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Structural Transitions And Fluctuations In Hot Rotating Selenium Isotopes

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The structural transitions of a couple of isotopes of Selenium nuclei at high excitation energy, along with the influence of thermal fluctuations on the shape parameters, are analyzed. The Landau theory of phase transitions is employed to ascertain the evolution of shape in relation to temperature and spin. The constants in the Landau expression for free energy are derived from the free energy surfaces computed through the finite temperature variant of the cranked Nilsson - Strutinsky shell correction technique. Pairing is not included in the study. We present our findings that the ground state of the examined ^{72}Se nucleus exhibits a prolate shape, while the ^{74}Se nucleus is spherical. As the spin increases, the nucleus maintains its shape with significant elongation; however, at high spin, the shape transitions to oblate in the first case and to oblate via triaxial in the latter case. However, at elevated temperatures and spin, when thermal fluctuations are taken into account, the distinct transitions between spherical, prolate, and oblate shapes result in a triaxial configuration. It is seen that with thermal fluctuations the averaged shapes for the above nuclei at different temperatures and spins are mostly triaxial which are quite different from the most probable prolate or oblate shapes.

Key words: High spin states of nuclei, structural transitions, thermal fluctuations, Landau theory of phase transitions, cranked Nillsson - Strutinsky method.

1. Introduction

The investigation of structural transitions of hot rotating nuclei at elevated excitation energy is a subject of contemporary relevance in the field of nuclear structure research. Currently, there is an increasing amount of experimental data regarding the shapes and characteristics of hot rotating nuclei that are produced in heavy ion fusion reactions, where the transfer of energy and angular momentum from their relative motion excites the compound nucleus. The characteristics of these hot rotating nuclei are typically examined by analyzing the decay patterns of particles and gamma rays from the compound nucleus. It is anticipated that hot and rotating nuclei will display a diverse range of shapes. One of the significant advantages of utilizing newly developed multi-detector arrays is the enhanced precision in studying shape transitions in hot rotating nuclei. In order to investigate the shapes of hot rotating nuclei, it is necessary to employ mean field theories such as the microscopic Hartree-Fock Bogoliubov cranking theory [1-3] and the macroscopic Landau theory [4-6]. Additionally, the more suitable Mottelson – Nilsson [7] and Nilsson – Strutinsky [8-9] methods can also be utilized for the examination of hot rotating nuclei. Mean field theories tend to overlook statistical fluctuations in the order parameters. For a nucleus containing a finite number of particles, thermal fluctuations can be significant [10]. These fluctuations can yield an average value for the order parameters that is qualitatively distinct from the equilibrium or mean field value [9,11-13]. Theoretically, it is essential to account for thermal fluctuations at finite temperatures. The objective of this study is to analyze the shape evolutions in the ^{72}Se and ^{74}Se isotopes as a function of both spin and temperature. In the initial phase of this research, the cranked Nilsson Strutinsky method with a fixed spin approximation [9] is employed to determine the shape and deformation of the nuclei under consideration. Subsequently, the Landau theory of shape transitions is applied to investigate the shape variations resulting from thermal fluctuations.

2. The theoretical method

2.1 Shape of excited Nuclei as determined by mean field method

The cranked Nilsson - Strutinsky method, applied in the rotating frame with a cylindrical representation, is utilized to derive potential energy surfaces for the selenium isotopes. In this approach, the nucleons are subjected to a cranked Nilsson potential, with deformation characterized by the parameters β and γ. The cranking process occurs around one of the principal axes, specifically the Z-axis, with the cranking frequency denoted by ω.

The shell energy computations for the non-rotating scenario (I=0) presumes a single particle field

$$H^0 = \sum_i h^0 \qquad (1)$$

where h^0 represents the triaxial Nilsson Hamiltonian, which is defined as follows:

$$h_i^0 = \frac{p^2}{2m} + \frac{1}{2} m \sum_{k=1}^{3} \omega_k^2 x_k^2 - \kappa \hbar \omega_0^0 [2l.s + \mu(l^2 - 2\langle l^2 \rangle)] \qquad (2)$$

The frequencies of the oscillators, denoted as ω_i , are defined according to the Hill Wheeler parameterization [14] represented

$$\omega_i = \omega_0 \exp\left[-\sqrt{\frac{5}{4\pi}}\beta \cos\left(\gamma + \frac{2}{3}\pi j\right)\right] \qquad (3)$$

subject to the condition of constant volume for equipotentials

$$\omega_x \omega_y \omega_z = \omega_0^{0\,3} = \text{constant}. \qquad (4)$$

The frequencies of the oscillators are selected independently for protons and neutrons,

$$\hbar\omega_0 = (41MeV) A^{-\frac{1}{3}} \left(1 + \frac{1}{3}\frac{N-Z}{A}\right) \quad \text{for protons}$$

$$\hbar\omega_0 = (41MeV) A^{-\frac{1}{3}} \left(1 - \frac{1}{3}\frac{N-Z}{A}\right) \quad \text{for neutrons} \qquad (5)$$

For the Nilsson parameters κ and μ, the following values are selected [15] independently for protons and neutrons:

Protons		Neutrons	
κ	μ	κ	μ
0.070	0.390	0.073	0.290

In the equation for h_i^0, the term involving $\left\langle l^2 \right\rangle$ has been multiplied by two to achieve improved concordance between the Strutinsky-smoothed moment of inertia and the rigid rotor value (which is within 10%). Consequently, the parameter D has been recalibrated using single-particle levels in the specified mass region A~70-80. The Hamiltonian is diagonalized in cylindrical depiction up to N=11 major shells.

In the scenario of rotation (I≠0), the Hamiltonian is expressed as

$$H^{\omega} = \sum_i h_i^{\omega} \tag{6}$$

where

$$h_i^{\omega} = h_i^0 - \omega j_z \tag{7}$$

provided that it is presumed the rotation occurs around the Z-axis.

