Shape evolution and test of the critical-point symmetry $X(5)$ in ^{176}Os*

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Abstract The lifetimes of excited states in the yrast band of ^{176}Os have been measured up to $I = 20\hbar$ level using the Doppler shift attenuation method. The high-spin states of ^{176}Os were populated via fusion evaporation reaction ^{152}Sm(^{28}Si, 4n)^{176}Os at a beam energy of 140 MeV. The results support an $X(5)$ structure for ^{176}Os at low spin. This structure disappears at high spin and shows a symmetry rotor character. The shape change of ^{176}Os is similar to that of ^{178}Os.

Key words shape evolution, critical point symmetry, lifetime

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1 Introduction

The $X(5)$ critical point symmetry, introduced by Iachello[1, 2] as an analytical solution to describe the transition from a spherical harmonic vibrator $U(5)$ to an axially deformed rotor $SU(3)$, has stimulated considerable efforts both experimentally and theoretically. Initial work concentrated on the nuclei in the rare-earth region with $N = 90$. The lifetime measurements of excited states in ^{152}Sm[3], ^{150}Nd[4] and ^{154}Gd[5] display a structure very close to the $X(5)$ predictions. Whether the behavior is particular to $N = 90$ or also present in Hf, W, and Os nuclei with $N > 90$, requires a more detailed analysis of their structure. Later experiments provide that the yrast band energies as well as the B(E2) values are in agreement with the $X(5)$ predictions for ^{162}Yb[6], ^{166}Hf[7] and ^{178}Os[8].

One proposed signature[9, 10] of phase transitional behavior is a sharp rise in the $R_{4/2} \equiv E(4_1^+)/E(2_1^+)$ value as a function of neutron number as nuclei evolve from vibrator ($R_{4/2}$=2.0) to axial symmetry rotor ($R_{4/2}$=3.33). The $X(5)$ solution has an $R_{4/2}$=2.91 between that of the vibrator and rotor. The evolution of $R_{4/2}$ values in even-even nuclei as a function of Z is given in Fig. 1. The solid line represents the $X(5)$ value of $R_{4/2}$=2.91; the two horizontal dashed lines indicate the region of possible $X(5)$ candidates, $R_{4/2}$=2.91±0.10. An abrupt increase in $R_{4/2}$ with N increasing in Os (Z=76) isotopes is clearly exhibited by the ^{176}Os nucleus and its $R_{4/2}$=2.93 is very close to the $X(5)$ predictions.

Another quantity which is useful in searching for candidates of $X(5)$ nuclei is the P factor[11], defined as

$$P = \frac{N_{\mathrm{p}} N_{\mathrm{n}}}{N_{\mathrm{p}} + N_{\mathrm{n}}} , \tag{1}$$

where N_{p} and N_{n} are the numbers of valence proton and valence neutron, respectively. This approach has

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the advantage that the locus of possible phase transitional behaviour can be extended to regions where no experimental data are yet known. One expects an $X(5)$ phase transition to occur roughly when $P\sim 5$. For ^{176}Os, $P=4.5$ is close to the $X(5)$ prediction.

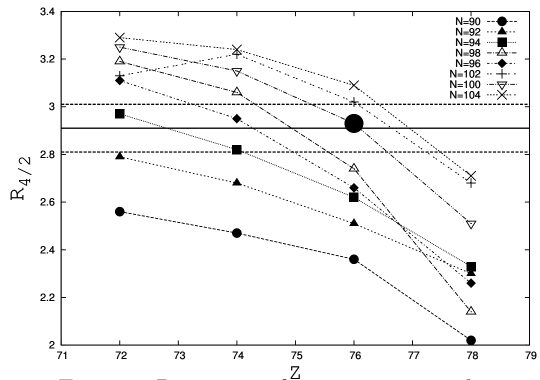

Fig. 1. $R_{4/2}$ ratios for even-even nuclei.

