Search For Hyperdeformation Through Jacobian Instability In Excited Medium Mass Nuclei

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Introduction

An outstanding question in Nuclear physics is the nature of the equilibrium shape of the nucleus at high excitation energies and at large angular momenta near the limit of what the nucleus can sustain. The rotating liquid drop model (RLDM) [1-2] predicts the nucleus should experience a shape transition, at very high spins, from oblate noncollective shape to hyperdeformed collective prolate (or nearly prolate) with major to minor axis ratio 5:2 (β=0.8) or 3:1(β=1.0) or even larger. The existing possibility of discovering such extremely deformed nuclear shapes has attracted the attention of both theoreticians and experimentalists for a number of years. The first reported experimental data interpreted as evidence for a hyper deformed nuclear shape was the observation by Galindo-Uribarri et al. [3], of a peak at $\Delta E \approx 30 keV$. Over the past few decades, a number of theoretical papers have made predictions of which nuclei are good candidates for observing hyperdeformations. Dudek, Werner and Riedinger [4] first predicted that deep hyperdeformed minima $(\beta_2 \approx 1.0)$ would occur at high spin in heavy nuclei. We can often ask ourselves a question, on which nuclei under which excitation energy and condition one has to look for the manifestation of the hyperdeformation phenomeno. The important role of hyperdeformation configuration is further enhanced by the loss of stability known as the Jacobian instability induced by rotation. The rotating liquid drop model (RLDM) has already predicted that nuclei should experience a shape transition at very high spins from noncollective oblate to collective prolate (or nearly prolate) with the superdeformed major to minor axes ratio of 2:1 or more. The shape evolution of rotating nuclei ultimately produces the above shape transition called the Jacobi shape transition which is analogous to the Jacobi shape instability occurring in gravitating rotating stars. While the Jacobi shape transition lead to super deformation with the above configurations, that can also lead to another more deformed case with β>0.8 called as hyperdeformation. Nuclei in the mass region A=70–90 have attracted considerable theoretical and experimental interest in recent years because of a wide variety of nuclear phenomena that occur in this region [5]. There is a great interest in the structure of the N=Z nuclei since, unlike in all other nuclei, it will be dominated by the T=0 residual interaction. The presently available experimental information indicates a small region strong deformation centered on ^{76}Sr. In this work, we aim at predicting such hyperdeformed shapes through Jacobi shape transitions in even-even Strontium isotopes, ^{76}Sr & ^{78}Sr as a function of spin.

Theoretical Formalism

The cranked Nilsson Strutunsky method is used in the calculations. The total energy E_{TOT} at fixed deformation is calculated using the expression

$$E_{TOT} = E_{LDM} + \sum_{p,n} \delta E + \frac{1}{2}\omega(I_{class} + \sum_{p,n} \delta I) \quad (1)$$

Here the liquid drop energy E_{LDM} is given by the sum of Coulomb and surface energies corresponding to a triaxially deformed shape defined by the deformation parameters β and γ. The spin $I_{classical}$ is obtained from the rigid-body moment of inertia with surface diffuseness correction. The shell correction (δE) is the difference between the deformation energies evaluated with a descrete single particle spectrum and by smoothening that spectrum ($\delta E = E - \tilde{E}$). Similarly, the shell correction corresponding to the spin is given by ($\delta I = I - \tilde{I}$). It is to be stated that pairing is not taken into account in these calculations since Jacobi transition occurs at very high spins where pairing is unimportant.

The calculations are carried out by varying ω values in steps of $0.025\omega_0$ from $\omega = 0.0$ to $\omega = 0.3\omega_0$, ω_0 being the oscillator frequency for tuning to fixed spins. Since we are interested in predicting the Jacobi shape transitions, γ is varied from -180^0 to -120^0 in steps of -10^0, $\gamma=-180^0$ corresponding to noncollective oblate and $\gamma=-120^0$ corresponding to collective prolate. Since the Jacobi transition involves hyperdeformation, β values are varied from 0.0 to 1.2 in steps of 0.1.

Results and Discussion

The constant spin potential energy surfaces are extracted for the even-even krypton isotopes, ^{76}Sr & ^{78}Sr, to study the shape evolution and also to look for the possible Jacobi shape transitions leading to hyper deformations in them. Table shows the equilibrium shape evolution of ^{76}Sr at different spins performed with the tuned spin cranked Nilsson Strutinsky method. We see from Table that ^{76}Sr is triaxial in its ground state and the shape changes to oblate as spin increases to 11ħ. As angular momentum increases, the oblate deformation also increases and acquires β=0.4 at I=40 ħ and which persists upto 42 ħ. The Jacobi shape transition takes place from noncollective oblate to hyperdeformed prolate with β=0.8 at an angular momentum I=46 ħ in ^{76}Sr. In the case of ^{78}Sr isotope (not shown) a shape change occur from spherical to oblate and persists in the oblate configuration upto I=46 ħ and the Jacobi shape transition takes place at an angular momentum of I=48 ħ with β=0.9. It is to be noted from the above discussion that the Jacobian instability is clearly occurring in the considered strontium isotopes at high spin and is found to be a second order phase transition which leads to hyperdeformed shapes.

TABLE: Shape transitions in ^{76}Sr with spin at T=0.0MeV

I (h)	γ (deg)	β	E (MeV)
0.00	-180	0.0	-2.61
4.00	-180	0.0	-3.12
7.99	-180	0.0	-0.96
10.99	-180	0.1	1.21
12.99	-180	0.2	3.18
16.99	-180	0.2	5.65
19.99	-180	0.2	10.78
23.99	-180	0.2	14.35
28.99	-180	0.2	20.23
30.99	-180	0.2	24.76
34.99	-180	0.3	29.88
37.99	-180	0.4	31.43
42.00	-180	0.4	36.93
45.99	**-120**	**0.8**	**43.04**

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