The energy of a single particle, denoted as e_i^{ω}, along with the wave function represented by ϕ_i^{ω}, is provided by

$$h_i^{\omega}\phi_i^{\omega} = e_i^{\omega}\phi_i^{\omega} \tag{8}$$

The spin projections are obtained as

$$\left\langle m_i \right\rangle = \left\langle \phi_i^{\omega} \middle| j_z \middle| \phi_i^{\omega} \right\rangle \tag{9}$$

The total shell energy is given by

$$E_{sp} = \sum_i \left\langle \phi_i^{\omega} \middle| h_i^0 \middle| \phi_i^{\omega} \right\rangle = \sum_i \left\langle e_i \right\rangle, \tag{10}$$

where

$$e_i^{\omega} = \left\langle e_i \right\rangle - \hbar\omega \left\langle m_i \right\rangle \tag{11}$$

Consequently, the overall spin and shell energy for the unrefined single particle level distribution is expressed as follows:

$$I = \sum_i \left\langle m_i \right\rangle \tag{12}$$

$$E_{sp} = \sum_i e_i^{\omega} + \hbar\omega I \tag{13}$$

Given that the challenges faced in assessing total energy for significant deformations via the summation of individual particle energies for the I=0 case may also arise in the I≠0 scenario [16], we employ the Strutinsky shell correction method, which has been adapted for the I≠0 case, by appropriately adjusting the angular velocities to achieve constant spins

For the Strutinsky smeared single particle level distribution Eqs. (12) and (13) transform into

$$\tilde{I} = \sum_i \langle \tilde{m}_i \rangle \tag{14}$$

and $$\tilde{E}_{sp} = \sum_i^N \tilde{e}_i^{\omega} + \hbar\omega\tilde{I} \tag{15}$$

The total energy in the cranked Nilsson Strutinsky prescription is therefore expressed as

$$E_T(T,I;\beta,\gamma) = E(T,I;\beta,\gamma) - TS - \tilde{E}_{sp}(T,I;\beta,\gamma) + E_{RLDM} \tag{16}$$

where E_{RLDM}, the energy of the rotating liquid drop at constant spin, is defined by

$$E_{RLDM} = E_{LDM} - \frac{1}{2} J_{rig}\omega^2 + \hbar\omega\tilde{I} \tag{17}$$

The second term on the right-hand side represents the rotational energy. In this context, the liquid drop energy E_{LDM} is expressed as the total of Coulomb and surface energies, along with J_{rig}, which denotes the rigid body moment of inertia characterized by β and γ, incorporating the surface diffuseness correction.

The calculations are performed by adjusting ω values in increments of $0.025\omega_0$ from ω = 0.0 to ω = $0.3\omega_0$, with ω_0 being the oscillator frequency used for tuning to fixed spins. The parameter γ is varied from -180^0 to -120^0 in increments of -10^0, where $\gamma=-180^0$ corresponds to a non-collective oblate state and $\gamma=-120^0$ corresponds to a collective prolate state. In a collective rotation, the axis of rotation is perpendicular to the symmetry axis. Conversely, in a non-collective rotation, the axis of rotation aligns with the symmetry axis. The values of β are adjusted from 0.0 to 0.8 in increments of 0.05.

To compute the energies of individual particles, the cranked Nilsson triaxial model is employed, utilizing the Hill-Wheeler parameterization for the frequencies to accommodate significant deformations. It should be noted that pairing effects are not considered in these calculations. Additionally, thermal fluctuations are excluded from the initial calculations.

2.2. Shape determination as described by Landau Theory of Phase Transitions

At finite temperatures, it is essential to take into account the thermal fluctuations that result in shapes differing from the most probable configuration achieved by minimizing the free energy F = E - TS. These fluctuations in shape can greatly influence the characteristics of hot rotating nuclei. Based on this theory, the free energy at $\omega = 0$ can be expressed to the fourth order in β as

$$F(T,\omega=0,\beta,\gamma) = Fo(T) + A(T)\beta^2 - B(T)\beta^3\cos 3\gamma + C(T)\beta^4 \tag{18}$$

where the coefficients Fo, A, B, and C are influenced by the temperature T, while β and γ represent the standard intrinsic deformation parameters.

The free energy which depends on β and γ will also depend on the orientation angles relative to the rotation axis ω for the rotating case ω ≠0.

Extending Eqn. (18) to the rotating case with ω parallel to Z axis,

$$F(T,\omega,\beta,\gamma) = F(T,\omega=0;\beta,\gamma) - \frac{1}{2} J_{zz}(\beta,\gamma,T)\omega^2 \quad (19)$$

For fixed spin this can be Legendre transformed as

$$F(T,I;\beta,\gamma) = F(T,I=0;\beta,\gamma) + \frac{I^2}{2J_{zz}(\beta,\gamma,T)} \quad (20)$$

Where

$$J_{zz} = J_0(T) - 2R(T)\beta\cos\gamma + 2J_1(T)\beta^2 + 2D(T)\beta^2\sin^2\gamma \quad (21)$$

with J, R, and D appropriately defined to incorporate different numerical constants. The R term exhibits the primary shape dependence of the rigid-body moment of inertia, whereas the D term by itself would indicate the primary shape dependence of the irrotational moment of inertia. For the ω dependent terms in equation (19), as referenced in [17], the rigid-body moment of inertia is presumed, establishing

$$J_0 = \frac{2}{5} m\mathrm{A}R_0^2$$

$$R = \left[\frac{5}{16\pi}\right]^{1/2} J_0$$

$$D = J_1 = 0\,, \quad (22)$$

In this study, the Landau constants A(T), B(T), and C(T) are assessed through least squares fitting using the ω = 0 free energy surfaces derived from the Strutinsky method. This approach offers the benefit of allowing the accuracy of the fitting to be verified by the resulting error bars.

In the Strutinsky prescription, the free energy is computed as,

$$F(T,I;\beta,\gamma) = E(T,I;\beta,\gamma) - TS - \tilde{E} + E_{RLDM} \quad (23)$$

Here, S is the total entropy of the fermion gas and is given by

$$S = -\sum_{i=1}^{\infty}[f_i \ln f_i + (1-f_i)\ln(1-f_i)] \quad (24)$$

Expressed in terms of Fermi-Dirac occupation numbers

$$f_i = \frac{1}{1+\exp[\frac{(e_i^{\omega}-\lambda)}{T}]} \quad (25)$$

The chemical potential is λ with the constraint $\sum_{i=1}^{\infty} f_i = N$, where N is the total number of particles.

$$E_{RLDM} = E_{LDM} - \frac{1}{2} J_{rig}\omega^2 + \hbar\omega\tilde{I} \quad (26)$$

Here the liquid drop energy E_{LDM} is given by the sum of Coulomb and surface energies, J_{rig} the rigid body moment of inertia defined by β and γ including the surface diffuseness correction, and $\tilde{I}$ is the Strutinsky smoothed spin.

