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Possible existence of triaxial superdeformation in ^{172,174,176}W*

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Abstract Two-dimensional total routhian surface (TRS) calculations are carried out to determine the triaxial superdeformation (TSD) of the even-even nucleus ^{174}W, and the result indicates that TSD state exists with deformation parameters ε_2=0.42 and γ=34.7°. In the same way, the total routhian surfaces for the nuclei ^{172,176}W are also calculated. It shows that the neutron shell correction energy plays a key role in the formation of TSD nuclei ^{172,174,176}W, while the high j intruder orbitals and rotational energy are also crucial in the formation mechanism.

Key words TRS theory , triaxial superdeformation, routhian surface

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1 Introduction

The existence of stable triaxiality in nuclei has been investigated theoretically and experimentally in recent years. Triaxiality is difficult to prove experimentally. Several observations that have been explained by deviations from axial symmetry signature and inversion or the measured transition probabilities, may also be interpreted in different ways. However, two phenomena that are uniquely related to triaxiality have been predicted theoretically[1, 2]: the occurrence of wobbling and chiral bands. Among the discovered TSD nuclei, most of them are located in the A∼160 region[3—10]. The triaxial behavior of ^{163}Lu has been further confirmed experimentally by the discovery of the wobbling mode. Recently high-spin states in ^{174}W were populated using the reaction ^{128}Te (^{50}Ti, 4n) ^{174}W at beam energies of 215 MeV and 225 MeV. Some new bands were found[11], and one of the new bands was studied. By using the TRS theory, we calculate the total routhian surface for the even-even nucleus ^{174}W (A∼180) and study the formation mechanism of ^{174}W. At the same time, the total routhian surfaces and the formation mechanism of the triaxial superdeformation for nuclei ^{172,176}W are also calculated.

2 A brief description of the TRS model

The Hamiltonian of quasi-particles moving in a quadrupole deformed potential rotating around the x-axis with a frequency ω can be written as

$$H^{\omega}=H_{\rm s.p}(\varepsilon_2,\varepsilon_4)-\lambda N+\Delta(p+p^{+})-\omega J_x\ , \qquad (1)$$

where $H_{\rm s.p.}$ denotes the deformed Hamiltonian of the single particle motion, the second term on the right hand side is the chemical potential, the third term is

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the pairing interaction and the last term stands for the Coriolis forces. The modified-harmonic-oscillator (MHO) potential with the parameters κ and μ for the mass region taken from Ref. [12] is employed in the present calculation. The pairing-gap parameter is determined empirically Δ=0.9$\Delta_{\rm o.e.}$, and $\Delta_{\rm o.e}$is taken from the experimental odd-even mass difference[13] . As an approximation, we did not take into account the deformation and rotation dependence of pairing.

The total routhian surface, namely, the total energy in the rotating frame as a function of ε_2, γ, and ε_4, of a (Z, N) nucleus for a fixed quasi-particle configuration c.f. can be calculated by

$$E^{\rm c.f.}(\varepsilon_2,\varepsilon_4,\gamma,\omega)=E_{\rm LD}(\varepsilon_2,\varepsilon_4,\gamma)+ E_{\rm corr}(\varepsilon_2,\varepsilon_4,\gamma,\omega=0)+E_{\rm rot}(\varepsilon_2,\varepsilon_4,\gamma,\omega)+ \sum_{\rm i\in c.f.} e_i^{\omega}(\varepsilon_2,\varepsilon_4,\gamma), \quad (2)$$

where $E_{\rm LD}$ is the liquid-drop model energy[14], $E_{\rm corr}$ is the quantum-effect correction to the energy, which includes both the shell[15] and pairing corrections[16]. The collective rotational energy $E_{\rm rot}$ can be microscopically calculated as the energy difference between the expectation values of H^{ω} with and without rotation, by using the wave function for the quasi-particle vacuum configuration[17]. The last term of Eq. (2) is the sum of quasi-particle energies belonging to the configuration c.f., which generates the deformation drive. All of the terms in Eq. (2) depend on (Z, N) numbers which are not written explicitly. The equilibrium deformations of the nucleus are calculated by minimizing the total routhian energy of Eq. (2) with respect to ε_2, γ, and ε_4[18].

