transition probabilities of high spin states are calculated by the two models and compared with the experimental results. Reasonable agreement between theories and experiment are obtained, while the shell model can give more fine structures. The large differences of elctromagnetic moments between the shell model calculation and observation call for more elaborate effective interaction and more active shells.

Key words shell model, cranked Nilsson model, high spin, reduced transition probabilitiy

PACS 21.10.Re, 21.60.Cs, 23.20.-g

1 Introduction

One of the most interesting and intriguing aspects of nuclei is the interplay between collective and single particle degrees of freedom. The termination of a rotational band is viewed as a transition from collective rotational band to the pure single particle state. The most widely used approach studying nuclear rotational structures is the cranking model. With the advances in computers, the high spin rotational structures of some nuclei are within reach in the shell model(SM)[1].

The high spin states in nuclei near doubly magic ^{40}Ca have drawn a lot of attention from both experimental and theoretical studies. The interesting features discussed for these nuclei, are band termination, superdeformation, $SU(3)$ and/or isospin symmetry violation, etc. The terminating states in ^{45}Ti were reported in Refs. [2, 3]. In this paper, the shell model and the configuration dependent cranked Nilsson-Strutinsky (CNS) approach[4] have been used to study the high spin properties in ^{45}Ti. Both models provide a microscopic description of nuclei. Comparing with the CNS approach, the shell model can give better agreements with observed data while the CNS approach gives more transparent physics interpretations. In our calculations, the shell model code, OXBASH[5], with full pf shell and KB3[1] residual interaction, were used. In the CNS approach, Nilsson parameters from Ref.[6] are adopted and pairing is neglected. The deformation parameters are quadrupole and triaxial deformation (ε_2,γ) and hexadecapole deformation ε_4. After nonadiabatic orbitals constructed, a sum of the rotating liquid drop energy and shell energy corrections gives the total nuclear energy of a fixed configuration at specified deformation and spin. After minimization with respect to deformation parameters, the energies and deformation for this configuration can be obtained. Systematic calculations with the CNS approach have been carried out for all mass regions [4, 7—9], and confirmed to be reliable in the high spin region.

Received 3 September 2008
1) E-mail: mhl624@ciae.ac.cn

2 The energy levels and reduced transition probabilities of negative parity bands in ^{45}Ti

Relatively to a ^{40}Ca doubly magic core, in ^{45}Ti there are two valence protons and three valence neutrons for the negative parity ($\pi = -$) states. With all valence particles aligned, this band will terminate at spin $I = 27/2^-$. The experimental and calculated energy levels are shown in Fig.1, where the energies of $7/2^-$ states have been set to be zero in three cases. We can see that shell model with KB3 interaction has reproduced the experimental data very well, except that the sequence between $11/2^-$ and $9/2^-$ is reversed, while in the low spin region, the CNS approach without pairing which is mainly valid in the high spin region[10], only can describe the bands qualitatively.

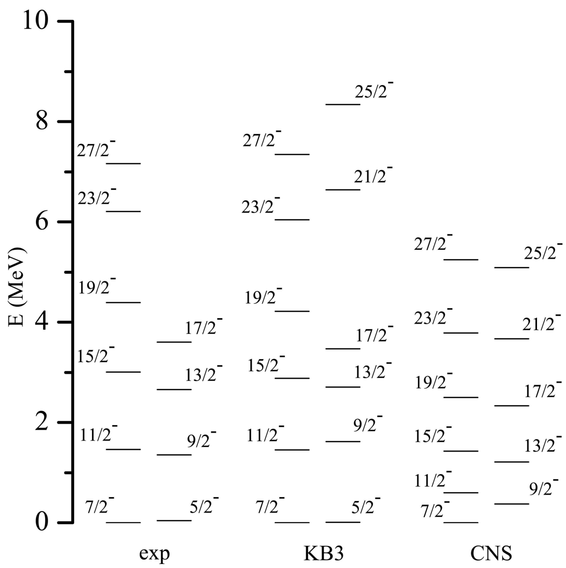

Fig. 1. The observed and calculated spectroscopy of negative parity bands in ^{45}Ti.

For a high-j single particle orbital, the favored signature is defined as $\alpha_{\rm f} = \frac{1}{2}(-1)^{j-1/2}$, which is $-\frac{1}{2}$ for the $f_{7/2}$ orbitals. However, the energy between $19/2^-$ and $17/2^-$ is larger than the energy between $17/2^-$ and $15/2^-$, which means the favored signature is reversed at this spin. This phenomenon has been well described by shell model. The shell model also predicts a large jump between $21/2^-$ and $19/2^-$, this may be the reason of the difficulty to observe $21/2^-$ state in the experiment.