2.3. Thermal fluctuations and their effect on the shape parameters

For a nucleus with finite number of particles and at moderately high temperatures, thermal fluctuations produce an average shape, which is qualitatively different from equilibrium shapes predicted by mean field theories. These shape fluctuations can significantly alter the properties of hot rotating nuclei. The probability of finding the nucleus in a state with deformation $\alpha_{2\mu}$ is characterized by the free energy $F(\alpha_{2\mu}; I,T)$ is,

$$P(\alpha_{2\mu};I,T) \propto e^{-F(\alpha_{2\mu};I,T)/T} \qquad (27)$$

with $$F(\alpha_{2\mu};I,T) = E(\alpha_{2\mu};I,T) - TS$$

Using classical statistics, therefore, the ensemble average of an observable X which is deformation – dependent, is given by an average over all possible shapes.

$$\bar{X}(I,T) = \frac{\int X(\alpha_{2\mu};I,T)e^{-F(\alpha_{2\mu};I,T)/T} D[\alpha_{2\mu}]}{\int D[\alpha_{2\mu}]e^{-F(\alpha_{2\mu};I,T)/T}} \qquad (28)$$

where $D[\alpha_{2\mu}]$ is the volume element in the deformation space.

Using equation (28), the ensemble average of β is,

$$\bar{\beta} = \langle\beta\rangle = \frac{\int \beta P(\beta,\gamma)\beta^4 \left|\sin 3\gamma\right| d\beta d\gamma}{\int P(\beta,\gamma)\beta^4 \left|\sin 3\gamma\right| d\beta d\gamma} \qquad (29)$$

Similarly the ensemble average of γ is

$$\bar{\gamma} = \langle\gamma\rangle = \frac{\int \gamma P(\beta,\gamma)\beta^4 \left|\sin 3\gamma\right| d\beta d\gamma}{\int P(\beta,\gamma)\beta^4 \left|\sin 3\gamma\right| d\beta d\gamma} \qquad (30)$$

where $\beta^4 \left|\sin 3\gamma\right| d\beta d\gamma$ is the volume element as given in the Bohr rotation – vibration model.

Equation (27) shows that when the temperature is zero, there are no thermal shape fluctuations. Then the averaged shape is identical to the most probable shape. But at finite temperature, the averaged shape may be different from the most potable shape.

3.**Results and Discussion**

The aim of this work is to study the shape evolutions in hot rotating ^{72}Se and ^{74}Se nuclei using cranked Nilsson Strutinsky method including the most important thermal fluctuations. The first step in the study of shape evolutions in excited medium mass ^{72}Se and ^{74}Se nuclei is to use the cranked Nilsson - Strutinsky method. In this the calculations are carried out with $\gamma = -120^0$ to -180^0 in steps of -10^0 and the deformation parameter β is varied from 0.0 to 0.8 in steps of 0.1 and spin I = 0 to 60 ħ for T=0.0 MeV. The second step is to study the shape evolutions and the effect of thermal fluctuations on shape transitions using Landau theory in the considered selenium nuclei. We performed calculations taking $\gamma = -120^0$ to -180^0 in steps of -10^0 and the deformation parameter β is varied from 0.0 to 0.8 in steps of 0.05 and spin I = 0 to 60 ħ for different temperatures. The resulting free energy surfaces are then least square fitted with those of Landau theory to extract the respective Landau constants. Then the averaged values of β and γ are evaluated by using equation (28) to obtain the shape variations with thermal fluctuations. Tables 3.1 to 3.2 show the shape transitions with and without thermal fluctuations in ^{72}Se and ^{74}Se with extended spins upto 60 ħ.3.1. Shape evolutions using cranked Nilsson – Strutinsky method

In order to carryout an depth study of shape transitions in hot rotating ^{72}Se and ^{74}Se nuclei we have used the cranked Nilsson – Strutinsky method with fixed spin tuning approximation. Thermal fluctuations are not included in these first calculations. In the calculations performed here to generate the potential energy surfaces, the spin is varied from I = 0 to 60 ħ. The Hill - Wheeler expressions for the frequencies have been used in the cranked Nilsson model in order to take care of large deformations involved in the calculations. Calculations have been done for neutron and proton levels separately by choosing the appropriate constants κ and μ applicable for this region [15]. The energy levels are generated up to N = 11 shells which is found to be sufficient for these calculations.

Figures 3.4 to 3.5 show the shape transitions with spin (*) obtained for ^{72}Se and ^{74}Se nuclei respectively. It is noted from fig. 3.4 that ^{72}Se nucleus is prolate in shape at its ground state (T = 0.0 MeV and I = 0 ħ) with deformation β = 0.1. The nucleus stays in the prolate shape on further increase of spin up to I = 20 ħ with deformation increases as a function of spin. As spin increases the nuclei undergo a shape transition from prolate to oblate at I = 30 ħ. On further increase of spin it stays in the same shape with much elongation. In the case of ^{74}Se (Fig. 3.5) it is noted that the shape at ground state is spherical and it says in the same shape up to I = 10 ħ. As spin increases to 20 ħ a shape transition occurs from spherical to prolate and an increase of deformation occurs as spin increases to 30 ħ. At I = 40 ħ there is a shape transition occurs from collective prolate with β = 0.2 to non-collective oblate with β = 0.3. The nucleus stays in the same shape with increased deformation on further increase of spin. It is noted from the above discussion that the shape of ^{72}Se nucleus is prolate in its ground state and at high spin, it undergo a prolate to oblate shape transition. But the ground state shape of ^{74}Se is spherical and on increase of spin the shape changes to prolate and then to oblate at high spin, which is in conformity with the experimental observations [18-19].

3.3. Effect of thermal fluctuations on shape parameters using Landau Method

For the study of shape evolutions in medium mass nuclei at moderate temperatures, it is necessary to include thermal fluctuations which may create shapes different from the most probable shape obtained by cranked Nilsson Strutinsky method. In the second step we have studied the effect of thermal fluctuations on shape evolutions of ^{72}Se and ^{74}Se using the Landau theory of shape transitions. The Landau constants A(T), B(T) and C(T) are evaluated by least square fitting with the ω=0 free energy surfaces obtained by using the cranked Nilsson- Strutinsky method. In this, the expansion of the Landau free energy is done up to fourth power of β. In the calculations performed here, to generate ω=0 free energy surface, the spin is varied from I = 0 ħ to 60 ħ in steps of 10 ħ at temperatures T = 0.5 MeV, T = 1.0 MeV, T = 1.5 MeV, T = 2.0 MeV and T = 2.5 MeV. In the potential energy calculation the deformation parameters β and γ are varied in the range β = 0.0 to 0.8 with Δβ = 0.05 and γ = -180° to –120° with Δγ =-10°. Since the considered nuclei fall in the mass region A=70 – 80, calculations have been done for neutron and proton levels separately by choosing the appropriate constants κ and μ applicable for the region considered.