3 The results and discussions

Using the TRS method, the deformation of nucleus ^{174}W is study. In the formation of the triaxial superdeformation, the shape-driving effect plays an important role, especially the high-j intruder orbitals such as $\pi i_{13/2}$, $\pi h_{9/2}$ and $\nu i_{13/2}$. In the calculation, we take into account two quasi-proton particle π[660]1/2, $\alpha=1/2\otimes\pi$[651]3/2, $\alpha=-1/2$ which approach to the Fermi surface. In this paper we fix the ω as $0.05\omega_0$, where $\hbar\omega_0=41/\sqrt[3]{A}$ MeV, namely, we take the rotational frequency $\hbar\omega$ as 0.37 MeV.

ε_4 is fixed as 0.025. Two-dimensional calculated result is shown in Fig. 1 with two local minima marked by "+". A represents the normal deformation and B represents the triaxial superdeformation with the deformation parameter (ε_2, γ) = (0.42, 34.7°).

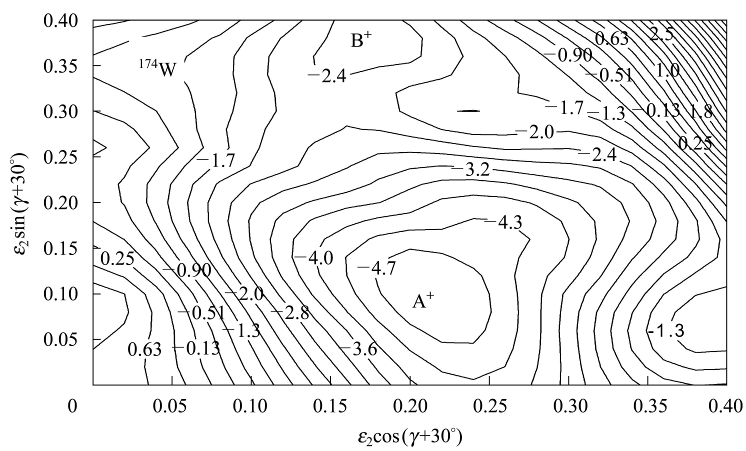

Fig. 1. The shape determination of ^{174}W. The contour lines with corresponding energy values are plotted. The point "B" represents the triaxial deformation with parameter $(\varepsilon_2,\gamma)=(0.42, 34.7°)$.

In order to investigate the formation mechanism of the triaxial superdeformed nucleus ^{174}W in detail, the shell and pair correction energy of neutrons and protons are given in Fig. 2, respectively. The sum of two quasi-proton particle energies and the rotational energy are also given in Fig. 3, respectively.

From Fig. 2 we see the shell correction energy of the neutrons plays a key role in the formation of the TSD ^{174}W nuclei. First, the position of the second local minimum in the total routhian surface is very close to the one in the neutron shell correction surface. Second, the shell correction energy of the neutrons, shown in Fig. 2(a), decreases sharply with increasing ε_2 deformation and therefore has a strong driving effect towards large elongation deformation.