However, both $R_{4/2}$ ratio and P factor serve only as a guide to possible candidates for $X(5)$ nuclei because the $R_{4/2}$ value of 2.91 and P factor of 5 are not unique to $X(5)$ nuclei. In order to enable more stringent tests, it is necessary to measure level lifetimes.

Lifetime of 2^+ state[12] in ^{176}Os and excited states below $I=10\hbar$ in the yrast band[13] have been measured previously using pulsed-beam technique and recoil distance Doppler shift technique respectively. The present work makes use of the Doppler shift attenuation method to measure the lifetimes above 8^+ level in the yrast band in ^{176}Os. These measurements will provide a more stringent test of $X(5)$ structure in ^{176}Os and examine whether the $X(5)$ structure will remain as the spin increases.

2 Experiment and results

The experiment was performed at the HI-13 tandem accelerator in the China Institute of Atomic Energy. The high spin states of ^{176}Os were populated via heavy-ion fusion evaporation reaction ^{152}Sm(^{28}Si,4n)^{176}Os at a beam energy of 140 MeV. The target consisted of 1.52 mg/cm^2 thick Sm was evaporated on a 7.39 mg/cm^2 Au backing. The γ-rays from the evaporated residues were detected with an array consisting of fourteen Compton suppressed HPGe-BGO spectrometers. More than $139\times10^6\gamma-\gamma$ coincidence events were collected.

The data was gain matched to 0.5 keV/channel. Spectra generated by gating on the transitions below the levels of interest were used and lifetimes have been determined up to $I=20\hbar$ level in the yrast positive-parity band. Lineshapes of the transitions were fitted with DSAMFT program[14] developed by J. Gascon. Zieglers electronic stopping powers were used in the program. A mean recoil velocity of v/c=1.55% when ^{176}Os entered the gold foil was obtained. The uncertainty of lifetimes is composed of the uncertainty of the stopping power and that in lineshape fitting. The uncertainty of the stopping powers adds a 10% relative error to all the lifetime values. The experimental and simulated lineshapes for γ ray deexciting the 18^+ level in ^{176}Os are shown in Fig. 2. The preliminary results are listed in Table 1. The lifetime τ values measured in the present work were used to derive values of the transitional quadrupole moments Q_t and β_2 deformation parameters. The lifetimes of the 12^+, 14^+, 16^+, 18^+ and 20^+ states have been reported for the first time.

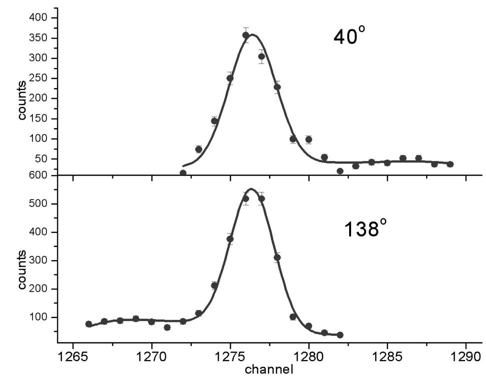

Fig. 2. Example of experimental and simulated lineshapes for the 637.7 keV γ-ray deexciting the 18^+ level in ^{176}Os. The upper frame shows the lineshape in the forward detector ($\theta=40°$), and the lower one shows the lineshape in the backward detector ($\theta=138°$).

Table 1. Experimental values of lifetimes, Q_t and β_2 in the yrast band of ^{176}Os.

level	E_γ/keV	τ/ps	Q_t/eb	β_2
20^+	664.1	<1.05	>4.10	>0.16
18^+	637.7	0.53±0.12	6.41±0.71	0.24±0.02
16^+	626.8	0.58±0.14	6.42±0.77	0.24±0.02
14^+	586.8	0.62±0.26	7.35±1.54	0.27±0.06
12^+	533.8	0.70±0.21	8.78±1.32	0.32±0.05
10^+	476.3	1.63±0.52	7.69±1.23	0.28±0.05
8^+	415.0	3.72±2.60	7.21±2.52	0.27±0.09