In table 3.3 to 3.4 we give the results of A(T), B(T) and C(T) at various temperatures obtained by using Landau method for ^{72}Se and ^{74}Se. In this study, this is done by using the extrema fitting method. The variations of τ, B/C and B^4/C^3 with temperature as sample results for the nuclei ^{72}Se obtained by using Strutinsky method is given in figures 3.1 to 3.3, from which the Landau constants can be extracted. It is noted from these figures that the variations in the Landau parameters are mild at high temperatures. In figures 3.6 to 3.15 we present the shape evolutions with spin obtained for temperatures T = 0.5 MeV, T = 1.0 MeV, T = 1.5 MeV, T = 2.0 MeV and 2.5 MeV respectively for ^{72}Se and ^{74}Se isotopes with thermal fluctuations using Landau method. It is noted from figures 3.6 to 3.15 that when thermal fluctuations are included, the sharp shape transitions turn into triaxial shapes with γ fascinating in between $–130^0$ and $–160^0$ which is clearly seen. It becomes clear from these figures that the sharp spherical, oblate and prolate shapes are washed out when thermal fluctuations are incorporated.

4.Summary and Conclusion

In conclusion, this study has aimed to investigate the shape evolutions of the hot rotating isotopes ^{72}Se and ^{74}Se utilizing the cranked Nilsson – Strutinsky method. The ground state of the ^{72}Se nuclei is identified as prolate. As the spin increases, the nucleus maintains its prolate shape while becoming significantly elongated. However, at high spin, a transition from prolate to oblate shape is observed. For the ^{74}Se isotope, the nuclei, which begin in a spherical shape at ground state, transition to prolate as spin increases, followed by a shift to an oblate shape. Any investigation of hot rotating nuclei must account for thermal fluctuations. To address this, we have employed the Landau theory of shape transitions, expanding free energy up to the fourth power of β to incorporate thermal fluctuations. The distinct shape transitions identified by the Strutinsky method evolve into triaxial shapes when thermal fluctuations are considered. Most of our predictions align well with the existing experimental results relevant to the nuclear region under consideration. It would be intriguing to experimentally determine whether such phase transitions and significant deformations can be observed in these medium mass nuclei through giant dipole resonance (GDR) associated with excited states.

Table 3.1 Shape transitions including fluctuations in ^{72}Se with extended spins upto 60 ħ.

I (ħ)	T=0.0 MeV		T=0.5 MeV		T=1.0 MeV		T=1.5 MeV		T=2.0 MeV		T=2.5 MeV	
	β	γ	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$
0	0.1	-120^0	0.3	-154^0	0.35	-143^0	0.4	-138^0	0.45	-134^0	0.45	-130^0
10	0.2	-120^0	0.3	-156^0	0.4	-148^0	0.5	-140^0	0.45	-136^0	0.5	-132^0
20	0.2	-120^0	0.35	-156^0	0.4	-152^0	0.55	-140^0	0.50	-138^0	0.55	-134^0
30	0.3	-180^0	0.4	-158^0	0.45	-156^0	0.55	-142^0	0.50	-138^0	0.6	-136^0
40	0.4	-180^0	0.4	-160^0	0.45	-158^0	0.6	-144^0	0.55	-140^0	0.6	-138^0
50	0.4	-180^0	0.45	-160^0	0.5	-159^0	0.6	-146^0	0.55	-142^0	0.65	-140^0
60	0.5	-180^0	0.45	-162^0	0.5	-160^0	0.65	-146^0	0.6	-142^0	0.7	-140^0

Table 3.2 Shape transitions including fluctuations in ^{74}Se with extended spins upto 60 ħ.

I (ħ)	T=0.0 MeV		T=0.5 MeV		T=1.0 MeV		T=1.5 MeV		T=2.0 MeV		T=2.5 MeV	
	β	γ	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$	$\bar{\beta}$	$\bar{\gamma}$
0	0.0	-120^0	0.3	-162^0	0.35	-154^0	0.4	-146^0	0.45	-142^0	0.45	-140^0
10	0.0	-120^0	0.3	-160^0	0.4	-152^0	0.5	-146^0	0.45	-142^0	0.5	-140^0
20	0.1	-120^0	0.35	-160^0	0.4	-151^0	0.55	-144^0	0.50	-140^0	0.55	-138^0
30	0.2	-120^0	0.4	-158^0	0.45	-150^0	0.55	-142^0	0.50	-138^0	0.6	-136^0
40	0.3	-180^0	0.4	-156^0	0.45	-148^0	0.6	-140^0	0.55	-137^0	0.6	-134^0
50	0.4	-180^0	0.45	-155^0	0.5	-149^0	0.6	-138^0	0.55	-136^0	0.65	-132^0
60	0.5	-180^0	0.45	-154^0	0.5	-150^0	0.65	-137^0	0.6	-134^0	0.7	-130^0

Table 3.3 Landau constants for ^{72}Se obtained by Strutinsky method using least square fit

T MeV	A(T)	B(T)	C(T)
0.0	$32.05 \pm 5.48 \times 10^{-1}$	-1.88 ± 1.72	$57.68 \pm 9.43 \times 10^{-2}$
1.0	$46.39 \pm 2.14 \times 10^{-1}$	$-1.86 \pm 6.34 \times 10^{-1}$	$33.26 \pm 3.62 \times 10^{-2}$
1.5	$54.31 \pm 7.75 \times 10^{-2}$	$-1.66 \pm 2.40 \times 10^{-1}$	$19.49 \pm 1.51 \times 10^{-2}$
2.0	$59.24 \pm 2.65 \times 10^{-2}$	$-1.98 \pm 7.75 \times 10^{-2}$	$13.24 \pm 4.41 \times 10^{-3}$
2.5	$62.36 \pm 7.88 \times 10^{-3}$	$2.87 \pm 2.44 \times 10^{-2}$	$8.91 \pm 1.43 \times 10^{-3}$

Table 3.4 Landau constants for ^{74}Se obtained by Strutinsky method using least square fit