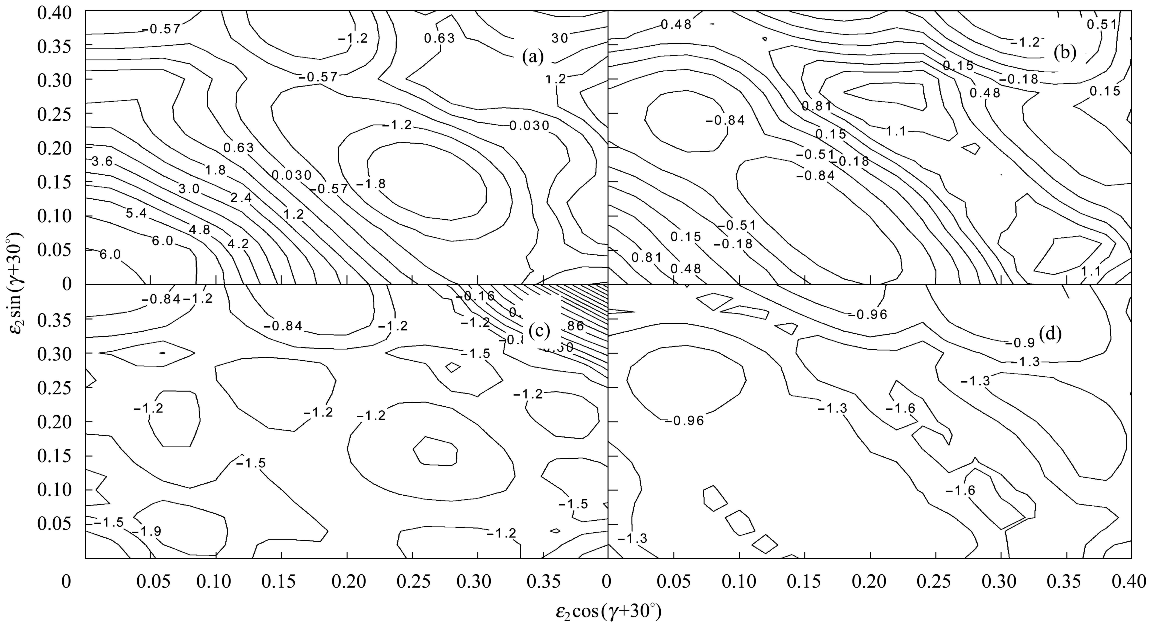

Fig. 2. The formation mechanism of ^{174}W. The contour lines of neutron and proton shell correction energies are plotted in (a) and (b), respectively, while the pair correction energy of neutrons and protons are shown in (c) and (d), respectively.

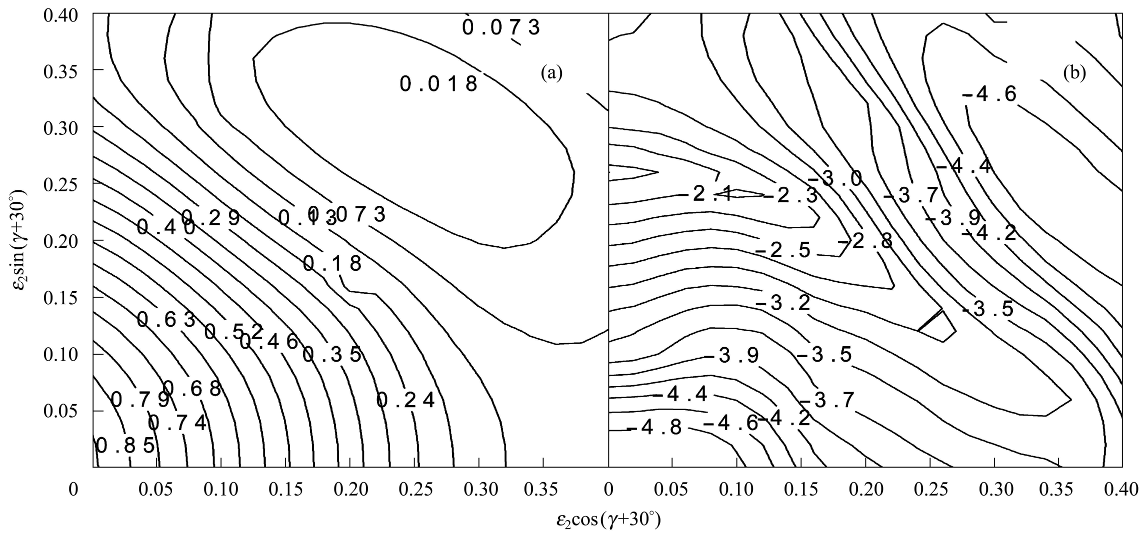

Fig. 3. The formation mechanism of ^{174}W. The sum of two quasi-proton particle energies and the rotational energies is plotted in (a) and (b) respectively.