In our shell model calculations of the reduced transition probabilities B(E2), the bare charges are adopted, i.e. $e_{\rm p} = 1, e_{\rm n} = 0$. The harmonic wave function with the parameter b=1.769 fm is used. In the

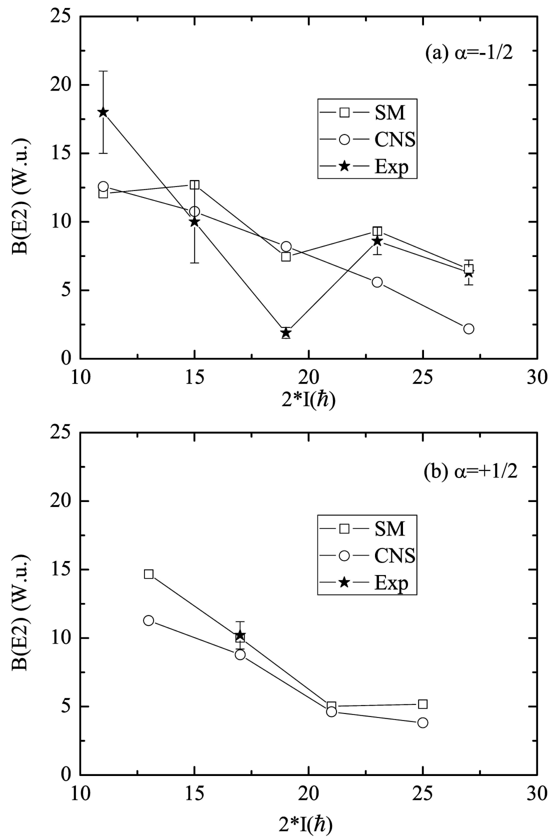

Fig. 2. The reduced transition probabilities B(E2) in ^{45}Ti. The experimental values are deduced from lifetime mesurements[3].(a) signature $\alpha = -1/2$;(b)$\alpha = +1/2$.

CNS approach, having values of the deformation parameters, it is possible to deduce the reduced transition probabilities B(E2) between two states via the following expression,

$$B({\rm E2}, KI_1 \to KI_2) = \frac{5}{16\pi} e^2 Q_0^2 \langle I_1 K 20 | I_2 K \rangle^2, \quad (1)$$

where $\langle I_1 K 20 | I_2 K \rangle$ is Clebsch-Gordan coefficient, K is the band head spin, I_1 and I_2 are the spin of the initial and final state, and Q_0 can be estimated through the formula[4]

$$Q_0 \approx \frac{4}{5} Z r_0^2 A^{2/3} \left[\varepsilon_2 \left(1 + \frac{1}{2}\varepsilon_2\right) + \frac{25}{33}\varepsilon_4^2 - \varepsilon_2 \varepsilon_4\right]. \quad (2)$$

In Fig.2, the reduced transition probabilities B(E2) obtained by the shell model and CNS approach are compared with experimental results, where the Weisskopf single particle B(E2) has been used as the unit, which is 9.508 e^2fm^4 for ^{45}Ti. From Fig.2, we can see that in most cases, the shell model and the CNS approach have shown similar trends. However, the shell model calculation shows better agreement with experimental results, as well as gives more fine structures. The $B({\rm E2} : 19/2^- \to 15/2^-)$ from experiment is extraordinarily low. The shell model gives the trend but the calculated result still is around 4 times larger than the experimental result.

Table 1. The electric quadrupole moments Q and magnetic moments μ of the $5/2^-$ and $7/2^-$ states in ^{45}Ti.

I^-	Q_{SM}	$\lvert Q_{\mathrm{exp}}\rvert$	μ_{SM}	μ_{exp}
5/2	-3.46	1.5(±1.5)	0.273	-0.133(±0.01)
7/2	-3.15		0.358	0.095(±0.002)

The eletromagnetic moments of the states $5/2^-$ and $7/2^-$ obtained by the shell model are shown in Table 1. Large differences can be found when comparing with the experimental results. The discrepancies may be the consequences of neglecting the contribution from sd shell.

3 Conclusion

In summary, the shell model and CNS approach have been used to investigate the negative parity high spin bands in ^{45}Ti. The shell model has successfully reproduced the experimental energy levels, especially has a good description of the signature inversion at $17/2^-$, while the CNS approach only gives the qualitative results. The reduced electric quadrupole transition probabilities of high spin states are obtained from two models and compared with the experimental results, and the shell model can give better description and more fine structures. The large discrepancies of the moments in the shell model calculation and the observation call for more elaborate effective interaction and inclusion of more active shells.

References

1 Caurier E et al. Rev. Mod. Phys., 2005, **77**: 427
2 Bentley M A et al. Phys. Rev. C, 2006, **73**: 024304
3 Bednarczyk P et al. Eur. Phys. J A, 1998, **2**: 157
4 Afanasjev A V et al. Phys. Rep., 1999, **322**: 1
5 Brown B A et al. MSU Cyclotron Laboratory Report No. 524, 1986
6 Bengtsson T. Nucl. Phys. A, 1990, **512**: 124; **95**: 420
7 DONG B G, GUO H C. Eur. Phys. J. A, 2003, **17**: 25
8 DONG B G, GUO H C. Chin. Phys. Lett., 2004, **21**: 2144
9 DONG B G, GUO H C, Ragnarsson I. Phys. Rev. C, 2006, **74**: 014308
10 Juodagalvis A, Ragnarsson I, Åberg S. Phys. Rev. C, 2006, **73**: 044327