T MeV	A(T)	B(T)	C(T)
0.5	$82.89 \pm 5.56 \times 10^{-1}$	-5.86 ± 1.72	$-21.96 \pm 9.44 \times 10^{-2}$
1.0	$75.07 \pm 1.96 \times 10^{-1}$	$-4.85 \pm 5.61 \times 10^{-1}$	$-7.95 \pm 3.34 \times 10^{-2}$
1.5	$73.26 \pm 6.88 \times 10^{-2}$	$-3.90 \pm 2.31 \times 10^{-1}$	$-3.63 \pm 1.35 \times 10^{-2}$
2.0	$72.71 \pm 2.58 \times 10^{-2}$	$-3.61 \pm 7.56 \times 10^{-2}$	$-.899 \pm 4.46 \times 10^{-3}$
2.5	$72.36 \pm 8.58 \times 10^{-3}$	$3.49 \pm 2.71 \times 10^{-2}$	$1.27 \pm 1.58 \times 10^{-3}$

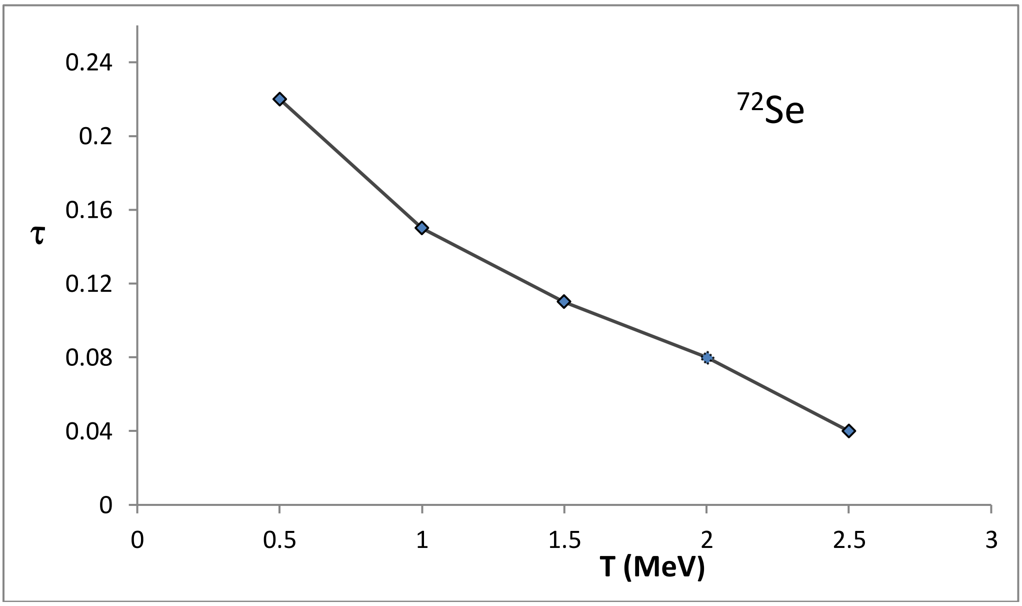

FIG. 3.1: Variation of τ with temperature for ^{72}Se using ω=0 free energy surfaces obtained by the Strutinsky method.

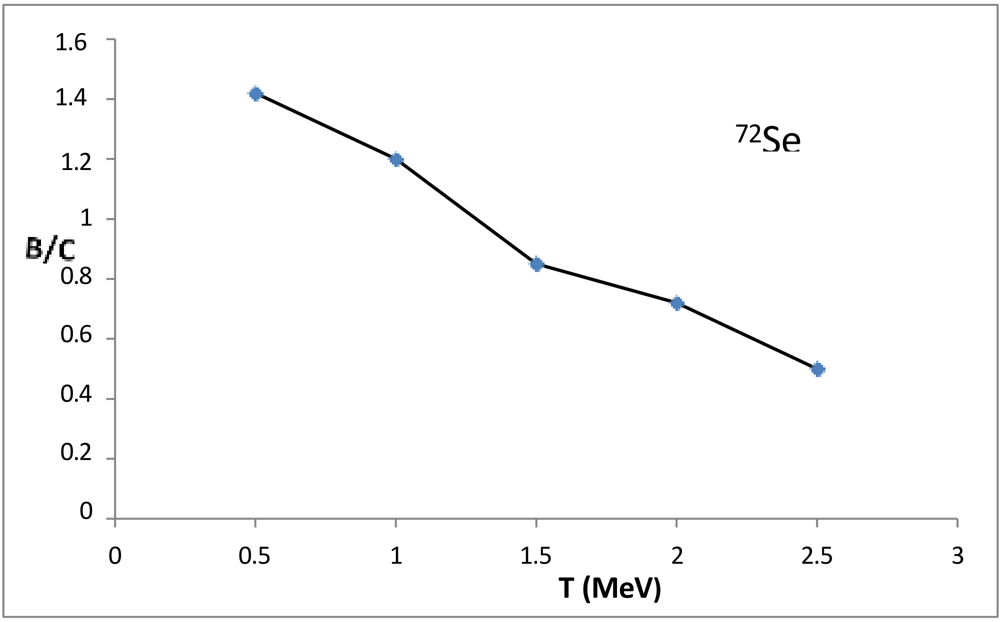

FIG. 3.2: Variation of B/C with temperature for ^{72}Se using ω=0 free energy surfaces obtained by the Strutinsky method

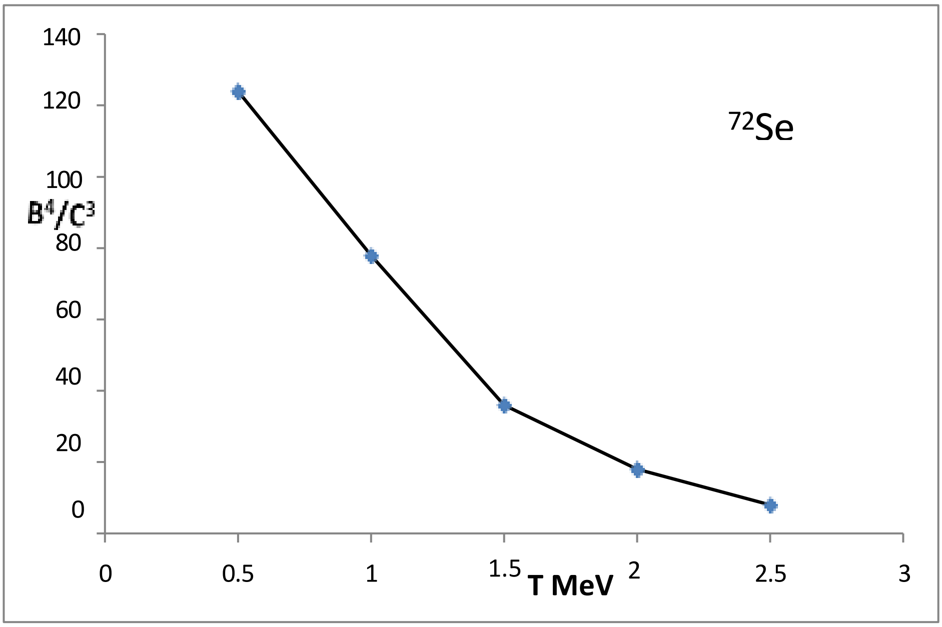

FIG. 3.3: Variation of B^4/C^3 with temperature for ^{72}Se using ω=0 free energy surfaces obtained by the Strutinsky method