From Fig. 3, it can be seen that the sum of two quasi-proton energies plays an important role in the formation of the TSD shape. Because near the $\varepsilon_2 = 0.37$, the sum of two quasi-proton energies, shown in Fig. 3(a), decreases sharply with increasing γ. Approaching the triaxial superdeformed point $(\varepsilon_2, \gamma) = (0.37, 34.8^\circ)$, the contour line becomes steep, and the sum of two quasi-proton energies becomes smallest at this point. So the high-j intruder orbitals have a strong driving effect towards large elongation deformation. The rotational energy also has an additional role to form TSD shape, because the rotational energy, shown in Fig. 3(b), decreases sharply with increasing large ε_2 deformation and therefore has a strong driving effect towards large elongation deformation equally.

The shape determinations of the nuclei ^{172,176}W are given in Fig. 4 and Fig. 5, respectively, whose formation mechanism is almost same as that of ^{174}W.

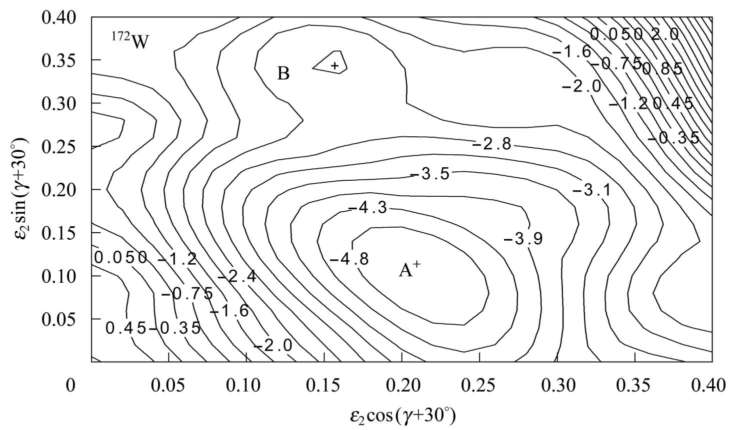

Fig. 4. The contour plot of the total routhian for ^{172}W. The unit of the number in the surface is MeV. Point "B" represents the triaxial deformation with parameter $(\varepsilon_2,\gamma)=(0.37, 34.8°)$.

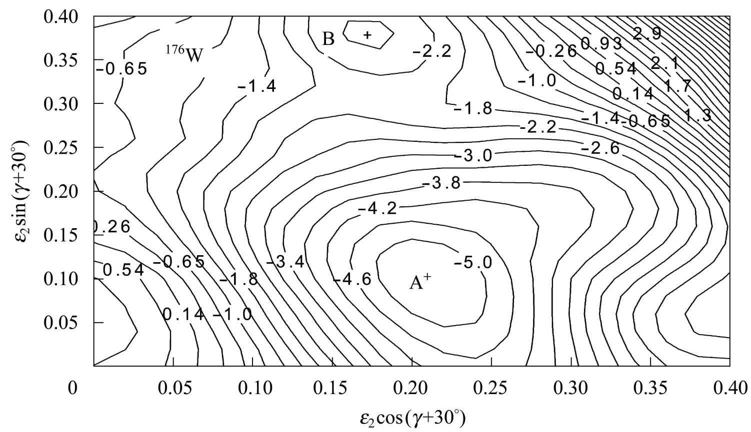

Fig. 5. The same as in Fig. 4, but for ^{176}W with deformation parameter $(\varepsilon_2,\gamma)=(0.42, 35.9°)$.

4 Summary

In summary, by fixing the rotational frequency ω as $0.05\omega_0$, we confirm that the nucleus ^{174}W has trixial superdeformation, the deformation value is (ε_2,γ) = (0.42, 34.7°). In the same way, we also calculate the total routhian surface for ^{172,176}W nuclei, the deformation parameters are ε_2=0.37, γ=34.8° and ε_2=0.42, γ=35.9°, respectively. The calculated results indicated not only the shell correction energy of the neutrons and the sum of the two quasi-proton particle energies play a key role in the formation of the TSD even-even nuclei ^{172,174,176}W but also the rotational energy also has an additional contribution to the TSD shape of the ^{172,174,176}W.

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