3 Discussion

The Q_t values determined for the 8^+ up to 20^+ states in yrast band in ^{176}Os are shown in Fig. 3(a). The values for the lower levels of the yrast band from previous work[13] on this nucleus are also shown in

Fig. 3(a). The Q_t values of the 8^+ and 10^+ levels are in good agreement with previous measurement using the recoil distance Doppler-shift method. The lifetime of 8^+ state is out of the subpicosecond range for the Doppler shift attenuation method, so the errorbars of Q_t of 8^+ level is very large. But this still supports that our results are reliable and confirm an $X(5)$ structure for ^{176}Os at low spin.

On the other hand, as illustrated in Fig. 3(a) and (b), the Q_t and β_2 values remain a constant value with spin increasing. These show that ^{176}Os shows a symmetry rotor character at high spin.

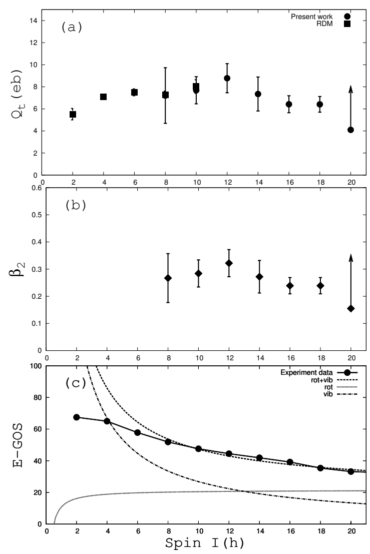

Fig. 3. Shape evolution of ^{176}Os. (a) Q_t values; (b) β_2 values; (c) E-GOS as a function of spin I.

In order to know how the shape change in nucleus we have another empirical approach to distinguish vibrational from rotational regimes in atomic nuclei, called E-GOS (E-Gamma Over Spin) curves[15]. An E-GOS curve of ^{176}Os is shown in Fig. 3(c), the E-GOS value of ^{176}Os at low spin is between that for vibrator and symmetry rotor, so the shape of ^{176}Os is between vibrator and symmetry rotor at low spin, and the E-GOS values of ^{176}Os remain a constant value with increasing spin, namely, ^{176}Os has the symmetry rotor character at high spin.

The shape evolution of ^{178}Os[16, 17] is shown in Fig. 4. By comparing the changing shape of ^{178}Os with that of ^{176}Os, we can find that the shape change of ^{178}Os is similar to that of ^{176}Os.

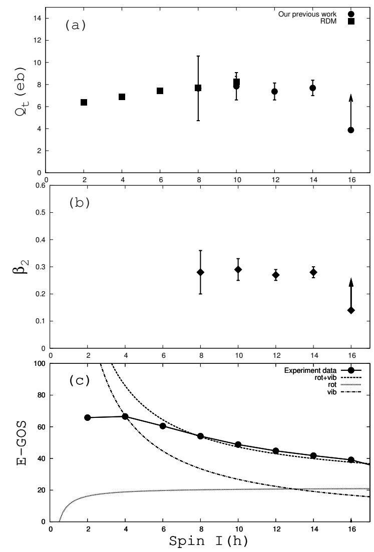

Fig. 4. Shape evolution of ^{178}Os. (a) Q_t values; (b) β_2 values; (c) E-GOS as a function of spin I.

4 Summary

The lifetimes of excited states in the yrast band in ^{176}Os have been measured up to $I = 20\hbar$ using the Doppler shift attenuation method. The high-spin states of ^{176}Os were populated via fusion evaporation reaction ^{152}Sm(^{28}Si, 4n)^{176}Os at a beam energy of 140 MeV. The results were consistent within experimental error with the previous measurements and supported an $X(5)$ structure for ^{176}Os at low spin. The $X(5)$ structure of ^{176}Os disappears at high spin and ^{176}Os shows a symmetry rotor character. The shape change of ^{176}Os is similar to that of ^{178}Os.

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