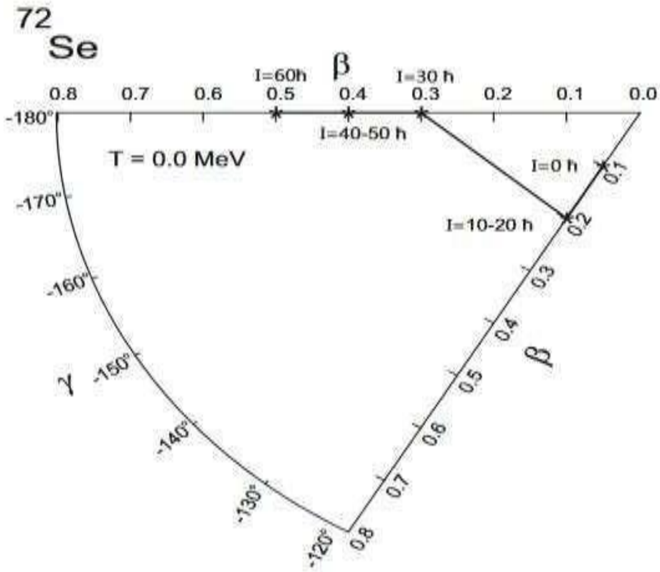

FIG. 3.4: Shape evolutions in ^{72}Se obtained as a function of spin at temperature T = 0.0 MeV

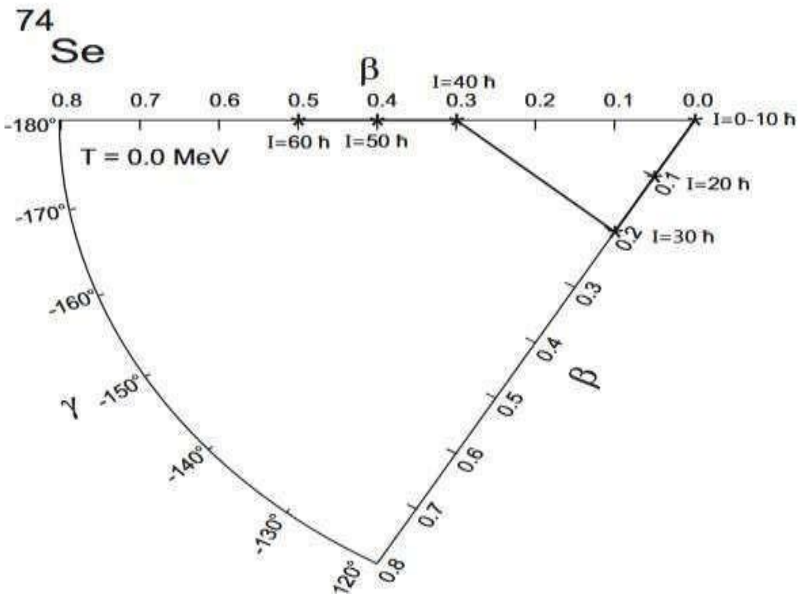

FIG. 3.5: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T = 0.0 MeV

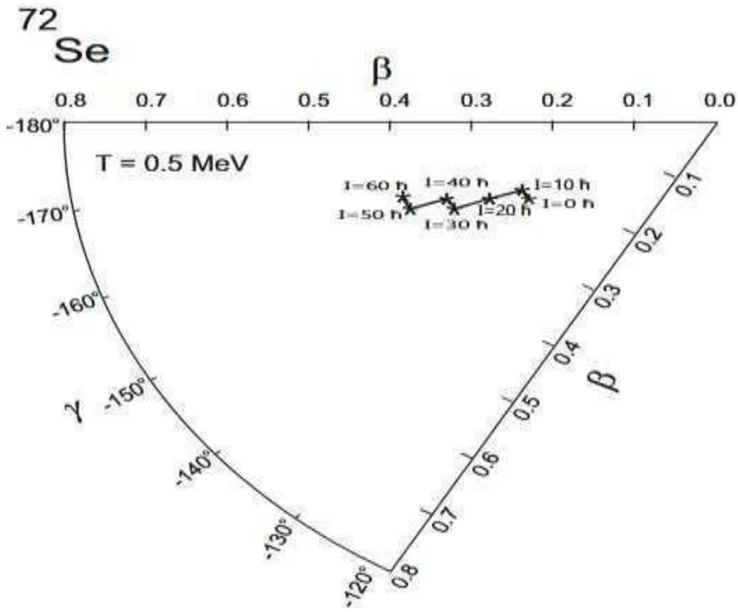

FIG. 3.6: Shape evolutions in ^{72}Se obtained as a function of spin at temperature T = 0.5 MeV with thermal fluctuations.

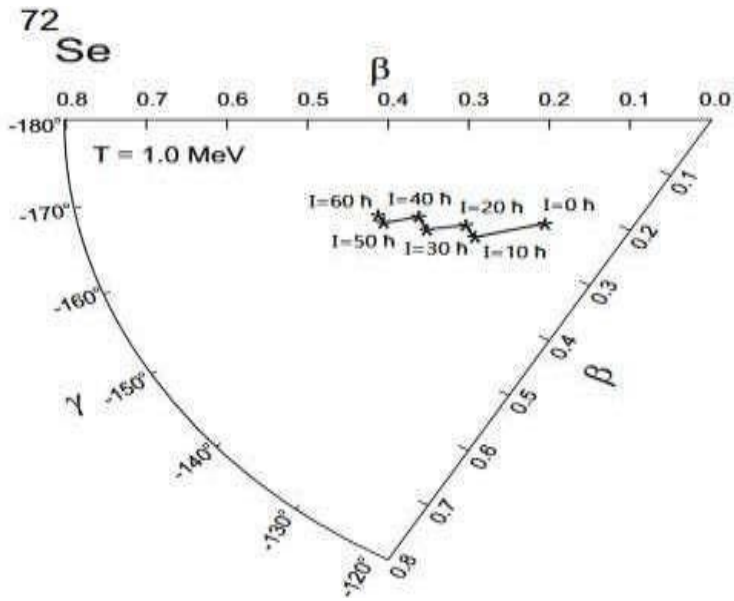

FIG. 3.7: Shape evolutions in ^{72}Se obtained as a function of spin at temperature T = 1.0 MeV with thermal fluctuations

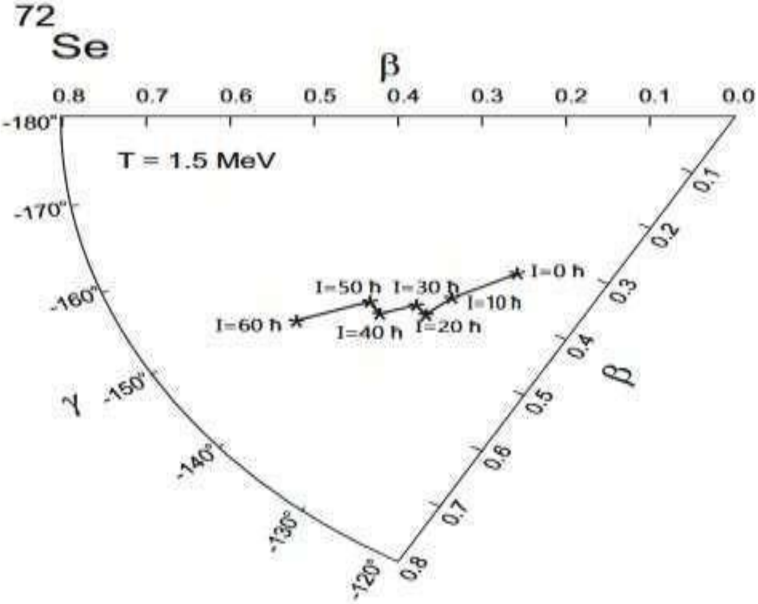

FIG. 3.8: Shape evolutions in ^{72}Se obtained as a function of spin at temperature T = 1.5 MeV with thermal fluctuation

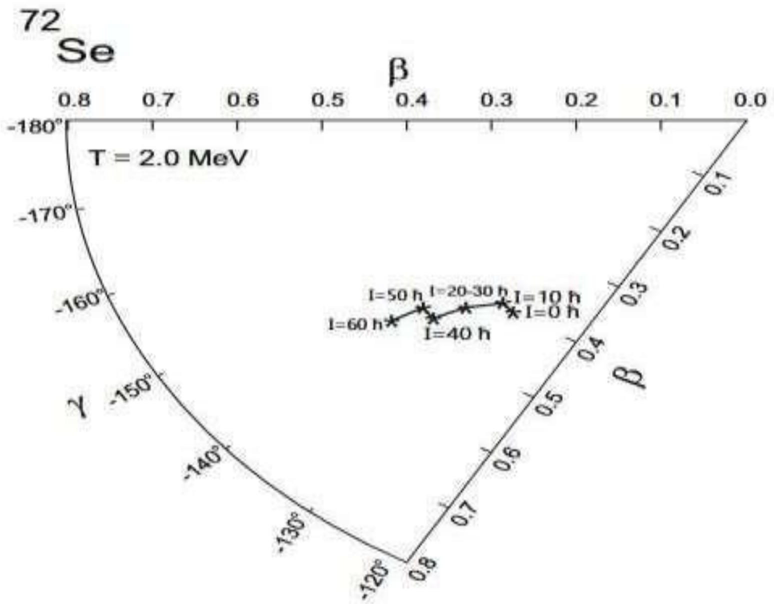

FIG. 3.9: Shape evolutions in ^{72}Se obtained as a function of spin at temperature T = 2.0 MeV with thermal fluctuations

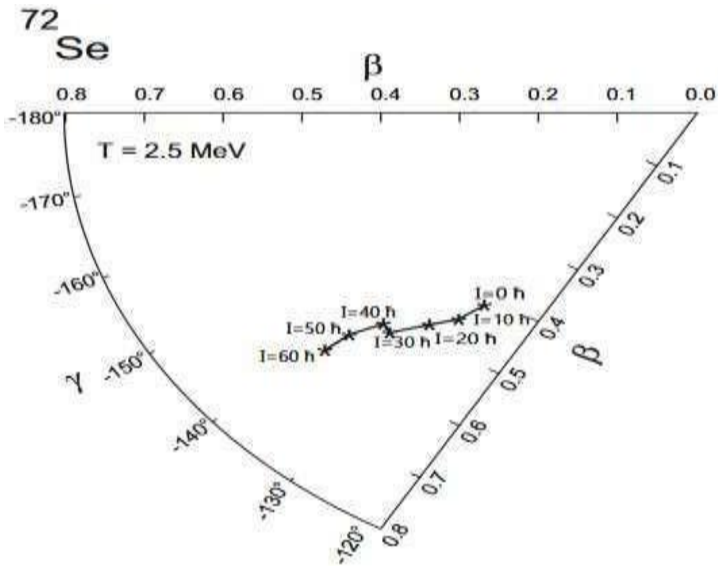

FIG. 3.10: Shape evolutions in ^{72}Se obtained as a function of spin at Temperature T = 2.5 MeV with thermal fluctuations

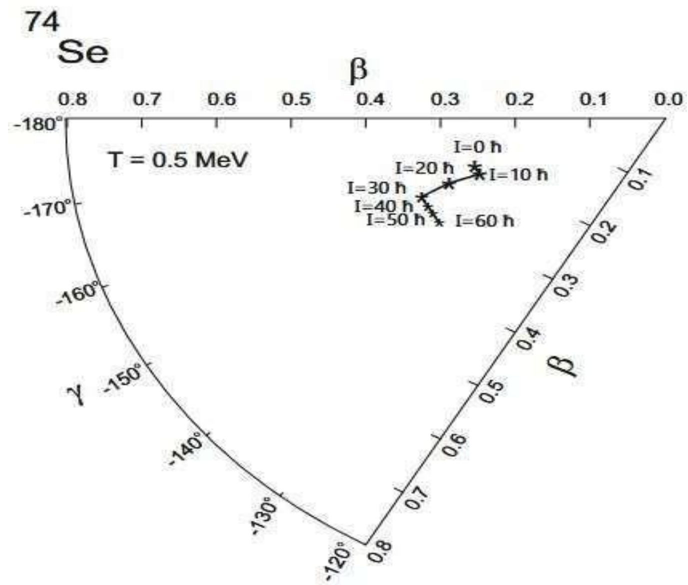

FIG.3.11: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T = 0.5 MeV with thermal fluctuations

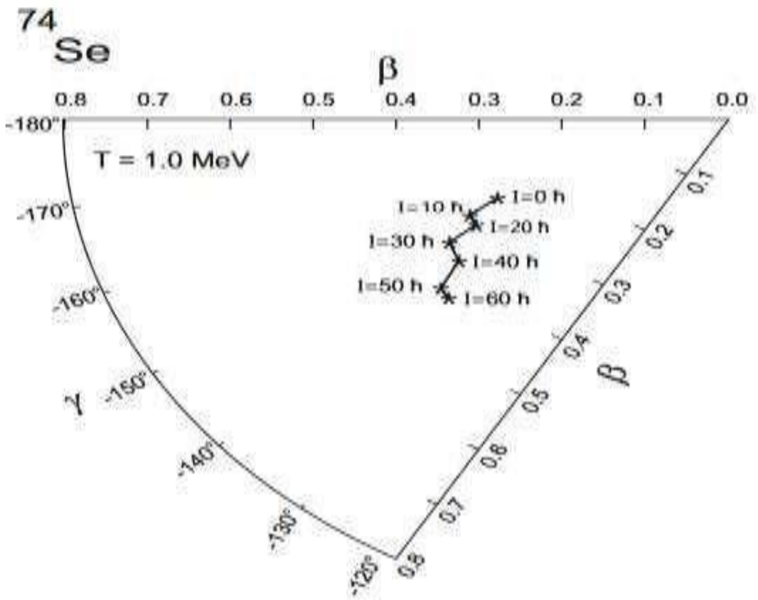

FIG. 3.12: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T = 1.0 MeV with thermal fluctuations.

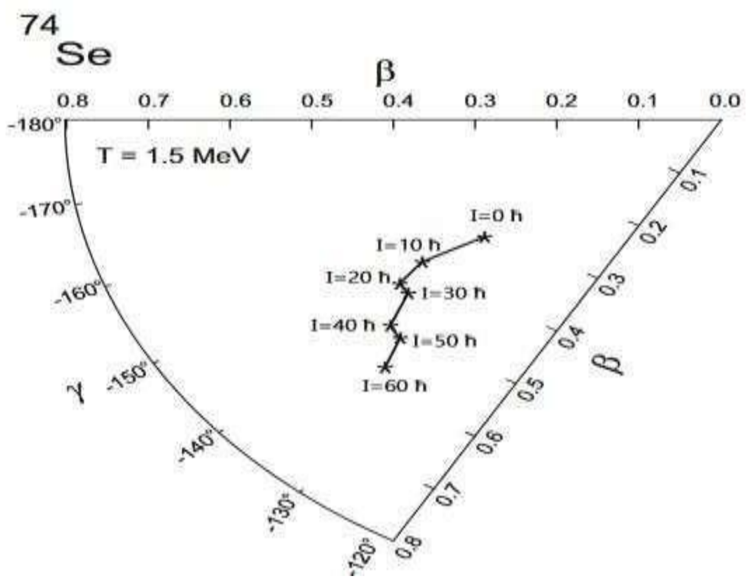

FIG. 3.13: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T = 1.5 MeV with thermal fluctuations

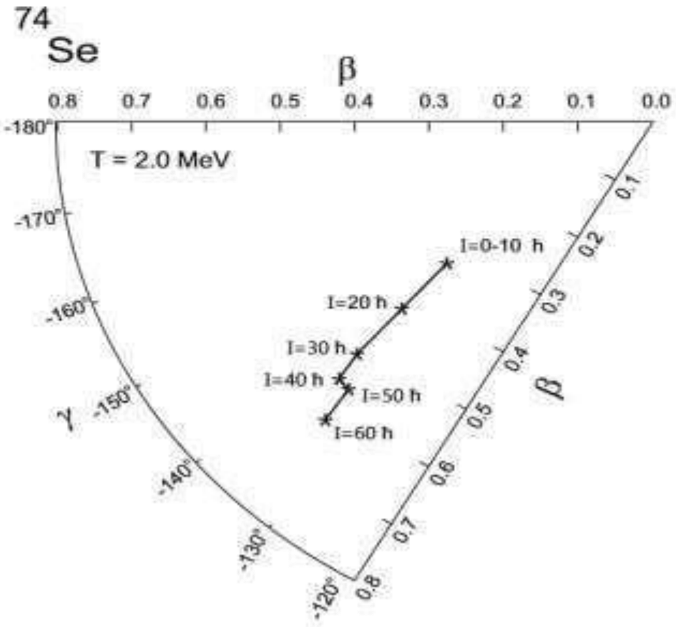

FIG. 3.14: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T = 2.0 MeV with thermal fluctuations

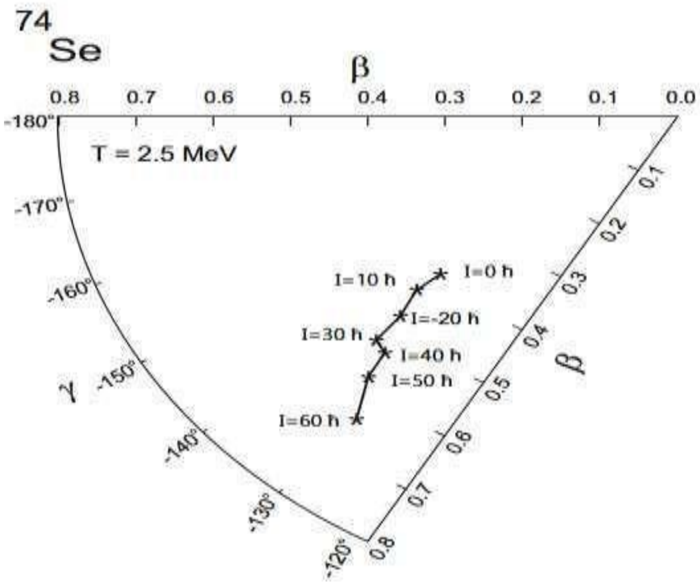

FIG. 3.15: Shape evolutions in ^{74}Se obtained as a function of spin at temperature T= 2.5 MeV with thermal fluctuations.

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